Beyond transparency: How students make representations meaningful

Victor R. Lee, Bruce Sherin, Northwestern University, 2120 Campus Dr., Evanston, IL 60208-2610
Email: victor@northwestern.edu, bsherin@northwestern.edu

Abstract: In current science education reform, two criteria are considered most critical for determining whether or not an external representation is pedagogically productive. One is whether or not the representation maintains a high level of epistemic fidelity. The other is whether or not the representation is transparent relative to the content it is supposed to represent. We believe that these criteria are too limited in scope and have been considered acceptable in part because we have a very limited understanding of how students construct meaningful interpretations of unfamiliar representations. To remedy that, we propose a new framework for understanding acts of interpretation that focuses on four major constructs: registrations, symbolic forms, interpretive genres, and interpretive maxims. We demonstrate this framework's utility by applying it to excerpts of middle school students interpreting unfamiliar representations of light reflection.

Introduction

One core belief of reform-oriented science educators is that it is important to apprentice students into the same kinds of interpretive practices as those of professional scientists, especially those that involve scientific representations. However, we lack sufficient guidance regarding the manner in which we should design for this. Rather, what we have is a loose set of evaluative criteria for determining the quality of a representation based on intuitions about epistemic fidelity (Roschelle, 1990) and representational transparency. The general idea is that in order for a representation to be included in a curriculum, it must be scientifically accurate, and it must minimize possible misinterpretations and subsequent misconceptions (Kesidou & Roseman, 2002). This is in line with a large body of research that has documented mistakes students make when interpreting external representations in science and mathematics (e.g., Leinhardt *et al.*, 1990 for examples involving graphs).

We find these evaluative criteria to be an inappropriate stopping point, in part because they rely on some unverified assumptions about science learning in relation to representations. One such assumption is that conceptualizations crystallize rapidly after exposure to misinformation, thus rapidly leading to misconceptions (e.g., Driver, 1994). A second assumption is that students simply do not come fully equipped to deal with the unfamiliar and abstract representational forms that pervade scientific practices – there are some classes of scientific representations that are too complex and others where students are likely to make mistakes. A third assumption is that interpretation can be equated to seeing. Knowledge is encoded in a representation and the student simply decodes what is presented to him or her. Taken together, the images we have are of students being representationally weak and of interpretation being a relatively simple act. Our larger research agenda is intended to refine those ideas. However, the goal of this paper is to specifically address the latter.

Our contention is that acts of representation interpretation have not yet been carefully examined and as a consequence, we lack the tools needed to develop more productive criteria for evaluating representations as pedagogically appropriate. Therefore, we should allocate some of our resources to unpacking what happens in an act of representation interpretation. To do this in a manner that can better inform theory and practice, we believe a *naturalistic* approach is needed. This involves capturing instances of students interpreting scientific representations and characterizing *how* and *why* those interpretations are made. Simply stated, we need to understand how students can take marks on paper, a chalkboard, or from a computer screen and from those marks construct a meaningful understanding.

There have been some significant steps taken in this direction. As a field, Learning Sciences is becoming increasingly aware of the range of representational abilities and resources students can utilize in the classroom and beyond (diSessa, 2004; diSessa *et al.*, 1991; Lehrer & Schauble, 2004; Sherin, 2000). Still, there remains significant work to be done. What we hope to do here is present a theoretical framework that can aid in the characterization of student resources and interpretive strategies and begin to inform how students construct meaningful interpretations. This paper attempts to demonstrate the utility of this framework through a brief analysis of some interview excerpts with middle school students who were in the midst of learning content around light and optics and who were encountering some unfamiliar representations in the domain.

As we will discuss later, light and optics seemed to be an appropriate place to do this work since much of what would be traditionally considered content in this area is structured around recurring technical representations, such as arrows and lines that are used for representing light rays and reflective surfaces. In the following section, we will describe some of the key aspects our framework for understanding how students construct interpretation of representations (Sherin & Lee, 2005). Following that, we will briefly apply this framework to the interview excerpts to identify two specific resources that these students used to facilitate interpretation, the *event narrative* and the *completeness* maxim. We hope that by the end of the paper, we can demonstrate the potential of this framework and provide some rationale for why they settled on their respective interpretations. From that, we hope that we can do a small part to help reframe how we think about representations for both learning and design.

Theoretical Framework

In this section, we introduce, by way of an example of a hypothetical interaction around a graph, our theoretical framework for discussing our cases in the following sections. We do this as both a rhetorical and theoretical strategy. The following example, abstracted from others we have seen, allows us to briefly illustrate some key phenomena. It also establishes a theoretical yardstick: our framework must, at a minimum, be able to do the work of accounting for these interpretive phenomena.

Consider the following situation. Lisa and Earvin are lab partners in class and they are producing a representation of the motion of two wind-up cars they have just observed. Lisa has just drawn the representation shown in Figure 1 in her notebook.

Figure 1. Lisa's graph.

Earvin sees this and says "So that's a graph. One of the lines is pretty much flat. The other curves a lot more – it's like exponential". Lisa responds "Yeah, I think this does a good job of showing how those cars were moving". Earvin adds, "I agree. Say, here I'm the green car going pretty much the same speed the entire time. But then here I'm the black car, starting really slow, but then I go really fast!" Lisa says "Huh. Yeah, and I can see now then the black car passes the green at this point. And then it gets to the end way before the green car. That's like we just saw in the demo." She points to where the lines intersect as she speaks. Then she adds, as she points between the two lines, "Yeah, that's right because the distance between them gets smaller and smaller". Earvin ends with, "Yeah, I see that."

In this example, there is a lot happening when Earvin and Lisa interpret this graph. First, Earvin interprets the graph as being made up of two lines that he can name and describe as flat and exponential. Then he produces a narration for each of the lines and associates them with each of the cars they had seen earlier. Lisa then interprets the graph as showing where the black car surpasses the green one and justifies it both with the point where the lines intersect and with the area between the two narrowing. Note that throughout this joint interpretation, there are some key features of how the interpretations are constructed. First, they carve up the marks in the notebook in many different ways. Sometimes the lines are the focus, whereas at other times, points or regions of space may be more relevant. Second, they engage in acts of *creative construction*. Earvin, as part of his interpretation, becomes the green and black car and is following the path of the lines on the graph. Lisa, as part of her later interpretations, begins to blend, albeit incorrectly, when the black car passed the green car with specific portions of the graph. Third, we can make the observation that there is a tremendous amount of agreement and coordination that happens quite seamlessly in this dialogue. Earvin and Lisa quickly can follow the other's interpretations and infer each person's intended meaning given just a quick utterance or finger point. These observations provide the backbone for our framework. The major constructs we propose, described below, are 1) registrations, 2) symbolic forms, 3) interpretive genres, and 4) interpretive maxims.

Registrations

The first component of this framework relies on the observation that the marks in an external representation may be "carved up" in a multitude of ways. For this, we borrow from Roschelle (1991) the term *registration*, which for our purposes, is used to identify the representational structures that may be made selectively salient and potentially meaningful during the course of an interpretive action. In the above example, the registrations include the two lines, the point of intersection, and the area between the two lines. In other situations, there could easily be others. We do not assume that all registrations are meaningful, nor must they be at a particular grain size. For example, in an equation, any character, term, or combination of operation symbols and terms could be a registration. In a graph, some segment of the line, a point on one line, or slope could all qualify.

Symbolic forms

In some limited, but extremely important situations, we believe that registrations are associated with simple conceptual schemas. We call these associations between registrations and conceptual schemas *symbolic forms*. This has been worked out in some detail for the case of physics equations (Sherin, 1996, 2001b). Examples of this also exist for graphing, as discussed by Nemirovsky (1992) which we applied in the above example. When Earvin describes the motions of the black car, the curvatures of the bottom line is adjoined to conceptual schema of *rapid growth*. He could have also been more sensitive to the slight dips in the top line and conceptualized them as *slight decline*.

Interpretive Genres

We noted before that the interpretations in the example with Earvin and Lisa involved creative constructions. We believe that interpretation of external representations in science regularly involves acts of creative construction in which individuals integrate registrations, conceptual knowledge, and familiar representational conventions, and they reason through these created spaces. These creative constructions, while often novel, will frequently display regular patterns of interpretations. These patterns could be regular sequences through registrations and symbolic forms or be recurring interpretive games that are played through which meaning is momentarily constructed with the representation. We call these games and patterns *interpretive genres.* For example, Earvin's constructions are consistent with *comparative* and *narrative* classes of genres. The comparative genre is invoked in the beginning, when he notes that the bottom line is "more curved" than the top one. The narrative genre is invoked when Earvin constructed a story that unfolded over time as the marks were traversed. We see a sort of *dual narration* in Lisa's construction in which two agents each follow narratives that eventually overlap. It is our belief that interpretive genres can serve multiple purposes in the interpretation of representations. By invoking a genre, an interpreter has a sort of template with some constraints on what registrations and what conceptual knowledge may be optimally relevant. Examples and comparisons of interpretive genres in physics equations and computer programs can be seen in work done by Sherin (2001a).

Interpretive Maxims

Our last component, *interpretive maxims*, deals with aspects of communicative interaction. Specifically, we understand interpretation of representations to always involve the making of inferences about their meaning. Therefore, it was appropriate for us to turn to ideas that have long been investigated in the linguistics branch of pragmatics. At the core of pragmatics is the notion that inference is based on the integration of a few externalized clues given verbally (or gesturally as may also be the case) by a speaker or author along with implicit rules for determining relevance and meaning, dubbed maxims (Grice, 1975). Our move is to apply these notions, which have been developed for communication generally, to representation interpretation. We see this as an appropriate move both because much of the data that we examine includes video of communicative interactions and because we are explicitly adopting a naturalistic approach. We expect that some of these maxims may apply generally across many kinds of representations and some may be more specific to particular classes, such as equations. In situations where all interpreters have expert knowledge of the representation, we can understand interpretive maxims to have crystallized into particular conventions, often unspoken, that individuals follow in the construction and interpretation of representations through communicative interaction.

Interpretive maxims operate in the background of interpretation, helping to constrain the space of meanings for registrations and genres. In the Earvin and Lisa example, we can understand Earvin as following an interpretive pattern that bears some similarity to what we have previously identified as a maxim of *global exhaustiveness* (Lee & Sherin, 2004). He makes attributions to each line as distinctly being associated with one of the cars and also attempts to make sure *all* elements in the representation are made meaningful. Similarly, some other interpretive conventions briefly appear – Lisa's move to interpret the intersecting lines as one car passing the other, follows conventions of interpreting lines as traversed paths.

Application of the framework to representations of light reflection

In this section, we present excerpts from interviews done with eighth grade students learning about light and optics as part of their science class. This comes from a larger corpus of data that includes videorecorded observations and interviews done with two eighth grade classrooms, one of which was each enacting a curriculum published by McDougal Littell (2005). The examples discussed here come from mid-unit interviews conducted with three students during the third week of the six-week McDougal Littell unit. The interviewed students comprise a focus group whose members had been videorecorded and interviewed throughout the entire unit as they were using the curriculum.

The mid-unit interviews discussed here were timed such that, the day before, the class had done an exploration of mirrors and been presented with a series of diagrams showing the law of reflection, diffuse reflection, and reflection in concave and convex mirrors. The goal of these interviews was to expose some of the interpretive strategies that students were using for representations of light for phenomena in which they were just gaining familiarity. Each student was interviewed individually and presented with copies of the diagrams that were discussed the previous day and asked to explain what each was showing. The interviewer then proceeded to ask follow up prompts for clarification.

As mentioned earlier, we chose to examine optics specifically because it is an area that often involves instruction around a regular set of simple and presumably familiar representations, that employ arrows, waves, and various lines for reflective or transmissive objects. Also, the study of optics often involves explicit focus on two graphically represented models of light: the ray model and the wave model. Furthermore, research that involves students understanding of light tends to focus on misconceptions (Driver, 1994) or challenges involved in using the representational conventions (Ramadas & Shayer, 1993; Ronen & Eylon, 1993) rather than interpretive resources and interpretive acts. We see the opportunity to indirectly contribute to that body of student conceptions literature as well.

Interpreting simple reflection with an event narrative

We present first an excerpt of a student interpreting a representation that was quite typical in most interviews and helps us to lay the groundwork for the subsequent excerpts. In this first excerpt, Lily is shown a picture similar to the one shown in figure 2. It was the first one that was presented in class the previous day and the teacher intended for it to illustrate the law of reflection, in which the angles formed by an incident ray with the normal is always equal to that formed by the reflected ray and the normal.

Figure 2. Diagram of light reflection.

Lily immediately provides an interpretation of this drawing. ("L" is Lily, "I" is Interviewer)

L: This picture shows the light, say a beam of it as it comes down, hitting a surface and bouncing off.
I: So this is the light, hitting a surface.
L: And it bounces off.

Her interpretation is relatively straightforward, and one that we would expect given the simplicity of the representation and the fact that Lily knew the purpose of the interview. However, we can still identify some important resources in the context of the above framework that she draws upon to do her interpretation. First, she describes a short sequence of events, suggestive of a simple interpretive genre – that of an *event narrative* – which enables her to parse this representation into three conjoined sequential segments in which an arrow first comes in, hits/bounces off a surface, and then continues in a new direction. Both arrows and the point of contact between the arrows and the horizontal line are active registrations here. She construes the first arrow as being both a sort of traveling entity and a straight-line path. This is consistent with particular interpretive conventions relevant to the use of arrows in these sorts of diagrams involving light. Rather than serving a labeling or connective function as it could in other representations, here it is an invocation of conventions of arrow-as-entity and arrow-as-path. At a more cognitive level, we see her invoking a symbolic form – bouncing – that occurs at the point of contact between the arrows and the horizontal line. This symbolic form is both a determiner of the final segment of the narrative (that the light changes direction and moves on) and the rationale for the behavior.

Registrations, Forms, and Genres for Interpreting Diffuse Reflection

The next interview question that was asked of all students involved having each student explain a diagram that was intended to show diffuse reflection, the reflection of light on a rough surface. In the previous day's class, they were shown a diagram much like the one shown in Figure 3.

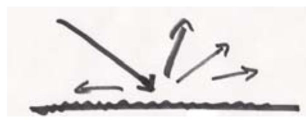

Figure 3. Diagram of diffuse reflection.

When Lily explains this one, she again invokes an event narration, but infers a new behavior of light from this representation.

> L: …This surface, when the light beam hits it, it's not like, it can't bounce off the same way. It's not smooth because it's sort of indented like this, I'm not sure, I think, but I'm not completely sure, it's not that it gets stuck, but it doesn't reflect at the same time. Because some of it goes further down because some if it is jagged. So the beam splits off into different directions, like that.
> I: Okay. So the beams split off in different directions after this one beam comes in and hits it?
> L: Yes, because- because of the way the surface is jagged, some of the beam may hit at a higher point or at this point or this point or that point so it causes them to split like that.
> I: Okay, and so let me say it back to you to make sure I understand. This is one beam coming in?
> L: Yeah
> I: So this is one beam coming in and it comes here and it hits and it splits into four little beams
> L: Yes. Because it's a rough surface, not a smooth surface.
> I: Okay. So then these arrows come from the first one?
> L: Yes. It's the beam splitting into multiple parts.

In this interpretation, the arrows are registrations, as is the jagged line. Furthermore, she also attends to specific segments of the jagged line, some of which are closer or further from the largest arrow. Her narration again initially involves three segments. The first segment is the single arrow coming in, which is again a beam of light. The second segment differs from her earlier interpretation: this time it involves a symbolic form of splitting at the varying points of contact. The final segment involves multiple arrows that are going in new directions after the splitting has occurred.

Susan makes a similar interpretation.

> I: So where are these little arrows coming from then?
> S: Cause there's not a big surface to have a single reflection, it's not like big smooth, it's bumpy so it takes a light and goes fshew! … And it goes out in all different directions.
> I: Okay. And how does it do that when there's only one arrow coming in?
> S: Diffraction? ... I think.
> I: What do you mean?
> S: When light hits something and it goes boom and bursts into lots of little things. It separates, into lots of little beams and the reason you can't see anything in it is because it's not one focused beam but lots of little ones that go – light.

One difference in Susan's interpretation is that she carves the bumpy line in a different way than Lily. Rather than following the path of the arrow into the nooks of the bumpy line, she treats the entire bumpy line as a primary registration. Therefore, her interpretation does not go into the same level of descriptive depth, but she still has a complete narrative, where the key event is the arrow's encounter with the bumpy line. What is common to Lily's and Susan's explanation is a perceived interpretive constraint where the first segment of the narrative involves a single arrow while the third involves multiple arrows. Because the narrative requires an event to account for the transition, they both converge on a splitting primitive, but associate them with different registrations.

Rita's interpretation follows the same event narration, and she fills the second slot of that narration with diffraction, like Susan did. However, her interpretation at this point does not place much priority on the bumpiness of the horizontal line.

> I: So where are these arrows coming from then?
> R: Umm, the same place, I think? Yeah, the light is here and it's just bouncing back from the surface.
> I: Okay, so these four little arrows, they're bouncing back from the surface. Where did the come from cause there's only like one arrow coming in?
> R: It diffracts, so like, yeah, here it spreads and then it sort of spreads out and bounces off, like if you have water and you push it through, it spreads out, sort of what it's doing, so it's bouncing and it just bounces off.

Rita's account is focused even more on the spreading behavior of the arrows that she infers from the diagram. It appears that the most relevant feature of the arrows that she reasons from is their individual headings, rather than any other features such as their size or linear form. She draws on diffraction as the event that accounts for this behavior, an idea that was discussed earlier in her class as a general behavior of waves and was consistently represented with arrows moving in outward directions. In this understanding of diffraction, the arrows do not necessarily come from splitting – rather, it is simply part of the diffraction phenomenon where the motion becomes spread out.

Pragmatics of interpreting diffuse reflection

Throughout these examples of interpretation of diffuse reflection, we can see that part of the work for the students is inferring the intended meaning of this diagram given their novice understanding of the phenomenona. This is instantiated in a couple of ways in these interviews. First, in all of these interpretations, we see that they do not arbitrarily construct separate meanings for each arrow in the diagram. Rather, there is an interpretive consistency in the arrows' ontology. For Lily, both the incoming and outgoing arrows are beam-like entities and paths. For Rita, they are indicators of directionality.

Secondly, all the students are inferring some intentionality and deliberateness in the representation. Lily's interpretation involves noting that the incoming beam splits into "4 little beams" - suggesting attention to the relative shortness of the outgoing arrows and privileging that feature to inform her construction. (In truth, the size of the arrows was more of an incidental feature of how the diagram was drawn.) Rita and Susan attend to the outgoing directionality of the arrows as if those were the author's intended feature. They also interpret the incoming arrow as being the only arrow that comes in.

We understand these interpretations to follow many interpretive maxims and, included among them, a *completeness* maxim. Following completeness, the students assume that the inscriptions that are present are the only ones that would be needed to do their interpretive work. We consider this to be very reasonable in most interpretive situations, and to be expected. However, the challenge is that completeness is relative to the intent of the author. The teacher, in presenting this representation the previous day, had particular intentions in mind for what this diagram would show compactly. It does not seem unusual, though, for individuals learning the domain to not be aware of this specific intent and to apply completeness too generally, thus leading to what we would consider undesirable interpretations.

Discussion

In this paper, we have taken the position that in order to take a move beyond epistemic fidelity and transparency as the best criteria for evaluating representations, we need to do more to unpack how it is that students interpret representations. We believe more work can be done to identify interpretive resources that students have in unfamiliar domains, and we believe that we can do more to account for why the use of these resources lead students to various patterns of interpretation. In the limited space of this paper, we briefly presented a framework for how students interpret representations and illustrated its application with cases of middle school students interpreting simple optics diagrams. As part of that application, we examined how, in interpreting representations of reflection, the students discussed here made frequent use of an event narrative to structure their interpretations. We also briefly talked about how this narrative was elaborated with various registrations and conceptual primitives. We also began to discuss the role that students' assumptions of completeness in a representation may influence students' interpretive constructions. In future work, we hope to discuss these ideas much further in depth and with examples from other domains. Regardless, we hope that this paper has illustrated how this framework may be a productive tool for us to better understand how students interpret scientific representations.

References

diSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction, 22*(3), 293-331.

diSessa, A. A., Hammer, D., Sherin, B., & Kolpakowski, T. (1991). Inventing graphing: Meta-representational expertise in children. *Journal of Mathematical Behavior, 10*, 117-160.

Driver, R. (1994). *Making sense of secondary science: Research into children's ideas*. New York: Routledge.

Grice, H. P. (1975). Logic and conversation. In P. Cole & J. L. Morgan (Eds.), *Syntax and semantics* (Vol. 3, pp. 41-58). New York: Academic Press.

Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from project 2061's curriculum review. *Journal of Research in Science Teaching, 39*(6), 522-549.

Lee, V. R., & Sherin, B. L. (2004). What makes teaching special? In Y. Kafai, W. Sandoval, N. Enyedy, A. Nixon & F. Herrera (Eds.), *Sixth international conference of the learning sciences* (pp. 302-309). Santa Monica, CA: Lawrence Erlbaum Associates.

Lehrer, R., & Schauble, L. (2004). Modeling natural variation through distribution. *American Education Research Journal, 41*(3), 635-679.

Leinhardt, G., Zaslavsky, O., & Stein, M. M. (1990). Functions, graphs, and graphing: Tasks, learning, and teaching. *Review of Educational Research, 60*, 1-64.

McDougalLittell. (2005). *Waves, sound, and light*. Evanston, IL: McDougal Littell.

Nemirovsky, R. (1992). *On the basic forms of variation*. Cambridge, MA: Technical Educational Research Center.

Ramadas, J., & Shayer, M. (1993). Schematic representation in optics. In P. J. Black, Lucas, A. M. (Ed.), *Children's informal ideas in science* (pp. 172-189). London: Routledge.

Ronen, M., & Eylon, B. (1993). To see or not to see: The eye in geometrical optics - when and how? *Physics Education, 28*(1), 52-59.

Roschelle, J. (1990). *Designing for conversations.* Paper presented at the AAAI Symposium on Computer-Based Environments for Learning and Teaching, Stanford, CA.

Roschelle, J. (1991). *Students construction of qualitative physics knowledge: Learning about velocity and acceleration in a computer microworld.* University of California, Berkeley.

Sherin, B. (1996). *The symbolic basis of physical intuition: A study of two symbol systems in physics instruction.* Unpublished dissertation, UC Berkeley.

Sherin, B. (2000). How students invent representations of motion: A genetic account. *Journal of Mathematical Behavior, 19*(4), 399-441.

Sherin, B. (2001a). A comparison of programming and algebraic notation as expressive languages for physics. *International Journal of Computers for Mathematical Learning, 6*, 1-61.

Sherin, B. (2001b). How students understand physics equations. *Cognition and Instruction, 19*(4), 479-541.

Sherin, B., & Lee, V. (2005). On the interpretation of scientific representations, *2005 Annual Meeting of the American Educational Research Association*. Montreal, Canada.

Acknowledgments

Work on this paper was partially supported by a Graduate Research Grant from the University Research Grants Committee at Northwestern University. We would like to also acknowledge the participant students and teachers as well as Heather Johnson for feedback on an earlier draft of this paper.