

Constructing Definitions as a Goal of Inquiry

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Abstract. In a class on perception, students, over the course of 3 weeks, constructed an account of “blurriness” with respect to vision, describing blurriness as occurring when “more than one ray from two separate points out in space are hitting the retina at one point.” This account of blurriness, however, was just one of many introduced early on in our investigations of the eye. As students worked to model the eye and developed a consensus description of how lenses and pinholes create images, the “the separate points in space to one point on the retina” idea was refined, gained prominence in discussions and became a stable, useful, and precise concept. This paper explores one student’s progressive understanding of blurriness, and the activities and interactions that supported the development of this definition.

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INTRODUCTION

A debate regarding the definition of a “personal epistemology” recently appeared in the *Journal of the Learning Sciences* as Sandoval [1] argued that clarity of definition is necessary for theoretical progress, while Elby [2] countered that theoretical progress must, to some degree, precede the definition. “The scope of personal epistemology should not be decided entirely *a priori*,” Elby claims, noting, “it is more productive not to converge on a definition until further empirical and theoretical progress points us toward the best way to ‘cut up [nature] ... along its natural joints’ [3, p. 64].”

We point this out not to make a statement regarding personal epistemology, but definitions. Many curricula take Sandoval’s “front end” approach to definitions: students are given precise definitions for important terms (or construct them) early on in their investigations; they then use these definitions to help structure the inquiry and enable students’ progress on understanding and applying the ideas. An alternative to this approach is the “iterative” approach suggested by Elby: allow for theoretical and empirical progress before converging on a precise, consensus definition.

The front-end approach has its strengths, particularly if (1) the definitions have been through a vetting process in the scientific community (e.g., *momentum* or *evolution*) and (2) the goal of instruction is familiarizing students with these definitions and giving them practice in applying the definition to a range of phenomena. But in a course where the goal is to engage students in *doing* science, including constructing, evaluating, refining and critiquing scientific accounts of phenomena, we might view the iterative approach as more authentic.

The iterative approach certainly has precedent in the history of science. As Bazerman notes [4, p. 164], “In Bacon’s day the word acid meant only sour-tasting; then it came to mean a sour-tasting substance; then, a substance which reddens litmus; then, a compound that dissociates in aqueous solution to produce hydrogen ions; then, a compound or ion that can give protons to other substances; and most recently, a molecule or ion that can combine with another by forming a covalent bond with two electrons of the other... The tasting and taster vanish as the structure emerges.” That is, as progress is made on understanding acids, the definition changed not only in its precision but in the nature of the definition, here shifting from a subjective experience to an operational definition to a theoretical account.

There is little work, however, on how we might facilitate student inquiry and discourse to promote this iterative process in undergraduate physics, or even what such iteration might look like. This paper reports on a preliminary analysis of the evolution of an account of “blurriness” that students constructed in a course on scientific inquiry, co-taught by the authors, with attention to how student conversations, particularly efforts at reconciling multiple accounts, led to an increasingly scientific understanding and definition of blurriness.

COURSE SETTING

The data presented here is from a course designed to engage undergraduate, elementary education students in scientific inquiry on topics related to perception. In the course, students encounter complex phenomena, such as pinhole cameras and the eye, and work in small groups and whole-class discussions to

generate explanations. By starting with complex phenomena and working as a community to construct explanations of those phenomena, we expected that the inquiry would require students to develop scientific habits of investigation, communication and explanation, and the inquiry would better reflect characteristics of professional scientific research.

It is worth keeping in mind that the instructors' goal was not necessarily to develop a scientifically accurate account of blurriness, but to construct that account in a scientifically authentic manner. The role of the instructor in this course is to foster particular styles of discourse and investigation rather than a scientifically accurate conceptual understanding.¹

EVOLUTION OF IDEAS

(Day 24) "Maybe, like, too many rays of light?"

(Day 31) "Overlapping rays from multiple origins or points will cause an image to be blurry."

The question we begin to address in this paper is how descriptions of blurriness, above, shift from a vague to a productive description—one that conveys mechanism, is consistent with observations, connects to their understanding of light, and resolves ambiguities. The analysis below focuses on one student in the class, Breanna, detailing how her initial idea is influenced by others' ideas, and by her attempts to reconcile these different descriptions.

Initial ideas

The following conversation took place midway through the semester after students dissected cows' eyes and were challenged with explaining how the eye works. After several days of student-designed small group investigations on a variety of topics (lenses, pinholes, peripheral vision), it became clear that many groups were grappling with the question of why some images were crisp and others blurry. Thus, we crafted a class period around thinking about blurriness by first requesting each group to demonstrate a blurry image versus a crisp, focused image. One demonstration that will play into the discussion that follows was shining light through a figure cut out of tinfoil (creating a crisp-edged shadow) contrasted with shining light through that same figure, but now covered with translucent paper (creating a blurry glow and no image). Students were then asked, "what is blurriness?" The first response was from Amber:

Amber: Not as focused. [Laughter.]

We interpret the laughter as indicating that students identify this first definition as not a serious attempt to answer the question, likely because they recognize it

as circular and therefore unproductive.

An attempt is then made by Breanna to explain blurriness as:

Breanna: Not as much light hitting that spot. Like a small amount of light hitting a spot.

Her tone is hesitant. While her ideas are somewhat vague, they are likely related to an observation her group had recently made: by changing the lens/screen/bulb distances, they could create a small bright spot of light. Breanna's notes from this observation are shown in Fig. 1.

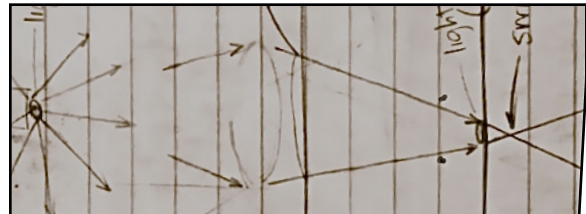


FIGURE 1. Breanna's research notebook from Day 22.

A second student (whose group has discussed why you cannot read something if it is even slightly in your peripheral vision) follows Breanna by saying:

Amanda: ...we were talking about peripheral vision, how it's like more unfocused and maybe that's because the light from those - from, y'know this area over here [motions to periphery] is coming in at like angles so the lens can't like focus it right to the middle.

Breanna follows this by attempting to reconcile her idea of blurriness as "a small amount of light" and Amanda's idea of only being able to focus on objects in the center of your vision:

Breanna: And then the spots you're looking straight at - plenty of light rays are hitting that - those spots, entering your eye and going straight.

It's unclear exactly what Breanna means—she could be thinking of flux—but it is clear that she's trying to put together Amanda's idea with hers. A sketch from her research notebook from this day (Fig. 2) illustrating her ideas (the curve in this diagram is the back of the eye, looking at a tree) is similarly unclear.

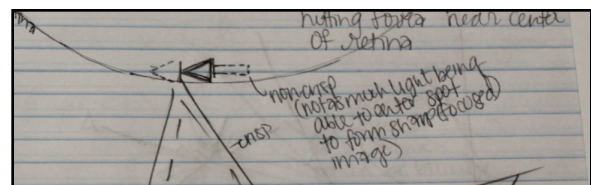


FIGURE 2. Breanna's research notebook from Day 24.

When the instructors ask if there are other ways of understanding blurriness, a third account attempts to

¹ Further details on the course can be found at: <http://phys.csuchico.edu/latkins/SGSI>

explain why a figure cut out of tinfoil will cast a crisp-edged shadow, but if the figure is covered with translucent paper, you see a blurry glow and no image. After a some discussion, they conclude that this is because light rays travel “straight through” the cutout, but, if the paper is there, the light rays are “broken” and “spread out” by the translucent paper.² Thus they describe blurriness as:

Caitlin: More light lines. Like more rays of light or like more light, less concentrated... I was saying more rays. Because the rays are like broken at the (paper).

And Breanna, again working to reconcile this with her initial description (in which *more* light is *focused* and *less* light is *blurry*), addresses Caitlin:

Breanna: But they're not as strong. There's more rays but they're not as strong.

It's a subtle change, but Breanna is being more precise in what she means by “plenty of light rays,” distinguishing the *number* of rays and the *strength* of those rays. We can see this precision as a move away from the nondescript “not as much light” towards the final description she offers of blurriness as “overlapping rays from multiple origins.”

Nicole then chimes in to comment on an idea of “overlapping” rays as causing blurriness, essentially the first comment that addresses multiple sources as responsible for blurriness:

Irene: What do you mean by overlapping?

Nicole: ...There's so many. One on top of the other - like, yeah, they're like basically on top of each other [gestures two spread-out hands].

Amber: Like a double image.

Irene: Yeah, so what you're saying is that light from this part [points to top of cut-out] can overlap in this spot [points to screen] with light from this part [points to bottom of cut-out].

Nicole: Yeah, exactly.

Breanna, however, disagrees, noting:

Breanna: But I think that that would kind of be the opposite. Because, um, this, the top one [a crisp shadow] there's no overlapping. It might be more dim. And then the bottom one if there's overlapping it would be brighter... What I think is there's so many little fragmented rays, they're going many different directions that's why it's going blurry... There might be a lot of them but they're hitting so many spots on the paper that it doesn't make a crisp image.

We interpret Breanna's disagreement as failing to recognize Irene and Nicole's point that there are rays from *multiple sources*, and focuses on the notion of “overlap,” an idea she associates with focused images

(see Fig. 1). This becomes a point of confusion for students, with some noting that rays (from one origin) must be brought together to create a focused image, others recognizing that rays (from multiple origins) that are brought together create blurry images.

Further progress

Students were given a homework assignment to explain the observation discussed above (light through translucent paper in the shape of a “y”). After students turned in their individual assignments, groups sketched their ideas on white boards. Breanna and Caitlin work together; their individual homework assignments are below (Fig. 3), along with their group white-board. Breanna's is notably lacking in mechanism: it is hard to determine how the fragmented rays of the y create the squiggles on the screen. While we do not have data from their small-group conversation, the final group diagram is similar to Caitlin's homework, and Breanna's comments are consistent with the consensus diagram.

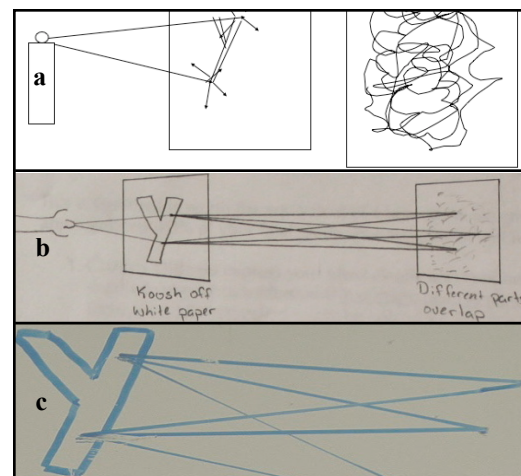


FIGURE 3. (a) Breanna's, (b) Caitlin's and (c) Breanna-&-Caitlin's-consensus diagrams.

The diagrams were discussed as a class; initial ideas discussed how the secondary rays² were responsible for the blurriness, in a way that suggested that the fragmentation somehow “broke” the image. To clarify, the instructor asks:

Leslie: So what makes the secondary rays blurry?

Breanna: We- we said that they were overlapping. Like there were so many going in so many directions that they were overlapping and that would make them blurry. 'Cause there's no like specific image being- like. There's no ray being, like, to a specific direction they're just like all going in random

² This idea of light “fragmenting” when it hits a non-mirrored surface and sending less intense rays out in all direction was a key idea developed in the third week of class. Students thus refer to diffuse reflection as a “koosh” and the rays as “secondary rays.”

directions.

Caitlin: So it was like pieces of light from the top of the Y was overlapping with light from the bottom of the Y.

Here Breanna has, for the first time, not included any description of “bright” or “dim” in her account of blurriness, focusing instead on the quantity (“so many”) and direction of the rays. Also of note is how she changes her word choice mid-sentence from an “image” to a “ray”—which may indicate she is distinguishing a ray of light from the image that is created by the collection of rays (a difficult idea for students; see [5]). However, it is Caitlin who ties together the information that rays from the top and bottom fragments overlap.

Nonetheless, there is evidence Breanna adopts this description of blurriness; in a writing assignment addressing why our eye needs a lens, she notes that without a lens:

We only see a hazy glow because rays from multiple points on the glowing y overlap on the screen. I drew light rays starting at points A, B & C that kooshed off white paper and sent light in all directions. This is just three points but in fact it is occurring all over the glowing y. Therefore, these overlapping light rays cause no image to be seen, just a glowing screen. ...Overlapping rays from multiple origins ... will cause an image to be blurry.

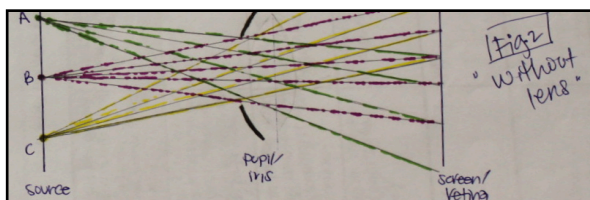


FIGURE 4. A figure from Breanna’s writing assignment addressing why our eye needs a lens.

DISCUSSION

While this paper traces Breanna’s changing ideas, similar shifts are occurring across the class: students are grappling with understanding how curved mirrors create “blurry” reflections, how lenses and pinholes correct blurriness, how the eye interprets information (many students initially thought of images “entering” the eye and being interpreted by the brain, rather than rays creating an image on the retina). Their tentative descriptions of blurriness—“overlapping rays,” “overwhelming the retina,” “spread out,” “too much light”—are all being refined and contributing towards a precise, mechanistic and consensus description. Breanna’s research group, for example, became intrigued by the question of why we cannot focus on

objects in our peripheral vision, attempted to show that all off-optical-axis objects could not be focused on the retina (see Fig. 5), and, failing to do that, pushed the class to distinguish *focus* and *resolution* in describing the “crispness” of an image.

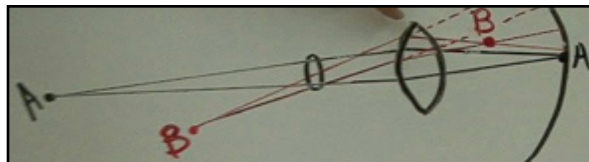


FIGURE 5. Breanna’s groups’ description of why peripheral vision is blurry.

The confusion between rays causing blurriness or focus when brought together is ultimately resolved, with Dee concluding the focus requires: “All the rays from an originating point come back together in the same spot on the retina. *One* originating point!”³

Rather than the *starting* point for inquiry, this definition is a *conclusion* of the inquiry—an idea that was negotiated, challenged, tested, refined and ultimately adopted. In doing so, students moved from vague descriptions to precise, mechanistic accounts, developing the theory necessary to make this definition possible.

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³ Compare to the ASM definition: “A point at which rays, originating from a point in the object, converge.”

