Misconstruals or more? The interactions of orbit diagrams and explanations of the seasons

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Abstract

This paper examines a "misconstrual hypothesis" regarding diagrams of the Earth's orbit around the sun and how middle school students explain the cause of the seasons. Drawing from 24 semi-structured interviews, I present qualitative analyses of students' explanations of why temperatures vary in summer and winter and how those are influenced by the elliptical shape of perspective drawings of the Earth's orbit, common to many science textbooks. The results of the analysis suggest that diagram interpretation does not necessarily follow what has been often predicted in the literature and that conceptualizations can shift quite rapidly as different diagram features are noticed. A knowledge-in-pieces approach for understanding diagram interpretation is ultimately recommended through specific examples.

Introduction

The relationship between diagrammatic representations in textbooks and conceptual understanding in science has frequently been characterized as a problematic one (Holliday, 1985). While diagrams and technical figures are essential to the practices and knowing of science, several critiques have been put forth over the past decades about how diagrams that appear in canonical textbooks can be problematic for student learning (American Association for the Advancement of Science, 2002; Carvalho, Silva, & Clement, 2007; Kesidou & Roseman, 2002; Kikas, 1998; Wampler, 2002). In the most extreme cases, suggestions are made that specific classes of commonly appearing textbook diagrams will induce specific misconceptions that have been described in the science education literature (e.g., Cho, Kahle, & Nordland, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994). This approach of conceptualizing diagrammatic representations as inducing specific and robust misconceptions as invoking what I term as a *misconstrual hypothesis*. The core of the hypothesis is that a fairly direct, causal relationship between external representation and mental representation exists. Astronomical and Earth Sciences have been an especially prime area for which the misconstrual hypothesis has been instantiated. Among the most famous predicted misconstruals involves perspective drawings of the earth's orbit around the sun, which is thought to be induce a misconception of seasonal temperature variation resulting from a dramatically elongated orbit. This predicted misconstrual has had such tremendous intuitive appeal that it has appeared in the well-known video case study A Private Universe (Schneps & Sadler, 1988), in empirical studies of students' misconceptions (Kikas, 1998), and even in a recent consensus report prepared by the national research council(Duschl, Schweingruber, & Shouse, 2007).

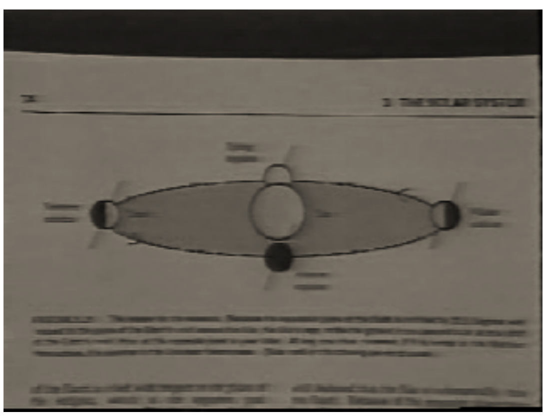


Figure 1: Screen still from *A Private Universe* video as the suggestion is made in the voice-over that diagrams such as this lead to the common orbit-based misconception about the seasons.

Yet, to date, little to no empirical investigation has been undertaken in order to determine, if indeed, that predicted relationship exists. Rhetorically, the misconstrual hypothesis has been invoked in critiques of curriculum or textbook images alone, or in studies of students' alternative conceptions. But strong evidence that something like a perspective drawing of the Earth's orbit leading to misconceptions about the causes of the seasons has been lacking. This paper seeks to address that absence through an empirical study of diagrammatic representations of the earth and sun and student conceptualizations of the causes of the seasons. I will present the results from a qualitative study (N=24) with middle school student who, at the time of the study, had no prior formal instruction about the seasons. These students each participated in think-aloud interpretations and semi-structured conceptual interviews with one of three randomly-assigned, commercially published textbook representations. Using this data, I will argue that a direct relationship between perspective depictions of the earth and sun are not clearly leading to the expected seasons misconceptualization. Rather, an entirely different and undocumented alternative conception is most frequently articulated, and then these are eventually adapted as students engage in closer inspection of the representation.

Theoretical perspective

The introductory language follows from studies of students' mental models (Gentner & Stevens, 1983) and alternative conceptions (Driver, et al., 1994), and is intentional in that it motivates the work of this paper. Specifically, this paper examines a strongly implied (or at times, directly stated) relationship between diagrams and cognition that presumes relatively stable conceptualizations in the minds of students. As the empirical results will show, this is ultimately not the most generative theoretical framing, as there is far more fluidity to students' explanations of scientific phenomena and a much more dynamic interaction between representation, conceptualization, and task context than is often assumed.

In response to these results, I advocate for a Knowledge-in-Pieces perspective to characterizing the observed student science cognition (diSessa, 1988). According to a Knowledge-in-Pieces perspective, the underlying intuitive knowledge system is understood to be composed of a large number of individual elements of diverse form that interact and give rise to emergent explanations and accounts for scientific phenomena. Following a knowledge analysis approach (diSessa, 1993; Duncan, 2007; Sherin, 2001), I take specific excerpts of the interviews and dissect them in a fine grained manner to articulate the elements of knowledge that appear to be most active and involved in the generation of what are seemingly incorrect interpretations and explanations. By its nature, this is a challenging endeavor, as it is difficult to pinpoint when an element has been validly identified. However, I use the criteria of generativity and plausibility to make my case with the data excerpts. An additional move I make in this knowledge analysis is through analysis of not only the elements of knowledge that are active, but also the elements of the diagram which are attended to by the students. The assumption with orbit drawings is that the elliptical shape is the element in orbit diagrams receives immediate attention. However, as it turns out, there are far more features than that which are detected and considered by this sample of students. By characterizing the elements of the diagrammatic representation, I attempt to use the knowledge-in-pieces framework in a manner which is distributed both between the minds of students and with the physical representation itself (Martin & Schwartz, 2005).

Data sources

The data comprise of a corpus of video-recorded semi-structured interviews with 24 middle school students, grades 7 and 8, from three different schools located in or near a major Midwestern city. These students were all volunteers, from a range of academic abilities and backgrounds, who agreed to be interviewed individually by a university researcher during the student's science class. Each interview spanned four different science topics and lasted between 45 minutes and one hour.

The interviews required students to examine an isolated representation taken from a science textbook and think-aloud as they made sense of what was being shown to them.

Following that think-aloud period, the students were then asked to explain a major scientific idea related to the diagram they were examining. For the earth's orbit drawings, the students were asked what they believed caused seasonal temperature variation. Following that, each student was asked a standard set of questions in which he or she was to locate, by pointing, where the Earth would be in its orbit when it was hottest and coldest for the city they lived in, and then again for a city located in Australia. Half of the students in the sample were also asked, prior to viewing of the given diagram, to explain the cause of the seasons and locate the Earth in its orbit under the same city and temperature conditions through a drawing of their own creation, in order to establish a baseline. This baseline helped to establish that, beyond their teacher's reports, that the students had not had pre-existing instruction about the cause of the seasons.

Three diagrams from actual science textbooks were used and were randomly assigned for students to examine. These diagrams came out of a corpus of texts analyzed for a separate study on historical change in representation design in instructional materials (Lee, 2010). Two of these involved elliptical depictions of the earth's orbit and one involved a circular depiction. Each student was only shown one of the orbit diagrams during their interview.

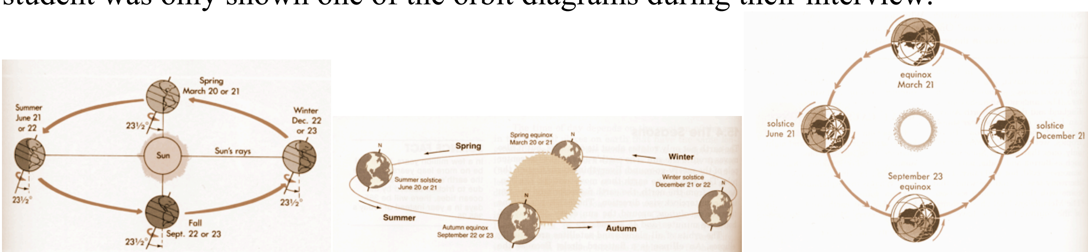
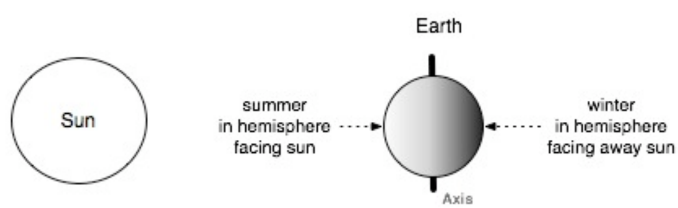


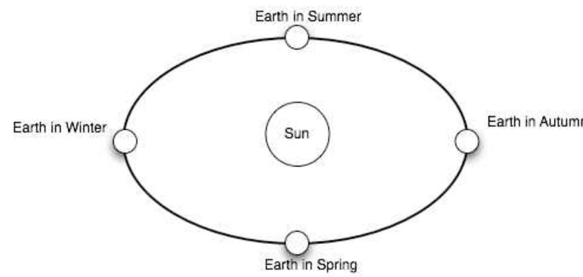
Figure 2: Orbit diagrams used in this study.[1]

Results

Lines and passages that referenced the cause of the seasons in the transcribed interviews were coded on the basis of four explanations emerged from the data and have been observed in other research (Atwood & Atwood, 1996; Sadler, 1987). They include the following:

Explanation	Illustration of explanation
Seasons are because one hemisphere is facing the sun and the other is facing away. This explanation for the cause of the seasons involves designating the half of the earth that is closest to the sun as experiencing summer because it is facing and the side that is farther is experiencing winter.	

[1] Images from *Principles of science* (1979) by Heimler & Neill, published by Merrill, *General Science* (1989) by Watkins, et al., published by Harcourt, Brace, & Jovanovich, and *You and science* (1955) by Paul F. Brandwein, Alfred D. Beck, Leland G. Hollingworth, Anna E. Burgess, published by Harcout Brace

<table>
<tr><td>Seasons are because the Earth is closer to or farther from the sun during its orbit. This explanation for the cause of the seasons is similar to and inclusive of the misconception documented by Sadler and others. The elongated orbit is responsible for seasonal variation.</td><td>
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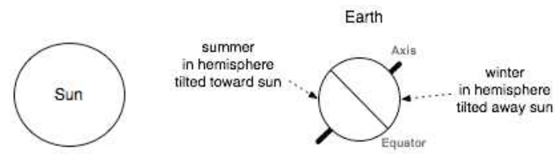
<tr><td>Seasons are because one hemisphere is tilted toward the sun and the other is tilted away. This explanation correctly incorporates the axial tilt. However, it does not involve the angle of incidence of sunlight on the Earth's surface and often relies on justifications such as the northern or southern hemisphere is closer to the sun or gets a greater amount of sunlight.</td><td>
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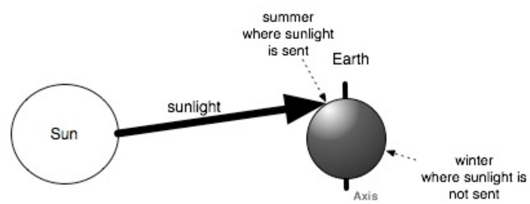
<tr><td>Seasons are because the sun shines more onto the hotter area and less on the cooler one. This explanation was uncommon and was coded when a student would state that the hotter season is where the sun shines on the earth and the colder season is where the sun does not shine.</td><td>
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Table 1: Common explanations for the seasons in the data corpus

A second coder independently coded a subset of the data and yielded a kappa reliability coefficient of 0.81 for these explanations for the seasons when provided with transcripts and raw video.

When comparing the explanations for the seasons that emerged given the elliptical or circular depictions, the distributions in the table below were observed. Note that they are very similar in percentage. Also note that the most frequently given explanation is the one that involves one hemisphere facing the sun as being responsible for seasonal temperature variation. This is contrary to what has been documented elsewhere in other research on conceptualizations of the seasons, in which the absolute distance from the sun during the Earth's orbit is seen as the most common explanation (Atwood & Atwood, 1996).

	Hemisphere facing the sun	**Earth orbits closer to sun**	**Hemisphere tilted toward sun**	**Sun shines onto hot area**
Elliptical depictions	54% (13)	24% (6)	20% (5)	4% (1)
Circular depiction	56% (5)	22% (2)	22% (2)	0% (0)

Table 2: Frequency of explanations among the sample

Moreover, students gave multiple explanations and changed their ideas frequently. This is a contrast to the stable characterization that has sometimes been attributed to students' intuitive ideas and conceptualizations in science (Ioannides & Vosniadou, 2002). What this suggests is that ideas about what causes the seasons are highly sensitive to the immediate context, and the mental models that form from the underlying knowledge system can vary greatly because different knowledge elements come into play.

Dynamism in interpretation and explanation

To illustrate dynamic changes in explanations for the seasons and how attention to different features affects interpretation, I present brief transcript excerpts from two interviews involving students interpreting the left-most orbit diagram in Figure 2. The first involves a student, Lana, who shifts her explanation of the seasons and interpretation of the given diagram.

At the beginning of the interview, she is given the diagram and asked to explain why it is warmer in the summer and colder in the winter. She fumbles through an explanation, using words like 'closer' and warmer. To get at what she was thinking after exploring some possibilities on her own, the researcher asked her to restate her idea.

Excerpt 1

I: Okay, can you tell me again why it's warmer in the summer and colder in the winter?

L: Because in the winter, the like, where you are is facing more away from the sun so like farther away from the sun while in the summer where you are is facing towards the sun so like it gets more sunlight so it becomes warmer.

In her initial interpretation of the diagram, Lana says that the seasons are caused by one hemisphere facing the sun while the other is facing away from the sun. She is looking down at the diagram as she says this and we can infer that part of this is being cued because the drawing uses shading to show orientation relative to the sun. That makes one half of the Earth darker than the other, and presumably offers a good explanation for why one season is warmer and colder.

This way of interpreting the drawing is confirmed with follow-up questions in which she is asked to point to specific locations for the Earth in its orbit when it is hottest and coldest for her hometown (in the Midwestern United States) and for a more distant place, such as Australia. She picks the Earth with the North American continent in the unshaded region for the warmest time for her and the coldest for Australia. She picks the opposite Earth for as the time when the US is coldest and Australia is warmest. Note that both of these Earths are located on the left and right edges of the diagram. If this drawing is seen as showing an oval shaped orbit, those would be the two points at which the Earth is farthest from the sun.

Towards the end of her interview, she is asked if there is a time when the Earth is closest to the sun. This is to gauge whether or not she knows about the actual elliptical nature of the Earth's orbit. Here, she changes the causal mechanism for the variable temperatures during the seasons.

Excerpt 2

I: Great. And as the earth is moving, is there a time when the earth is closest to the sun?

L: I think so… I think it's during the summer because then it would be warmer and in the winter it's farther away so it would be colder.

I: Does this picture show the closest part and farthest part?

L: It sort of does. Here it's farther and here it's closer. *(She points to the major and minor axes of the ellipse)*

I: Does that fit with what you were talking about?

L: Yeah.

Lana now says that summer would be when the Earth is closest to the sun and winter would be when it is coldest. When asked if this is reflected in the picture, she says that the picture at least partially shows what she was talking about. However, what she points to as evidence are the major and minor axis. The right most earth is when it is coldest, and the topmost earth is now the warmest. This is already in conflict with what she had said earlier when she said the seasons related to one side of the earth facing the sun. Yet when she is asked explicitly about it, she does not see any obvious conflict.

Finally, in order to get at what she thinks of the Earth's orbital path, she is offered two options. The Earth is either a perfect circle or it is more elliptical or oval-like. She is posed with this question after having said that the Earth was closer in the diagram.

Excerpt 3
I: I've heard some people say that the earth moves around the sun in a perfect circle, and then some people say it's not actually a perfect circle, it's actually a little bit of an ovally thing. What do you think?
L: Um, well from this picture it kind of looks like it moves in an oval but like I know from the past that it goes in a circle.
I: If your teacher or parents were to ask you, what's the shape of it?
L: Circle.

At this point, Lana accepts that the picture looks like an oval, but instead discounts what it shows and states that she would report that the orbit is a circle. Toward the end of the interview, she disengages with the information in the diagram (i.e., she attends to the orbit shape, but discounts its validity) and comes up with an idea that is at odds with what she had said last. If the Earth were to be in a strictly orbital path around the sun, it would not have a point at which it would be closer or farther.

A broad look at dynamism.

From Lana's example, it would not be easy to characterize her as possessing a single, stable misconception. Rather there are a number of ideas that are being cued and activated, and this can be privileged or brought into alignment with specific diagrammatic features being registered in her visual field. The changes in explanations were not at all uncommon. In fact nearly all students interviewed in this study changed explanations over the course of a few minutes. These changes were not always as clear as suggesting a whole new mental model was formed, but there were certainly moments at which it appeared they were strongly tending toward or reasoning from some aspect of a new model. To illustrate, several students are represented in the chart below to show what explanation they had and what, if any, they changed to over time.

Student	Rep-3	Rep-2	Rep-1	Rep	Rep+1	Rep+2	Rep+3
LT	CF	FNF	CF	**FNF**	CF		
BF			TH	**FNF**	TH	FNF	
SN		DS	FNF	**CF**	DS	FNF	
JJ	CF	DS	FNF	**TH**	CF	TH	
EO			TH	**FNF**	TH	FNF	
KH				**CF**	FNF		
TL				**TH**	FNF	TH	FNF

Figure 3: Chart summarizing some of the different explanations that were generated by students in sequence during their interview

In this figure, the intepretation and conceptualization that each individual students had at the time of their initial viewing of the given diagram is listed under the column "Rep". FNF referes to the facing-not-facing explanation, CF refers to the Closer-farther explanation, and TH refers to the Tilted Hemisphere explanation. If the student maintained that same explanation (e.g., row RS in S2), no other changes were marked in any adjacent columns. If they had produced a different explanation prior to the one they gave with the diagram (e.g., row AM in S1), then that appears in the "Rep-1" column. Any other explanations that differed and were given prior to that are listed in the "Rep-2" column. Similarly, any changes in explanations after they had initially interpreted and reasoned from the representation are shown in the "Rep+1", "Rep+2", "Rep+n" columns.

Across all the drawings, shifting in explanation was common. It happened prior to the appearance of the drawings when students were asked to come up with an explanation, so this is not a phenomenon strictly tied to the use of the particular diagram. It also turns out that the diagrams had a range of influences. In some cases, students tended to stabilize once the diagram was provided, but for others, they destabilized and changed explanations after.

In order to understand what is happening, I offer a more detailed analysis of an interview with a student, Kasey, who exhibited shifting behaviors during her interview, above and beyond what is represented in Table 1. From this, I moved toward offer a possible way of looking at this kind of data as being the product of knowledge 'in pieces' and also involving a diagram being seen 'in pieces'.

Kasey and explanation shifts

This example is from an interview with a 7th grade student, Kasey, who was asked the same seasons questions described above with Figure 3 initially presented to her as a resource.

Kasey goes from a closer-farther orbit to a facing-not-facing explanation for the seasons

All students in this study knew they would be asked about science content and it would involve a drawing or representation of some sort being provided to them. Like all the other students, At the beginning of Kasey's interview, she was given no advance knowledge of what the representation was going to be used or what science content was to be discussed. For students in Kasey's condition, an unknown representation was given to them and they were asked to think aloud as they examined it and extracted some meaning from it. When she began this diagram interpretation phase of the interview, she first identified some of the depicted objects, and then quickly determined this was for depicting the seasons.

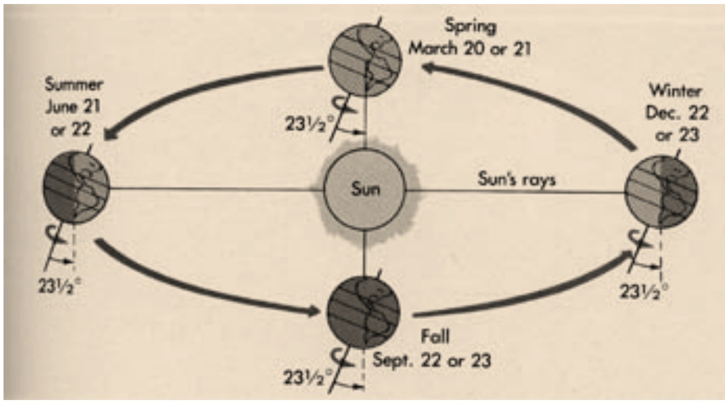

Figure 2: Representation of the Earth's orbit and how it is involved in the seasons, from *Principles of Science* (Heimler & Neal, 1979)

> Kasey: I think that's the sun *(points at center of picture)* and that's the moon *(points at the rightmost earth)* and those are pictures of the moon when they are in different seasons of the year *(motions in a circle over the orbit),* because they have like different-- the moon rotates and so does the sun *(twirls index finger)*…

In this initial quote, we see that Kasey mistakenly referred to the earth shapes as representing the moon, but decided immediately that this relates to the seasons and each of the blue shapes corresponded to the different seasons. Her recognition that the diagram was about the seasons was likely based on the fact that the representation had labels for each season associated with each of the four Earth shapes.

Just as Kasey finished describing this, she then proceeded to correct herself. She changed her statement about the diagram as depicting the moon, and once she established that it was actually the Earth, Kasey generated a closer-farther explanation for the seasons.

> K:…- oh, the earth! That's not the moon, that's the earth! And so the earth rotates *(twirls index finger)* and it revolves around the sun *(moves index finger over orbit shape)* so in different seasons of the year the sun is stronger because it is closer to the-because the earth is closer to the sun and so is the, in, in like winter it is, it's cold because it's also- (*Kasey moves her hand toward the rightmost earth, but then stops talking and stares at the representation.)*

As she spoke, Kasey placed her hands on her lap and restated the circular motions she had just mentioned, correctly stating it with the Earth. She then gave her closer-farther explanation for the seasons: "the earth is closer to the sun and so is the, in, in like winter it is, it's cold…". After tracing the orbit with her finger, she began to raise her hand again to point at the winter earth on S1 (while she was saying "because the earth is earth is closer to the sun and so is the, in, in like winter it is…").

Based on the timing of her hand movements and statements, Kasey appeared to have interpreted the diagram as showing a highly elliptical orbit. However, as she was pointing to the winter earth to support her interpretation, Kasey stopped herself midsentence. From the video, it appeared that Kasey had glanced at the leftmost earth shape, which had been labeled "summer". The sudden stop suggests that some problem had arisen at that moment. After several seconds of silence, she resumed her utterance.

> K: It's not as, but then you get the summer. (*brief pause)* Well, I guess it's just like, it just shows where the earth is in different seasons of the year and since the sun… I don't know.

For a brief moment, Kasey had the closer-farther explanation, but upon her noticing summer she stops. Her intonation changed to a higher register when she said "but then you get summer", and then she pauses, which suggests puzzlement. Kasey did not mention why 'getting summer' was a problem, though in the diagram, we can plainly see that the summer and winter earths are depicted as equidistant from the sun. If this was what she noticed, then it accounts for the interruption of her closer-farther explanation. After she attempted to re-explain the diagram (e.g., "it just shows where the earth is…"), Kasey paused again. She the proceeded to attempt another way to use the diagram to help her explain the seasons.

> K: It also depends on where we, like where our, like the earth is also turns *(grasps imaginary round shape in midair)*, so even where if the sun is really is closer *(grasps another imaginary round shape in the air with left hand)* to the earth than usual, and but our country is like facing, it's not facing the sun then it could still be really cold so it just depends on how the earth is facing too, so.

In that last utterance, we see that Kasey had puzzled over the situation. She then proceeded to recall the ideas she stated earlier regarding how the earth had a turning motion. Kasey continued to accept that the representation showed the Earth being closer to the sun at times, as is suggested by the different distances between the sun and Earths in the drawing. But in her reconsideration of the Earth's rotation, she encountered another idea: the earth could be close to the sun, but part of the earth could be facing away from it. That could hold true even if it the Earth was farther away in the summer.

The reappearance of knowledge that the Earth rotates, and therefore different parts of the earth could be facing away from the sun marks the beginning of a new segment in the interview where Kasey started to reason about the seasons as involving one hemisphere facing the sun and another facing away. This is inferred from her gesturing and her use of the term "facing".

Still, Kasey's statement about the Earth as "facing" was ambiguous. She was then asked for a clarification about her last statement.

> I: What do you mean by facing?
> K: Like here *(bottom earth),* that is a different country at the top than here *(points to top earth)* because they're both closest to the sun - that's like South America and that's like North America, and so in this section, South America would be closer. It would be warmer than North America and in this section North America (*she points to the North America shape in the bottom Earth)* would be warmer than South America *(she points to the South America shape in the bottom Earth).* And with everything else too *(she twirls her index finger).*

In response to the interview question, Kasey returned to the representation and used it as support for her reasoning. She selected the bottom earth to use as a basis for her elaboration, pointed at the closed shape inside of that circle (i.e., the North American continent from the Spring Earth) and then pointed at the top earth and the bottom-most closed shape (i.e., the South American continent in the Fall Earth). As she pointed at these regions in the two different Earth shapes, Kasey explained that they were both close to the sun ("Like here, that is a different country at the top than here…"). She then labeled each continent shape ("that's like South America and that's like North America"), and then described specific scenarios for each. In the top Earth circle shape, she explained that South America was closer to the sun and warmer while North America on that same earth was farther from the sun. The opposite held true in the bottommost Earth circle. Basically, Kasey was thinking that the top region of the earth was closer to the sun in the bottom position of the drawing while the bottom region of the earth was closer to the sun in the top of the drawing.

It is interesting to note that, as Kasey gave the above elaboration for what she meant by "facing", she refrained from using the actual term "facing" that she used seconds earlier. Instead, she described closeness to the sun is the determining factor. She could have attempted another way to communicate that it was orientation, but the description she gave with "closeness", seemed to involve some resemblance to how she first explained the seasons as involving the Earth being closer or farther to the sun. What is also interesting at this point is that Kasey's explanation of "facing" was unconventional. It appears that she had dramatically misread the perspective shown in the diagram, and interpreted the diagram as genuinely showing the Earth being very close to the sun in both the Spring and the Fall.

From this example, there are three things that are important to notice. First, conceptions changed, and they did so quite quickly. Once she had examined the entire representation, she began to offer a closer-further explanation for the seasons. Then this changed to a facing-not facing explanation, which was then elaborated in such a way that the perspective in the diagram was really misread. All of these shifts transpired over a period of less than two minutes, during which the interviewer made one comment. Second, the shift from the closer-farther orbit explanation to the facing-not facing one had been initiated by Kasey. There was no effort to correct her. She simply noticed an incompatibility in her explanation, found that dissatisfying, and independently tried to resolve it. That makes this example different from Lana's, and should raise issue with any concerns that she was being led on by the interviewer. Finally, there is clearly a great deal of interplay between a lot of different pieces of knowledge and different pieces of the representation. Among the most prominent knowledge here is what she knew about how seasons vary in temperature, how the sun is involved in providing heat to the Earth, the relationship between distance and perceived temperature, and the different motions of the Earth. How this knowledge was instantiated changed rapidly as different aspects of the representation were noticed and considered. By the end, when she had offered her final description of continents being closer or farther, she appeared to be misread perspective and only attune to the absolute distances shown in the diagram.

Kasey shifts from seeing an oval to seeing a circle

As with Lana's interview, we fast forward to the end when a discussion about orbit shape takes place. Near the end of Kasey's seasons interview, more shifts in reasoning about the seasons and how Earth moved around the sun were observed, although these were more subtle. Kasey was asked about the accuracy of the scale in this representation. Her response involved two shifts in her reasoning. One of these was related to the shape of the Earth's orbit. Kasey shifted from thinking of the Earth as being very near or very far from the sun during its orbit to thinking of the Earth as instead maintaining the same distance from the sun. The other shift related to her explanation for the seasons. Her new explanation involves the sun 'pointing' at some part of the Earth. Though she used language that suggests some sunlight is being directed to a predetermined location (the directed-sun explanation from the previous chapter), some of her other comments are suggestive of a shift to a facing-not facing explanation. In contrast to the explanation she ended with in the previous section, the distance of the Earth from the sun was not emphasized in the same way as it had been before.

> I: Um, and are they about the right distance away from each other? The earth and sun?
> K: Uh *(brief pause)* Not sure.
> I: Could you say a little what you're thinking right now?
> K: Well, I think like, it seems weird that the earth is so far away from the sun in the summer, but then again, the sun is like pointing almost directly at North America. And in winter I can guess that it would be far away because it's cold. But then again, it could- I think, I don't think there would be a difference in distance. I think it would just be like the same amount *(motions finger in a circle shape over the orbit),* like it would just be a regular circle *(makes circle shape with both hands).* It wouldn't be an oval, because it just depends on how the earth is turned, like how, where it is on the axis.
> I: What do you mean where it is on the axis?
> K: Like, if it's, with, where, wherever the sun is pointing should be like, like direc- wherever the sun is pointing directly would probably be like directly would probably be the warmest. And I don't think it would matter necessarily the difference between the space between the sun and the earth. And I think it's just like going around basically *(motions with finger in circle).*

Here, the mention of distance by the interviewer appeared to nudge Kasey into noticing, once again, that the distance between the left-most earth circle and the sun was the same as the distance between the right-most earth circle and the sun. This seemed to be incompatible with her inclination to think of the earth as being closer to the sun in the summer ("it seems weird that the earth is so far away from the sun in the summer"). But then she had noticed that "the sun is like pointing almost directly at North America". From the video, it appears that she may have noticed the shading pattern on the Summer Earth. The North American continent in that particular Earth was in the lighter blue region, and that gave it the appearance of receiving 'direct' sunlight. That realization enabled her to change her conceptualization, and to make the distance from the sun less central to her explanation for the seasons. She then described the orbital path as being "a regular circle. It wouldn't be an oval". At that moment, Kasey's stance toward the diagram shifted. She had gone from accepting the distances as they were shown to seeing the distances as something that could be questioned or dismissed. What was shown in the diagram was, for a brief moment, something that Kasey understood to be taken to be as questionable and subject to doubt.

A possible way to think about Kasey's responses

Like with Lana and Figure 2, what these excerpts from Kasey's interview illustrate is how dynamic and changing the interpretation and reasoning about scientific phenomena can be and how knowledge and representation can interact with each other. The representation does not strictly drive the reasoning and the knowledge that Kasey has does not determine how the representation is seen. These things are changing fluidly with the situation and the different aspects of the representation that are being noticed and Kasey's prior knowledge are rapidly interacting with each other. These changes, along with knowledge the student has and aspects of the representation that are involved are presented in the Table below. Six points in Kasey's interview are presented there where she had settled on or had begun to shift in her reasoning. Some of the most visible aspects of the representation and some ideas that she had about the phenomena are listed in the last columns.

Conceptualization	Utterance	Knowledge	Representation
Closer-farther to Facing-not facing			
Closer-farther explanation for the seasons	"…and it [the earth] revolves around the sun so in different seasons of the year the sun is stronger because it is closer to the-because the earth is closer to the sun and so is the, in, in like winter it is, it's cold…"	• Sun is the source of heat for the seasons • Earth's motion around the sun • Summer is warmer, winter is colder • Effect of distance on temperature	• Sun shape & label • Earth shapes & labels • Arrows depicting motion around sun • Distances between Earth shapes and sun
Shifting initiated	"but then you get the summer. Well, I guess it's just like, it just shows where the earth is in different seasons of the year and since the sun… I don't know".	• Sun is the source of heat for the seasons • Earth's motion around the sun • Summer is warmer, winter is colder • Effect of	• Equal Distances between summer and winter Earth shapes and sun

		distance on temperature	
Transition to facing-not facing	"the earth is also turns *(grasps round shape in midair)*, so even where if the sun is really is closer *(grasps another round shape in the air with left hand)* to the earth than usual, and but our country is like facing, it's not facing the sun then it could still be really cold so it just depends on how the earth is facing too, so."	• Sun is the source of heat for the seasons • Earth's motion around the sun • Earth's rotational motion on axis • Summer is warmer, winter is colder • Effect of orientation on an influence (such as temperature)	
Facing-not facing explanation for the seasons	"Like here *(bottom earth)*, that is a different country at the top than here *(top earth)* because they're both closest to the sun - that's like south America and that's like north America, and so in this section, south America would be closer, would be warmer than North America and in this section North America would be warmer than South America"	• Sun is the source of heat for the seasons • Summer is warmer, winter is colder • Effect of distance on temperature	• Sun Shape • Bottom earth shape • Top Earth shape • North America Shapes • South America Shapes • Distances between continent shapes and sun
Oval to circle			
Oval-shaped orbit	"…and it [the earth] revolves around the sun so in different seasons of the year the sun is stronger because it is closer to	• Earth's motion around the sun	• Distances between Earth shapes and sun

	the-because the earth is closer to the sun and so is the, in, in like winter it is, it's cold…"		
Circle-shaped orbit	"I think, I don't think there would be a difference in distance. I think it would just be like the same amount, like it would just be a regular circle. It wouldn't be an oval, because it just depends on how the earth is turned, like how, where it is on the axis."	• Earth's rotational motion on axis	• Distances between Earth shapes and sun

Table 3: A summary of Kasey's ideas and sketch of contributing pieces

This table should illustrate that it is possible to understand the explanations that Kasey had formed can involve specific pieces of knowledge that were cued and together formed the content of her conceptualization. At certain times, features of the diagram were noticed and brought in as support or motivation for those conceptualizations to form. Note that there is not an established model that she is working from. As others have discussed, her mental model is being generated "on-the-fly" (Sherin, Lee, & Krakowski, 2007). What is also important to note is that the diagram is not being treated holistically either, and it is not being read as a unitary entity. Instead, different features are being registered and selected to be part of her explanation. She is not misconstruing the diagram so much as changing in what aspects become salient to her perceptually.

While this is simply a demonstration, I believe a general approach in which knowledge pieces are identified and discussed with respect to a how they interact with specific aspects of a diagram is a fruitful path for future work. It goes beyond assuming a wholesale misconstrual will take place and captures some of the nuance of in-the-moment reasoning of students. I see this as being much closer to a "knowledge-in-pieces" approach (diSessa, 1988) because it takes a multifaceted view of the underlying conceptual system. From that system, different conceptualizations or coherences can be generated. The extension here is that the drawing is also seen as being 'in pieces'.

It is important to note there are key points where this does not fully do the work of other fragmented knowledge approaches. Specifically, this account does not get down to something like a primitive knowledge element (diSessa, 1993). However, it is hoped that this approach, although it may not get to the atomic bits of knowledge that underlie science cognition, is a move in the right direction.

Relevance to the field

As many claims and suggestions are made about the impact of diagrams on student thinking, it is important to take the opportunity to consider whether or not those claims or suggestions are actually supported by observed student behavior. The inclination to make such claims are exercises in voicing a misconstrual hypothesis, though this paper illustrates why that may not always be an easily characterized or verified hypothesis, and that may require that we make more complex assumptions about knowledge and representation than has been the norm. The empirical data presented here suggest that a straightforward misconstrual to a specific conceptualization does not appear to be likely. A step toward a possible approach has been demonstrated through the detailed analysis of conceptualization with one diagram involving the Earth's orbit. This paper also further demonstrates that representation interpretation can be understood as involving dynamic and fluid processes, often using as raw material components of a representation that are registered, pieces of knowledge that align well with the registered aspects of a representation, and driven by the type of explanation the student is trying to construct given those resources (e.g., Lee & Sherin, 2006).

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