

The Roles of Evidence in Scientific Argument

Leslie J. Atkins

Department of Physics, California State University – Chico, Chico, CA 95928-0202, USA

Abstract. Over the past decades, education researchers have shifted their understanding of science from “a rhetoric of conclusions” – that is, a fixed canon of content – to a social process of knowledge construction. While much of the research has investigated individual learners as they engage with scientific ideas, experiments, and methods, increasingly researchers are turning to the social processes of science as it is constructed in a community, with particular interest in scientific argumentation. This emphasis on argument recasts the role of evidence and data in scientific classrooms: rather than being used to demonstrate the scientific canon or even to guide students to construct correct scientific principles, it is the grounds on which claims – generated by students in the process of argumentation – are warranted. In this paper, I explore a transcript of scientific discourse, exploring the rules by which participants in the discourse endorse or reject scientific claims. I appeal for a more nuanced understanding of evidence as one of many criteria by which scientific claims are evaluated, and that evidence, at times, is incommensurable with other, possibly more scientific, criteria for evaluating claims. This view of argumentation, and the peculiar discourse games associated with argumentation, is particularly relevant for understanding difficulties that diverse student populations may face.

Keywords: scientific discourse, scientific argumentation

PACS: 01.40.Ha

INTRODUCTION

Our understanding of science over the past decades has shifted to an appreciation of science as a social process of knowledge construction where claims are “grounded through the process of argument—relating the imaginative conjectures of scientists to the evidence available” [1]. This view of science as argument has led to investigations of the ways in which students provide grounds and warrants for claims [2, 3, 4] and the development of curricula to promote discourse consistent with scientific argumentation [5, 6]. These efforts consistently give a primary role to evidence in argumentation, with claims accepted or rejected based on their consistency with the evidence that is available.

This paper reports on the analysis of the role of evidence in scientific argumentation between non-science high school teachers. The question they are discussing—what causes the seasons—is one posed by the teachers themselves. In analyzing the conversation, the interest is in the ways in which the conjectures of the participants in the conversation are evaluated, and, ultimately, endorsed or rejected within the community. What role does evidence play? What other criteria are brought to bear in evaluating claims?

Below I provide a brief overview of frameworks for analyzing arguments. I then analyze the teachers’

discourse, with particular attention to the various ways in which evidence is used in argumentation. I then argue that evidence as arbiter of scientific ideas masks the more nuanced role that evidence plays in constructing mechanistic explanations.

SCIENTIFIC ARGUMENTATION

In the following transcript, a group of non-science teachers is sitting in the faculty dorm of a residential high school discussing why we have seasons. After some time, a central question arises: will an object in the sun’s light continue to heat up? Below, Ben argues that it will not:

Leslie: Does *David*¹ keep warming up indefinitely?

Alex: Right.

Ben: No because there’s finite amount of—he would reach a stable point.

Leslie: Why?

Nick: Yeah—why? There’s ... no way for you to radiate that heat.

Ben: No but you do- but you do radiate the heat.

John: You don’t heat up indefinitely—

¹ The object in space under consideration is Michelangelo’s *David*, stemming from an earlier conversation in which the teachers discussed whether or not a human would explode in space. They began by considering a solid, human-shaped object—hence *David*.

Ben: —because all matter would evaporate.

There are two analytic frameworks I will use to interpret the arguments: Toulmin’s argumentation pattern and Sfard’s commognitive framework.

Toulmin [7] outlines a generic structure for interpreting arguments, breaking them (at their most basic) into claims, grounds and warrants:

- *Claim*: “The position you are asking us to agree to as the outcome of your argument.”
- *Grounds*: “Statements specifying the particular facts about a situation relied on to clarify and make good the previous claim.”
- *Warrants*: “Statements indicating the general ways of arguing being applied.”

Sfard [8], in analyzing mathematical discourse, has proposed an analytic framework that includes the following categories:

- *Narratives*: “any text that is framed as a description of objects... that is subject to endorsement or rejection.”
- *Routines*: “Well-defined repetitive patterns in interlocutors’ actions,” including two kinds of rules—*object level rules* (about the objects being manipulated), and *meta level rules* (propositions about the discourse rather than about its objects).

Meta-Rules: Evidence

Using Toulmin’s framework, we can analyze Ben’s comments as follows (Fig. 1). As is common in argumentation, the grounds are implied by the warrant rather than explicitly stated. Note that the warrant that links the grounds to the claim is an almost categorical argument relating “heating up” to “evaporation.”

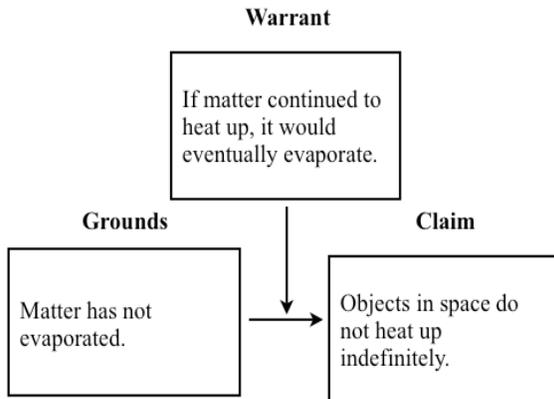


FIGURE 1. Ben’s Argument.

Using Sfard’s framework, the narrative to be accepted or rejected is that “objects in sunlight do not warm up indefinitely.” Ben, by offering relatively direct evidence that matter has not evaporated, is employing a meta-level rule that *scientific narratives*

are accepted or rejected based on their consistency with available evidence.

Meta-Rules: Mechanism

The meta-rule Ben employs above (and throughout the conversation) is consistent with the National Science Education Standards [9]: “Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature....” The logic of the argument seems unassailable, and is reiterated later in the conversation by others who give additional grounds: “Pluto is, like, frozen solid,” and “the moon, so far, has not exploded.”

However, there are other meta-rules for endorsing narratives—ways in which claims are warranted—that are employed during the conversation, in particular, the meta-rule of mechanism. As summarized in [10], “mechanisms account for observations by showing that underlying objects cause local changes in the system by acting on one another.” For example, consider Alex’s argument for why an atmosphere (or lack thereof) might matter for converting light to heat²:

Alex: I think an atmosphere matters because radiant light hits the one sixth, whatever, atmosphere of the moon there are particles to hit— that that light can, I don’t know, whatever, I’m making it up— triggers molecules to move, creates heat.

Compare Alex’s argument (Fig. 2), to Ben’s.

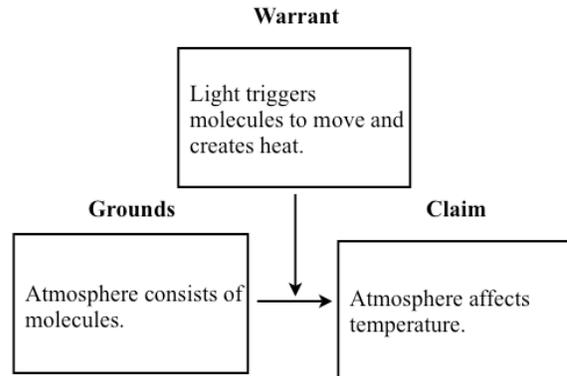


FIGURE 2. Alex’s Argument.

Here the warrant links the grounds to the claim via mechanism. That is, the grounds do not provide *direct evidence* that atmosphere affects temperature (e.g., the

² At this point in the conversation, the teachers are trying to determine why distance is not responsible for the seasons. An idea has been proposed that argues that as you step back from a fire it gets colder because the energy from the fire is lost to the atmosphere. Since there is no atmosphere in space, light energy travels without diminishing. This idea is eventually refuted.

greenhouse effect). Instead, the grounds identify the entities involved [10], and the warrant describes the activities of those entities that bring about the claim.

Incommensurate Rules of Argument

It is reasonable to expect that strong scientific arguments employ all of these rules: claims must be consistent with available evidence, supported with mechanistic explanations, and alternative claims must be refuted. And, since all scientific claims must refer to physical phenomena, using these data as the grounds for their claims, emphasizing the use of evidence to endorse or refute claims is unproblematic.

However, as the conversation proceeds, these different meta-rules of discourse lead the participants in the discussion to engage in strikingly different patterns of argument. The result is an impasse that ends the conversation, with participants commenting that it feels like “a heated argument” and that they are “not enjoying it anymore.” Below, I will argue that Ben’s use of evidence as grounds for a scientific claim is incommensurate with Alex’s use of mechanism and that, so long as each does not understand the rules the other is employing, the arguments each sets forth cannot be resolved: Ben provides evidence to support his claims, Alex (and others) reject those claims because they do not offer mechanism.

In the transcript below, the teachers are still engaged in the question of whether an object in sunlight will continue to heat up. Several exchanges have passed in which Ben is insistent that the statue does not heat up indefinitely (he has provided evidence earlier that demonstrates this), but his arguments are rejected, leaving Ben puzzled:

Ben: *David* does radiate heat.

Anna: But only for a while, right? Is he radiating it as fast as he gets it?

Ben: Once he reaches a stable point—

Julie: **You can’t play that card.**

Ben: Why?

And later in the conversation from Ben is pressed on what happens after *David* first enters the sunlight and heats up:

Alex: What’s to stop him from heating?

Ben: He heats to the point that he heats.

Alex: **That’s teleological.**

Ben: No- *but it happens.*

Ben’s claims are rejected by Julie and Alex, and it is interesting to note their rationale—Julie noting that Ben “can’t play that card” and Alex claiming that the argument is teleological. When seeking mechanism, “teleological” is a valid criteria for rejecting a claim; when seeking *evidence*, however, it is obvious that a stable point exists (as mentioned earlier in the

conversation, Pluto and the moon have reached a stable point).³ Ben, having provided such evidence, is stymied as to Julie’s and Alex’s rejections of his claim, plaintively declaring: “*But it happens.*”

Later, Ben is again pressed for mechanism and responds by explaining why evidence is hard to come by (“you can’t see it”) while failing to recognize that he is being asked for a mechanism, not evidence:

Anna: [agreeing with Ben] Things aren’t exploding in space.

Nick: But this- but what our question fundamentally is is: how, in what way [does that happen]?...

Anna: He doesn’t know –

Ben: I’m telling you it’s infrared- you can’t see it!

The conversation grows more heated as the two sides continue to reiterate their points, Alex seeking a mechanism by which the statue can reach an equilibrium temperature, Ben offering evidence that it has and noting that a rejection of his claim is inconsistent with evidence:

Alex: So if it’s always in the sun it’s going to continue to collect infinite amounts of energy?

Ben: ...it’s constant—it’s just it’s just it’s just stable.

Alex: It’s not stable! [many voices]

Ben: [to Alex]...What you’re saying is the sun is hitting it and it’s constantly accelerating because it’s constantly getting new energy, right? Tick---tick-tick-tkktkktk pow! Right? That’s not what’s happening—it’s just tick, and some energy comes in. Just as it’s about to slow down it gets new energy so it—it’s that energy that keeps it at that constant rate.

Alex: I don’t buy equilibrium.

Ben: Uh uh?

Alex: **I reject that. I reject the assumption of equilibrium.**

It’s a particular kind of game that Alex is playing—a unique set of rules for discourse—that allow him to “reject the assumption of equilibrium.” And it is different from the game Ben plays, because for Ben equilibrium is not an unwarranted assumption—it’s grounded in evidence: if equilibrium does not happen then “Pow!” and “that’s not what’s happening.” Alex’s rejection, however, is not a rejection that equilibrium happens; rather, it is a rejection of this evidence as the grounds that warrant such a claim.

³ It seems that Ben has either not understood Alex’s question, “What’s to stop him from heating?,” or is evading it. I do not think Ben is willfully evading the question, but instead the question does not fit into the framework for argumentation that Ben is employing and he answers the question in a manner consistent with his argumentation pattern.

IMPLICATIONS FOR INSTRUCTION

It has been argued [10, 11] that the meta-rules that Alex employs (refuting alternative explanations and using mechanistic explanations to warrant claims) are deeply scientific. What I would like to stress is that these meta-rules imply a very particular kind of argumentation, with characteristics that are not obvious to all students: the assumptions that are allowed, the rules by which one rejects and endorses claims, and the role played by evidence. In particular, it is not evidence alone—or even primarily—that distinguishes these strong scientific arguments, but the ways in which that evidence warrants the claims. Students employing other rules (in particular, evidence), may be engaged in an argumentation pattern that is incommensurate with this more sophisticated scientific argument.

That is not to say that grounding claims in evidence is not important; it is—deeply so. But in emphasizing evidence without reference to mechanistic warrants that link that evidence to the claim, we run the risk of promoting “science fair science,” in which hypotheses (e.g., “sunlight affects plant growth”) linked to evidence (e.g., “plants in the closet do not grow well”) are considered scientifically “complete,” and students miss the point of scientific inquiry: not to detail what happens as an end in itself, but to pursue mechanisms that explain *why* those things happen [11].

Furthermore, without scaffoldings students’ engagement in this pattern of argumentation, they may be perplexed by the arguments that are being set forth and the reasons that claims are endorsed or rejected. This is particularly relevant for students from cultures that do not typically engage in this pattern of argumentation.

As an example of these two meta-rules at play in teaching, consider the role of density in predicting whether or not an object will float. Frequently, curricula on this topic engage students in constructing arguments that are evidence-based, asking students to “explain” whether or not an object will float by noting its density and the density of the medium. In a high school course in physical science, I press instead for mechanistic reasoning, asking students to explain floating mechanistically. During a unit on sinking and floating, after students had determined that density would predict whether or not an object would float, a student wrote the following reflection:

“I first found the formula [mass/volume] and used that to explain things sinking and floating... The problem was that I never figured out how or why the formula should work. I understand *that* it works but that is not scientific knowledge. It is the same as how people understood that the sun would come up and go

down and they could predict when and where but they still don’t know why. I need to take a step back and figure out what density really is.”

Over a series of weeks, the class offered various mechanisms in which density played a role—e.g., that when water is less dense the object can “fall through” the less-tightly-packed molecules—before finally teasing apart the different roles played by mass and volume, and imagining the scenario as a balance.

As science education researchers take up the task of developing students’ capacities for scientific discourse and argumentation, we need to pay close attention to the role of evidence in argumentation that we are expecting, and how students meet those expectations. Simply grounding a claim in evidence is not enough: warranting those grounds mechanistically is crucial.

ACKNOWLEDGMENTS

I would like to thank the faculty and staff of the Governor’s School of North Carolina for participating in the research.

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