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ABSTRACT

This study investigated the influence of scaffolds on prospective teachers'(PTs') construction of scientific arguments. Participants were enrolled in an innovative science course aimed at providing PTs with experiences learning science using inquiry empowering technologies. PTs' arguments were constructed within the context of a light unit in which they collected evidence about the properties/behaviors of light from 10 investigation stations. The study examined the nature and development of arguments PTs constructed about light using Progress Portfolio (a generalized software tool for articulation and reflection), noting how scaffolds in Progress Portfolio influenced the articulation and revision of PTs' arguments about light. Data collection involved reviewing students' electronic journals and examining videotapes of students working at the investigation stations and interacting with Progress Portfolio. Results indicated that the computer-based scaffolding supported articulation and reflection of evidence-based explanations. The PTs showed increasing sophistication in their explanations, and the prompts within the Progress Portfolio seemed to stimulate PTs to become more precise in their explanations, to offer justifications, and to connect evidence with claims. An appendix presents content of light unit investigation stations. (Contains 41 references.) (SM)

Scaffolding the Construction of Scientific Arguments by Prospective Teachers Using Inquiry-Empowering Technologies

Carla Zembal-Saul and Susan Land

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SCAFFOLDING THE CONSTRUCTION OF SCIENTIFIC ARGUMENTS BY PROSPECTIVE TEACHERS USING INQUIRY-EMPOWERING TECHNOLOGIES

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Introduction

Contemporary reform efforts in science education call for science teaching that supports all students' meaningful learning (e.g., Mintzes, Wandersee & Novak, 1998) and scientific inquiry (AAAS, 1990; NRC, 1996, 2000). In particular, the *National Science Education Standards* (NRC, 1996) call for the centrality of inquiry in science learning:

> The *Standards* call for more than *science as a process*, in which students learn such skills as observing, inferring, and experimenting. Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills. (p. 2)

The importance of inquiry in science learning has an established history (Bybee & DeBoer, 1993; DeBoer, 1991; Trowbridge & Bybee, 1990) dating back to Dewey (1910) and Schwab (1962, 1978). However, the renewed emphasis on science inquiry reflects a distinct shift from *science as exploration and experiment* to *science as argument and explanation* (NRC, 2000, p. 113). From the reform perspective, priority is given to evidence and the development and evaluation of scientific explanations. During all phases of the inquiry process, "students and teachers ought to ask *what counts?* What data do we keep? What data do we discard? What patterns exist in the data? Are these patterns appropriate for this inquiry? What explanations account for the patterns? Is one explanation better than another" (NRC, 2000, p. 18)?

This approach to science learning presents new challenges for students engaged in authentic investigations of science phenomena. Loh and colleagues (1997) explain, "The complexity of open-ended investigations poses difficulties for groups of students who must continually negotiate plans and share understandings throughout an investigation" (p. 1). Not only do students struggle with organizing evidence and interpreting results, they often leave important questions unanswered when they are unable to make critical connections across various aspects of their investigations. The question for science educators becomes one of how to support learners as they participate in complex, data-rich investigations of scientific phenomena that require giving priority to evidence and constructing and evaluating scientific explanations? Furthermore, how do we support prospective and practicing teachers in orchestrating these types of learning opportunities for their students when most have not experienced learning science in this way themselves?

In this study, we investigated the influence of software scaffolds on prospective teachers' construction of scientific arguments. Participants in this study were enrolled in an innovative science course aimed at providing prospective teachers (PTs) with experiences learning science as inquiry using *inquiry empowering technologies*[1]. PTs arguments were constructed within the context of a light unit in which they collected evidence about the properties/behaviors of light from 10 investigation stations. Prior research suggests that PTs are likely to experience difficulties with various aspects of the explanation building process (Haefner, 2001; Haefner & Zembal-Saul, 2001, 2002). In response to this, *Progress Portfolio*, a *generalized tool for*

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[1] The phrase, *inquiry empowering technologies*, was coined by our colleague and mentor, Professor Vince Lunetta, to help us characterize the kinds computational tools that we select and integrate into science instruction. More specifically, *inquiry empowering technologies* refer to those computational tools that have the potential to enhance students' science learning as they engage in authentic, extended science investigations.

articulation and reflection developed at Northwestern University as part of the Supportive Inquiry Based Learning Environment (SIBLE) project (Loh et al., 1997) was used to provide support to PTs as they engaged in the extended investigation of light. In particular, *Progress Portfolio* was intended to assist PTs in selecting and organizing artifacts throughout the investigation, as well as examining the experimental evidence for patterns and constructing/articulating scientific arguments about light. The research questions that guided this study were: (1) What is the nature and development of the arguments PTs construct about light using *Progress Portfolio?* (2) In what ways do scaffolds in *Progress Portfolio* influence the articulation and revision of PTs arguments about light?

Literature Review

As mentioned previously, the renewed emphasis on scientific inquiry in contemporary reform shifts the focus to *science as argument and explanation* (NRC, 2000, p. 113). Practices, such as assessing alternatives, weighing evidence, interpreting texts, and evaluating the potential viability of scientific claims are all seen as essential components in constructing scientific arguments (Driver, Newton & Osborne, 2000; Latour & Woolgar, 1986). Recently, various authors have called attention to the significance of argumentation to science education. For example, Jimenez-Aleixandre and colleagues (2000) explain, "Argumentation is particularly relevant in science education since a goal of scientific inquiry is the generation and justification of knowledge claims, beliefs and actions taken to understand nature" (p. 758). Other authors highlight the importance of argumentation for a variety of reasons. First, learners can experience scientists' practices that would situate knowledge in its original context (Brown et al., 1989), as well as provide opportunities to learn *about* science, not merely science concepts (Driver et al., 2000; Osborne, Erduran et al., 2001). Second, learners' understandings and thinking can become more visible (Bell & Linn, 2000), representing a tool for assessment and self-assessment (Abell et al., 2000; Zembal-Saul, Munford, Crawford, Friedrichsen & Land, 2001; Sandoval & Reiser, 1997). Finally, argumentation can support learners in developing different ways of thinking (Kuhn, 1991, 1992, 1993) and facilitate science learning, taking into consideration the role of language, culture and social interaction in the process of knowledge construction (Pontecorvo, 1987).

As suggested above, engaging in the construction of scientific arguments as a way of learning science is becoming more prominent in the literature (e.g., Driver et al., 2000; Kuhn, 1993; Linn, 2000; Newton, Driver & Osborne, 1999). For example, Abell, Anderson and Chezem (2000) chronicled their experiences fostering science as argument and explanation with third-grade children engaged in inquiry-oriented instruction on sound. Students explored sound phenomena directly, then participated in discussions that required them to formulate and communicate evidence-based explanations. Although some students ultimately did not align with scientifically accepted ideas, the researchers concluded that the learning experience was valuable for all students because they had "opportunities to investigate, to invent sensible explanations, and to develop arguments in support of their explanations" (p.77).

To be clear, approaching science learning in this way is complex and fraught with difficulties. Over the past decade, researchers have been investigating the role of instructional *scaffolds*, or supports, to facilitate learner comprehension and reflection on complex tasks (Brown, 1992; Palincsar & Brown, 1984). Although much of the research on scaffolds has focused on the role of social interaction, especially dialogue and modeling, to enhance comprehension monitoring and strategy use (Palincsar, 1986), others have promoted the use of technology to scaffold learning and reflection (Lin & Lehman, 1999; Salomon, Globerson, & Guterman, 1989). Recently, Lin and colleagues (1999) gave a detailed treatment of various design approaches to scaffold reflection with technology-enhanced environments, including reflective social discourse (dialog with peers and instructors); process prompts (technology-based prompts or questions to help students organize, interpret, and externalize thinking); process displays (use of technology to track and reflect back to students the process they have engaged in); and process modeling (using expert processes as a model for learning). Although specific features and software tools might be primarily designed to support one dimension of Lin et al's framework, it is probable that designs typically cross several at one time (e.g., use of process prompts with reflective social discourse).

Use of prompts or guides to help students make their thinking explicit has shown to be a compelling strategy to foster reflection and learning (see for example, Palincsar & Brown, 1984; Salomon et al., 1989; Scardamalia & Bereiter, 1995). By prompting students to externalize and articulate their thinking (e.g., observations, interpretations, explanations), they become more aware of what they know, which then makes their thinking available to them for reflection, monitoring, and revision (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989; Schwartz, Lin, Brophy, & Bransford, 1999). Eliciting learner explanations and justifications through prompting can help them to draw conclusions and make inferences that can lead to increased comprehension (Chi, Bassok, Lewis, Reimann, & Glaser 1989).

In this study, prospective teachers (PTs) were engaged in an extended investigation of the properties/behavior of light and required to construct evidence-based arguments. The use of *inquiry empowering technologies* designed specifically to support science inquiry and scientific argumentation was fundamental to this work. For the purposes of this research, *scaffolding* is defined as supports that allow students to perform tasks that they would otherwise be unable to accomplish *and* to learn from that experience (i.e., improve performance on future, related tasks) (see Quintana, Reiser & Davis, 2002 and Reiser, 2001).

Despite the strong support for argumentation and the growing number of computational tools designed specifically to scaffold the process, argumentation practices have been rare in science classrooms (Newton, Driver & Osborne, 1999). Teachers' lack of pedagogical strategies to support students in engaging in argumentation, as well as the limited resources to assist teachers in doing so have been identified as the major barriers to the inclusion of argumentation in school science (Driver, Newton et al., 2000; Zeidler, 1997). It is unrealistic to expect teachers to adopt argumentation as a pedagogic practice to teach science if they do not develop more elaborated understandings of argumentation in the context of science learning themselves. Such development is possible only if teachers engage in "the practice of constructive argumentation" (Zeidler, 1997, p. 485). However, virtually nothing is known about how science teachers (and in particular future science teachers) engage in argumentation as science learners to construct knowledge about the natural world and the practices of science (Zembal-Saul et al., 2001; Newton et al., 1999). Therefore, the purpose of this study was to investigate the nature and development of PTs arguments about light and the ways in which scaffolds in *Progress Portfolio* influenced the articulation and revision of those arguments.

Method

Instructional Context & Participants

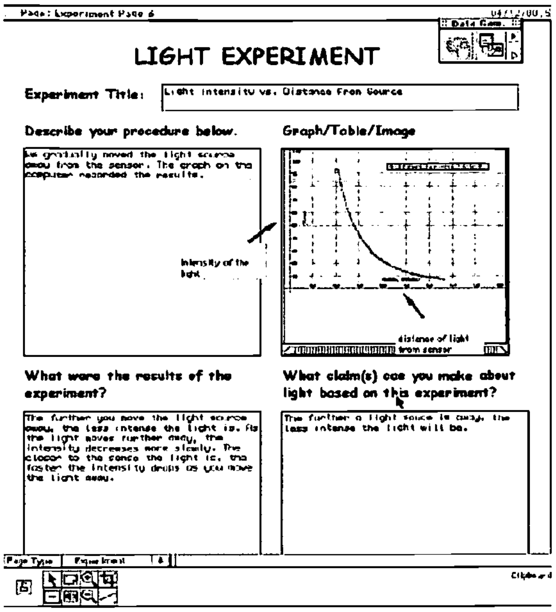
This study took place within the context of a physical science course developed specifically for prospective elementary teachers and prospective secondary teachers with emphases other than science. The course, ENGR 497F: Fundamentals of Science, Technology and Engineering Design, was developed collaboratively by faculty from Science Education and Engineering. Approximately 20 PTs were enrolled in the course during the semester in which the study was conducted. Two pairs were identified for in-depth examination.

The course was constructed around three instructional units. In this study, we focused solely on PTs as they engaged in the light unit. The light unit spanned eight, two-hour class sessions and addressed the driving question, *What happens to light after it leaves its source?* The unit was adapted from KIE: Knowledge Integration Environment, developed at Berkeley (Linn, 2000). The fundamental goal of the light unit was to help PTs develop a conceptual understanding of light, as well as to gain insight into evidence and its use in the expert community. PTs worked in pairs to collect data/evidence from 10 instructor-designed investigation stations. Scientific ideas addressed through the stations included the law of reflection, energy transfer, inverse square law, and light gathering power (see Appendix A for a description of each station). These experiments utilized both traditional and computer-based data collection methods and were designed to facilitate collection of usable evidence and stimulate ideas for other experiments.

As mentioned previously, novices tend to "get lost" when engaging in long-term, complex, data-rich investigations. More specifically, they tend to struggle with organizing evidence and interpreting results, and fail to address important questions because they are unable to make critical connections across various aspects of their investigations (Loh et al., 1997; Quintana et al., 2002). Therefore, PTs managed their investigations and constructed their arguments using the software program, *Progress Portfolio*, which was designed to promote reflective inquiry during learning in data-rich environments (Loh et al., 1998). The software is a shareware application and was developed by researchers at Northwestern University. *Progress Portfolio* is an open-ended environment that allows teachers and/or students to tailor various templates to guide students during the learning process. That is, it allows students to build an electronic portfolio that documents the process by which they progressively develop understanding during learning. The software includes a variety of general features such as "sticky notes," which are similar to electronic post-it notes that can be inserted by students for labeling purposes, or by instructors for the purpose of providing feedback. It also includes a "data cam" feature that allows students to easily toggle between different computer applications and capture images for insertion into their portfolios. Finally, it includes a built-in presentation mode that allows for electronic presentations to a class (similar to basic uses of *PowerPoint).*

Two main types of pages were developed by instructors to guide PTs through the investigation of light – experiment pages and argument/explanation pages. The experiment page template was designed to scaffold PTs organization and articulation of findings from the 10 investigation stations. Figure 1 shows an example of a typical experiment page. While at the various stations, PTs performed several experiments that generated data necessary for constructing an overall argument about what happens to light after it leaves its source. PTs used experiment pages to document their learning at each station by describing their procedures, representing data/evidence in an appropriate manner (e.g., data table, graph, digital image), interpreting the data from that station, and connecting their interpretations with the driving question about light. Explanation pages were completed at points during the investigation. The purpose of these pages was to get PTs to reflect on what they were learning across the various investigations, examine the data/evidence for patterns, and construct and revise an evidence-based argument in response to the driving question. PTs were guided to use the structure of claims, evidence and justification to craft their arguments. Figure 2 is a sample explanation page.

Figure 1. Sample Experiment Page



LIGHT EXPERIMENT

Experiment Title: Light intensity vs. Distance From Source

Describe your procedure below.

We gradually moved the light source away from the sensor. The graph on the computer recorded the results.

Graph/Table/Image

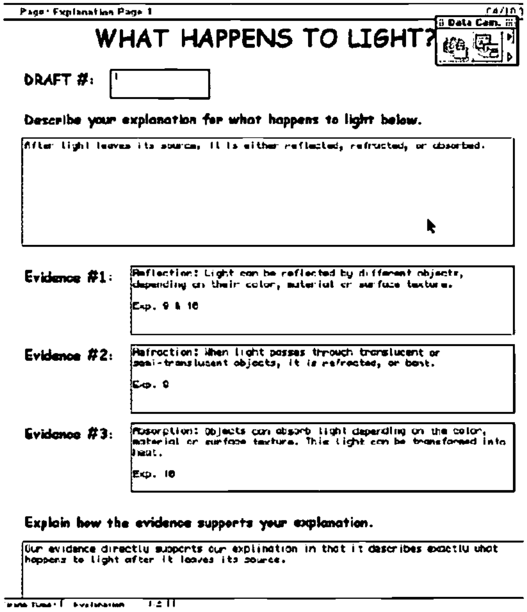
What were the results of the experiment?

The further you move the light source away, the less intense the light is. As the light moves further away, the intensity decreases more slowly. The closer to the source the light is, the faster the intensity drops as you move the light away.

What claim(s) can you make about light based on this experiment?

The further a light souce is away, the less intense the light will be.

Figure 2. Sample Explanation Page



WHAT HAPPENS TO LIGHT?

DRAFT #: 1

Describe your explanation for what happens to light below.

After light leaves its source, it is either reflected, refracted, or absorbed.

Evidence #1: Reflection: Light can be reflected by different objects, depending on their color, material or surface texture.
Exp. 9 & 10

Evidence #2: Refraction: When light passes through translucent or semi-translucent objects, it is refracted, or bent.
Exp. 9

Evidence #3: Absorption: Objects can absorb light depending on the color, material or surface texture. This light can be transformed into heat.
Exp. 10

Explain how the evidence supports your explanation.

Our evidence directly supports our explination in that it describes exactly what happens to light after it leaves its source.

As mentioned previously, approximately 16 hours of instructional time were devoted to the light unit across eight class meetings. The initial session introduced the driving question and *Progress Portfolio* software. Sessions two through five were dedicated to investigating phenomena associated with light and documenting findings and developing ideas about light in *Progress Portfolio*. PTs also drafted an initial version of their argument during this time. Session six was devoted to informal peer review of draft arguments and subsequent argument revision/refinement. Session seven was used to assess PTs understanding of concepts of light and light phenomena. The final session was used for argument presentations, formal peer review and interaction, and a large-group discussion aimed at synthesizing central science ideas associated with the unit.

Research Design

As you can see from the extensive description of the course, the light unit and the instructional tasks, this study sought to make sense of PTs argument construction in a complex and carefully planned instructional context. Thus we characterize this study as naturalistic and interpretive – and in the vein of design experiments (Brown, 1992). The researchers worked closely with the course instructor to transform the learning environment into one in which priority was given to evidence in examining and explaining light phenomena. Learning outcomes were co-constructed using reform-oriented perspectives of science as argument to guide the design of appropriate learning opportunities. Additionally, authentic assessments of PTs understanding of science concepts and abilities to engage in scientific argumentation were developed both to support the learning process and to contribute to an emerging theory of authentic science learning using inquiry empowering technologies.

As mentioned previously, two pairs of PTs were selected for in-depth study. Both pairs were selected based on their representativeness of the overall class composition (i.e., prospective teachers, non-science majors), the completeness of the data sources, and their willingness to participate in the study (i.e., informed consent). Heather and Roxanne were typical elementary education majors (i.e., female, 20-22 years of age, limited science background) who both held naïve conceptions about light prior to instruction (Heather moreso than Roxanne). Their ideas about light appeared to be strongly informed by their prior experiences. The other pair, Anna and Jack, consisted of a secondary English major and elementary education major, respectively. Both appeared to have more formal knowledge of light; however, little of their reported prior knowledge was directly related to the light unit.

Two main types of data were collected from these pairs. First, after each class session, we saved a copy of the current versions of their electronic journals. Our intent was to capture the progressive development of their sense-making about light from the investigation stations, as well as the construction of their arguments about what happens to light after it leaves its source. We also videotaped each pair during every class session, both while they worked at the investigation stations and as they interacted with *Progress Portfolio*. Our purpose in doing this was to better understand how the investigation space provided by *Progress Portfolio* influenced the development and articulation of their arguments.

Analysis Framework

During the past three years, the Project ASSESS^2 (*Analyzing Software Scaffolds in Educational Settings for Science*) Research Group has been working to develop a series of guidelines for software scaffolds (see Quintana, Reiser & Davis, 2002). In their current state, these guidelines include the following: (1) structure tasks and functionality, (2) use representations and language that bridge learners' understanding, (3) organize the tool around the semantics of the discipline, (4) use representations that can be inspected by learners to reveal important properties of the underlying data, (5) facilitate articulation, (6) provide easy access to instructional support and/or expert knowledge, and (7) automate routine tasks. Given our interest in this study to use inquiry empowering technologies to support scientific argument building, we chose to focus our analysis on guideline five, facilitating articulation. This guideline has four subcategories: (5.1) highlight epistemic features of explanations to support the development of scientific explanations, (5.2) highlight epistemic features of descriptions to support the development of scientific descriptions, (5.3) give students a space to facilitate planning aspects of their work, and (5.4) provide reminders and guidance to facilitate monitoring. These subcategories provided a framework with which to consider research question two, *In what ways do scaffolds in Progress Portfolio influence the articulation and revision of PTs arguments?*

Analysis was conducted in several phases. First, the three versions (initial, middle and final) of the arguments for each pair were examined on the basis of (a) whether they represented the central concepts about light in a manner that was consistent with scientific ideas, and (b) the extent to which evidence was appropriately used and justified to support claims about light. Next, the videotaped interactions of each pair were analyzed using the framework described above. Simultaneous comparison of daily interactions and various iterations of the electronic journals were made. Finally, similarities and differences across the two pairs were noted.

Findings

The findings of this study are organized into two sections – the nature of the prospective teachers' arguments about light and the influence of *Progress Portfolio* scaffolds on PTs argument construction.

The Nature & Development of PTs Arguments about Light

Pair A: Heather and Roxanne. Pair A's final argument about what happens to light after it leaves its source consisted of three main claims (see Table 1): *(1) Light is absorbed with dark colors, and reflected off of light colors; (2) As light moves away from its source it spreads out;* and *(3) Light becomes less intense as it moves farther away from its source. The intensity decreased with an increase in linear distance. The intensity of light also decreases at the sides of a cone of light.* Although these claims were more consistent with scientific ideas than prior

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[2] Project ASSESS is supported in part by a grant from the National Science Foundation, KDI

versions, they did not reflect the totality of the light phenomena with which they interacted. In other words, additional overarching patterns should have been evident from the data. Interestingly, the claims that were emphasized by this pair, particularly claims two and three, were the ones with they struggled most during the associated light experiments.

Pair A's experiment pages were rarely completed. In particular, this group tended to avoid trying to articulate connections between individual experiments and the driving question. Moreover, they did not re-organize or group related experiments during the extended investigation of light. Each claim in Pair A's argument was supported by two pieces of evidence, whereas earlier versions of claims were typically supported by a single piece of evidence. In two cases, evidence was generated by the pair through experiments that they designed and conducted as extensions to the stations at which they were working. Evidence used in this final version was appropriate for the claims being made and represented more variety than previous iterations of their argument.

Heather and Roxanne treated justification largely as an opportunity to *restate* information provided elsewhere in their argument. In particular, justification tended to serve as a restating of findings/evidence. Unlike prior versions of their argument, the pair began using the *language of support* in the final version of their argument. That is, instead of suggesting that evidence *proves* that a claim is true, they attempted to articulate how a particular piece of evidence *supports* the claim with which it is associated.

It should be noted that the final version of the argument was developed in *Progress Portfolio's* presentation mode, as opposed to the portfolio mode. This allowed the pair to

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(NSF REC 9980055).

deconstruct their argument into its component claims and re-present each claim clustered with its supporting evidence and justification.

Figure 1. Heather and Roxanne's Final Light Argument

Claims	Evidence	Justification
1. Light is absorbed with dark colors, and reflected off of light colors. 2. As light moves away from its source it spreads out. 3. Light becomes less intense as it moves farther away from its source. The intensity decreased with an increase in linear distance. The intensity of light also decreases at the sides of a cone of light.	(1a). Experiment 6 shows this because the energy transfer for the black can was much faster than that of the white can. The black can absorbed more light and in doing so absorbed its heat faster. (1b). Our experiment showed this as well. When we used the black paper to make the cone, the intensity throughout was much less than it was when we used the white paper. The light was brighter when we used the white paper. (2a). Experiment 8 showed us this with a small revision on our part. We added extra white paper behind the light. This enabled us to see more of the spectrum of the light as it expands. (2b). Experiment 7 also showed this expansion of light through a flashlight. The flashlight enabled us to "see" the cone of light. 3a. Experiment 3 shows that the intensity of light decrease with an increase in linear distance. Using a light intensity probe it was easy to determine the decrease of intensity. 3b. Our experiment shows that the intensity of light decreases as you reach the outer edges of the cone of light.	1. Since the black can was able to transfer the heat more quickly than the white can, it must have absorbed more light. The black paper in our experiment must have absorbed more light than the white paper because it could be easily observed that there was not as much light shining on the floor as there was when the white paper was used. 2. Experiment 8 supports our expanding theory because we could see the different colors of the spectrum as it separated farther from the source of the light. Experiment 7 gave us this initial theory because it enabled us to see the cone of light which expands at the bottom or farther from the light source. 3. Experiment 3 supports that light decreases in intensity as it is farther from its source. Using the light probe we were able to graph this decrease over a distance of approximately 2 meters. Our experiment supports that the intensity of light decreases at the outer edges of a cone of light. We were able to graph this using a light probe.

Pair B: Anna and Jack. Pair B's final argument about light (see Table 2) consisted of multiple and related claims, and it was much more elaborated and integrated than Pair A's argument. The claims around which they structured their argument were generally consistent with scientific ideas and reflected the central patterns intended by the instructor and design team. Although it is impossible to determine precisely how Anna and Jack constructed the framework for their overall argument, there is evidence that they structured their initial argument on a structure they located using web-based resources for learning about light. Their initial claim read: *After light leaves its source it is reflected, refracted, or absorbed.* The pair was not observed discussing light in this way at the investigation stations or during the development of explanation pages.

Anna and Jack's experiment pages were well developed. They used sticky notes to annotate their graphs and diagrams, and always attempted to articulate how each experiment was connected to the driving question about light. The pair tended to organize their experiment pages by grouping them according to related findings. As the pair constructed various early versions of their argument, they took the approach of *plugging in* multiple pieces of evidence for each claim they made about light. Although the connection between claims and evidence was accurate scientifically, their initial approach was not thoughtful or reflective.

Figure 2. Anna and Jack's Final Light Argument

Claims	Evidence	Justification
After light leaves its source, its main objective is to expand and emanate away from its source in all directions. When it collides with an object, **transmission** occurs. If it is transmitted, three things happen. First, if it hits a transparent object, it will pass through it clearly. If it hits a translucent object, it will partially pass through but will be scattered or **refracted**. If it hits an opaque object, the light does not pass through. This brings us to the other two things that can happen to light after it leaves its source: **absorption** and/or **reflection**. Absorption is when light passes into a substance and is held there. Reflection is when light strikes a surface and bounces back off of it.	• Expansion: Experiments 1, 2, 3, 4 and 7 • Transmission: Experiment 8 • Absorption: Experiments 6 and 10 • Reflection: Experiments 5, 8, 9, and 10 • Refraction: Experiments 5, 8, 9, and 10	• Expansion: Light is always trying to expand from its source. As it expands, it loses intensity (Exp 3, and 7). If it reaches a hole in an object, it can be gathered and directed through the hole, and can be inverted in particular cases (Exp 1, 2, 4). • Transmission: As it continues to expand, beams of light collide with objects. The collision between the two us known as transmission. At this point, 3 things that can happen to it. • First, light can be absorbed. The color of an object influences its absorption capabilities (Exp 5). When the light is absorbed, it can be transformed into heat (Exp 6). • If light is not absorbed, two things can happen to it; reflection and refraction. • Reflection involves the repelling of the light ray off of the object it hits. The angle at which the light hits the object, or the anle of inflection, is symmetrically equal to the angle at which it bounces off, called the angle of reflection (Exp 5, 8, 9, & 10). • Refraction is a similar process, but in this case the light is bent, and not merely bounced back. When light passes through a semi-translucent object, it is bent away from it's original trajectory (Exp 5, 8, 9, & 10).

Like Heather and Roxanne, Pair B's justification statements merely described information that was provided elsewhere. However, considering justification (i.e., the relationship between evidence and claim) served an important function for this group. While Anna and Jack were constructing the second version of their argument, they recognized that justification was prompting them for explanation. As a result, they engaged in lively discussion and negotiation that resulted in the revision of the argument to include the claim, *After light* *leaves its source, it spreads out in all directions (and can then be transmitted, reflected or absorbed).* The pair then went back and re-evaluated their evidence.

Although the third and final version of their argument about light differed very little from the second version, Anna and Jack spent a significant amount of time negotiating the meaning of transmission and its relationship to refraction. Other argument refining discussions were centered on identifying the best evidence for supporting various aspects of their arguments.

The Influence of *Progress Portfolio* Scaffolds on Argument Construction

Developing Scientific Descriptions for Experimental Findings. When used appropriately, the experiment pages in *Progress Portfolio* helped PTs attend to important aspects of the light experiments, prompting them to interpret results and connect their results to the driving question. The purpose of the experiment pages was to scaffold PTs articulation of their experiment findings. For both pairs, we found that the scaffolds were useful for this purpose, as they seemed to stimulate students to summarize their findings and to highlight important aspects of the experiments. For instance, while working at an investigation station with a flashlight, Heather and Roxanne summarized, "Light spans out the further we go away." Yet, when articulating their findings on an experiment page, the pair articulated their thinking more clearly, using more scientific language: "What were the results of the experiment? When we moved the flashlight closer to the wall, the base of the cone … no, the *area* of the base of the cone, got smaller…"

Similarly, the scaffolding from the experiment pages seemed to prompt Pair B to articulate and reflect upon their understanding of the experiments. This process also was assisted by the lively negotiation that ensued in response to articulating their ongoing explanations and conclusions. For instance, Anna and Jack had the following interaction while working on an experiment page for the *Light Gathering Power* investigation station in response to the question of *What claims about light can you make based on this experiment?:*

> Jack: [types into *Portfolio*] The smaller telescope collected less light than the larger telescope. I think that is all that is needed.
> Anna: Well, don't we have to put ... because?
> Jack: Because more light could ... there was more opening for light to enter through the larger telescope than the smaller telescope.
> Anna: So, given more space to spread out, it will be more intense than if they are confined and directed.
> Jack: Um... I don't think intensity has to do with it. I think it is more the percentage of light that is hitting it.
> Anna: How is light being gathered? That is my question.
> Jack: The light is coming down from up here, and it has to go into the tube. Some of it is going out here around it, and some of it is going in it, and it leaves through the end to the light sensor. In the [small telescope], there is more room outside than inside for the light.
> Anna: So, more is being gathered in the larger one, simply because there is more space to gather it. So, the more space to gather, the more light will be collected.

This type of interaction occurred frequently with Pair B in response to revisiting experimental conclusions and being prompted to explain what claims could be made.

In contrast, Pair A often omitted information about their procedures, represented findings inaccurately or in ways that failed to convey meaning, or focused on extraneous variables. For instance, this team spent considerable time using a drawing program to represent their findings graphically. However, their drawings were irrelevant (e.g., illustrating the experimental setup) or inaccurate. For example, following an investigation station about convex and concave lenses and mirrors, Heather and Roxanne labeled the ray diagrams incorrectly in their portfolio (convex vs. concave shapes were transposed). The inaccurate diagrams led to confusion later, when they tried to use the data as evidence for their argument about light. It is important to note that little interaction and negotiation was present with Pair A. They rarely discussed or clarified ideas with each other; instead, Roxanne tended to direct the experiments, generate the conclusions, and input their work into *Progress Portfolio.* Heather assumed a more passive role, agreeing with the ideas and plans proposed by Roxanne.

Developing Evidence-Based Scientific Explanations. The purpose of the explanation pages was to scaffold learners to construct and articulate explanations for the driving question, to revisit and integrate evidence from the various experiments to support the explanation, and to justify how the evidence supports it. Pair B tended to revisit the evidence they collected and the explanations they generated from the various experiment pages when developing or refining explanations. For instance, while working on their final argument, Jack suggested that they go back and revisit their second explanation page. Upon reviewing it, they started to ask questions such as, "Did we incorporate the evidence from experiment 10 for this?" and "Why is experiment 10 listed as evidence for absorption?" This process of reviewing and reflecting upon previous versions of their explanation seemed to prompt them to question and to re-organize new, more coherent explanations. Consistent with Lin et al's (1999) discussion of scaffolds that utilize "process displays", the *Portfolio* supported PTs in keeping a running record of their prior ideas that could be subsequently revisited and reflected upon.

In contrast, we found that Heather and Roxanne initially experienced difficulty generating explanations for the driving question and linking them to evidence sources. Instead, they tended to think in terms of the specifics of experiments, or they identified multiple explanations that were not coherently integrated with supporting evidence. We noticed that, rather than approach the task as one that required coherent integration and reflection, Pair A instead seemed to view the task as one that required them to articulate what they had learned that day. Thus, for their second explanation page, they provided a bulleted list of their findings from the four days prior, rather than use the prompts to reflect upon and generate a coherent explanation.

An interesting paradox with this pair was that they *did* visit a previous explanation page (version one) when generating a new explanation page (version two). However, the explanation they revisited represented a misunderstanding (how a spectrum is formed). Although the pair had started to construct an explanation (version two) that was more consistent with scientific ideas and was based upon the results of several experiments, they abandoned their efforts and reverted to their focus on spectrum after reviewing their initial explanation page. In this case, revisiting the initial explanation actually inhibited the development of a more scientifically appropriate explanation. However, since Heather and Roxanne had neither evaluated the accuracy of the initial explanation nor concluded that it was limited, it remained a viable explanation for them. This finding draws attention to the fact that simply providing the opportunity to *revisit* previous explanations is not always adequate to scaffold the types of processing that are required to *cognitively engage* in reflecting on them.

Conclusions

The findings from this study are largely encouraging in that they suggest that computer-based scaffolds can support articulation and reflection of evidence-based explanations. We saw evidence of increasing sophistication in explanations, and the prompts within the *Progress Portfolio* seemed to stimulate PTs to become more precise in their explanations, to offer justifications, and to connect evidence with claims. These findings support those of others who demonstrated that reflective thinking can be prompted externally and lead to increased learning (Davis & Linn, 2000; Lin & Lehman, 1999).

Learning *science as argument and explanation* involves working on multiple investigations, analyzing diverse perspectives and data, testing ideas through experimentation, and organizing evidence into a coherent explanation or argument (NRC, 1996). In essence, doing and thinking are complementary, as reflection and action continually inform each other (Schön, 1983). Yet, managing this process on a meta-level can be challenging for learners who have little experience with the complexity of inquiry (Schwartz et al., 1999).

This study highlighted the importance of scaffolding articulation processes by requiring learners to make explanations overt and to make connections across various aspects of their investigation. As Salomon (1986) recognized, when learning environments are designed to support such thinking-intensive interactions, successful learning becomes highly dependent on learner voluntary cognitive engagement. Yet, these processes are not likely to be realized independently, without some form of externalized support or scaffolding (Salomon, 1986).

Reiser (2002) identified two mechanisms of scaffolding that are afforded by modern technology tools: (a) structuring the task; and (b) problematizing concepts. Our study provides insights into some of the conditions and strategies that can help learners in these endeavors. We found that by structuring the workspace to help learners attend to important information and to organize their ongoing explanations, they were aided in the process of self-regulating, even though they had little prior experience with learning in such a complex open-ended inquiry environment. Consistent with Lin et al's (1999) discussion of technology scaffolds that utilize "process displays", the *Portfolio* supported students to keep a running record of their prior explanations that could be subsequently revisited and reflected upon.

Similarly, by prompting learners to articulate and connect their experimental findings back to the larger driving question, "problematizing" was stimulated as learners negotiated and struggled with explaining the significance of the data. As shown by Anna and Jack (Case B), prompting explanation and justification also led to reflective social discourse (Lin et al., 1999), thus becoming a mechanism for reflection, negotiation, and awareness of when their understanding was limited.

Technology has enabled us to consider remarkably new environments and ways of representing information in inquiry-empowered environments. In order to seize the potential of these technological possibilities, however, explicit attention to scaffolding learner reflection and argumentation is in order. Lin et al., 199 further explain:

> In a systems approach, reflection is a means toward empowering learners, not an end in itself. The aim of teaching students to reflect on their thinking processes is to increase their awareness of their own learning, and to enable them to use that awareness to adapt their thinking in other situations. The power of technology for learning can be greatly enhanced through support for reflection, which helps learners construct the new kinds of knowledge and skills they need in this age of information. (p. 60).

More research is needed on how varied scaffolding methods can be incorporated into learning environments to help learners manage the complexity of inquiry-empowered environments. Technology, thoughtfully considered, can provide a vehicle for supporting argumentation and reflection consistent with contemporary reform efforts in science education.

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Appendix A. ***Content of Light Unit Investigation Stations***

Experiment	Experiment Description and Content Objectives
Absorption/ Reflection	• Students measured the intensity of reflected light off of light and dark objects • Conclusions: Lighter colored objects reflect more light than darker colored objects. Darker colored objects absorb more light than lighter colored objects
Energy Transfer	• Students measured the temperature of an equal volume of water placed into both a white and black aluminum can. A high intensity lamp illuminated both cans. • Conclusions: The water in the black can reaches a higher temperature because the black can absorbs more of the light. The absorption process involves a transfer of light energy into heat energy.
Inverse Square Law for Light	• Students measured the light intensity of a light source at various distances from the source. • Conclusions: Light intensity decreases (in a non-uniform way) as the distance from the intensity sensor to the light source is increased.
The Light Cone	• Students shone a flashlight on a flat surface and examined the circular illumination pattern. This procedure was repeated while varying the distance between the flashlight and the smooth surface. • Light from a flashlight spreads out as it moves through space. Consequently, the circular illumination pattern will increase in size and decrease in intensity when the distance between the flashlight and the smooth surface is increased.
Light Gathering Power	• Students measured the amount (intensity) of light that can be gathered by tubes of various diameters. • The larger the opening of the tube, the more light it can gather.
Pupil Dilation	• Students examined the behavior of the human pupil when exposed to various amounts of incoming light. • In a dark room, the pupil dilates (becomes larger) to gather adequate amounts of light for vision. If the pupil is abruptly exposed to intense light after it has dilated, it will quickly close adjusting for the increased supply of light.
The Pinhole Camera	• Students examined images of a flame that were formed by a pinhole that was punched into an index card. • The inverted image is evidence that light travels in straight lines.
Diffuse and Specular Reflection	• Students measured the intensity of light that was reflected off rough surfaces (diffuse reflection) and smooth, polished surfaces (specular reflection). • Rays of light that are reflected off a smooth, polished surface will travel in very predictable directions. Thus, most of the reflected light rays can be aimed directly at a light sensor. Consequently, the sensor will measure a greater intensity than that of light rays reflected off a rough surface, which travel in many, unpredictable directions.
Lenses and Mirrors	• Students investigated the properties of curved lenses and mirrors by observing how they modified incident rays of light. • Conclusions: Concave ***lenses*** diverge rays of light while concave ***mirrors*** converge rays of light; Convex ***lenses*** converge rays of light while convex ***mirrors*** diverge rays of light.
The Law of Reflection	• Students investigated how incident rays of light reflect off a smooth, flat (plane) mirror. • Conclusion: The ***angle of incidence*** equals the ***angle of reflection*** (where both angles could be defined as either the angle between the ray and the mirror surface or the angle between the ray and a perpendicular line drawn to the mirror surface).

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