The role of computer-based cognitive artifacts in scaffolding reflective inquiry

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Abstract: Inquiry-based science is a domain that requires students to be reflective inquirers in order to make sense of complex, open-ended investigations. The research study reported in this paper looks at students' reflective inquiry in middle-school science, addressing the issue of characterizing reflective inquiry in practice and investigating the role that computer-based, cognitive artifacts may play in students' inquiry-based software investigations. Data reported were collected from three pairs of 8th grade students from an urban school, as students engaged in a six-week, inquiry-based investigation. These students were using the Progress Portfolio, an inquiry-support tool to manage their investigation. Findings up to date offer evidence that software scaffolds provide students with opportunities to articulate their ideas and monitor important parts of their inquiry, as well as push them to consider the need to back up their claims and construct evidence-based explanations.

Introduction

Recent research on how people learn advocate that students should be actively involved in their own learning, a call also obvious in new science standards (National Research Council, 1996). As a result of this new push for more student-directed learning, students are often asked to manage complex data in open-ended, ill-structured investigations. In order to accomplish this, students need to assume more responsibility over their learning than what has been traditionally expected from them, and learn to plan, set, monitor, and evaluate their own goals and investigations, that is, be metacognitive in their inquiry. These metacognitive activities in the context of inquiry-based science are what we call "reflective inquiry".

The need to support reflective inquiry in inquiry-based science

Loh, et al. (2001) define reflective inquiry as "a style of inquiry that encompasses both effective inquiry strategies (e.g. systematically collecting and interpreting data) and reflective activities (e.g., monitoring, periodically evaluating progress, and revising plans)". If we desire that students be motivated in, and successfully take more control of their own learning, we need to support them in being reflective in their inquiry. The literature informs us that being reflective in their inquiry and managing complex investigations are difficult for novice learners, as is the case with most middle school students. Inquiry-based investigations in science can be difficult to manage due to the complexity of understanding how to conduct the investigation and manage the data in the course of the investigation (Carey, 1989). Another challenge reported in the literature is that, in spite of the established usefulness of such reflective inquiry components such as planning, monitoring and evaluating,, students do not always take the time to plan and reflect on their actions (Shute, Glaser, & Raghavan, 1989). In addition, students seem to not easily distinguish between hypotheses and evidence-based explanations (Kuhn, 1989), a focal distinction in understanding scientific practices.

In the last few decades there has been a lot of talk about scaffolding students as one way of helping them do parts of their investigation that are within their zone of proximal development (Vygotsky, 1978), but which they have difficulty in doing without assistance. Students are also expected to progressively develop skills to do the task autonomously; ultimately this should be feasible without the use of scaffolds, an idea known as fading. This paper will discuss how the Progress Portfolio, a computer-based tool can provide assistance in learning, by helping scaffold students' metacognitive engagement in inquiry-based science. In this context, scaffolding are all those elements in the learning environment that assist novices do and reflect on their inquiry process; these scaffolds are expected to fade with time (not necessarily at the end of the unit in which the scaffolds were introduced) and serve as temporary "training wheels". The software scaffolds could be in constant interaction with scaffolding provided by others (the teacher, peers) but this particular paper will only discuss the case of the software scaffolds and the effect they have on students' cognitive engagement.

Research Questions

The purpose of our research is to explore the role that a computer-based cognitive artifact, such as the Progress Portfolio tool, can play in scaffolding middle school students' reflective inquiry engagement in science. In specific we are interested in understanding what the spectrum of students' reflective inquiry look like and how can it be best characterized, what the study of the Progress Portfolio can indicate about the potential of software support tools in helping students be reflective inquirers, and what might be the challenges of reflective inquiry that are not addressed by the Progress Portfolio.

Context and Methodology

What is the Progress Portfolio?

The Progress Portfolio tool (Loh, B., Radinsky, J., Reiser, B. J., Edelson, D. C., & Gomez, L. M., 1997) is a computer-based, inquiry support tool, designed to help students manage their investigations, by providing them with an easy way to capture aspects of their investigation using the data camera capture tool, and a place to store and organize the captured information using template pages. These templates can be easily customized by the teacher, and can help structure students' investigation. The basic structural components of these templates are data boxes, in which students can paste and store the captured information, text boxes or tables which can serve as spaces for students' articulation, and prompts that can accompany the text or data boxes to help remind students of the task they are asked to do. The user also has the capability of adding sticky notes (similar to the paper-based post-it notes) on top of the information they store in the Progress Portfolio and draw arrows from these sticky notes to point to issues they wish to highlight. Students can create as many pages as they wish, and can usually choose from several templates; for example, for the study that we describe in this paper we designed six types of templates: a "Data page" template, intended to provide space for students to record their data, a "Planning and organizing your investigation" template, providing a space to plan their investigation, a "KWD" page, where students are expected to articulate what they know, what they want to know, and what they will do to find that out, a template where they are asked to write down what happened, and which feature of the finches might have played a role, a "Research summary page", where students were asked to write their hypothesis, construct an explanation about what happened and provide evidence for it, and a "Peer review" page, where peers were expected to provide feedback for the group. Figure 1 shows what a Progress Portfolio data page template looks like before and after students use it:

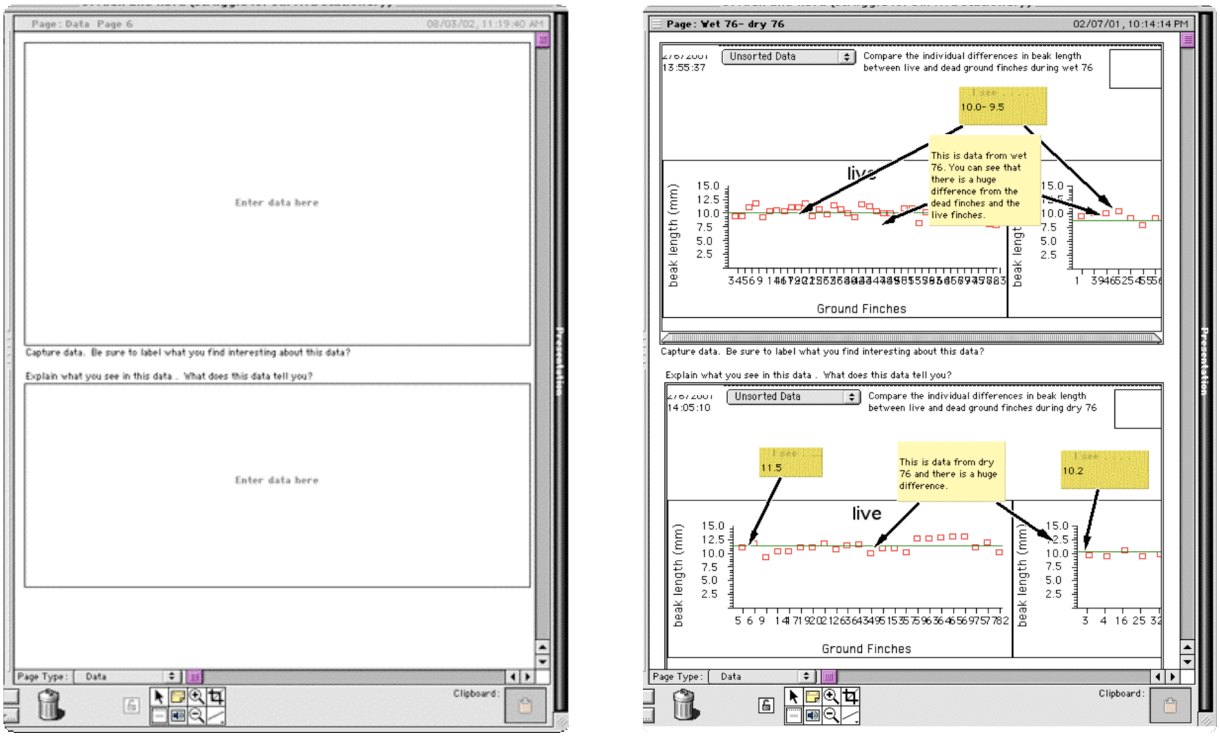

Figure 1: An example of a Progress Portfolio "Data page" template, generic (left), after students' work (right).

The discussion that follows is based on data from three pairs of students, as they were engaging with the Galapagos Finches investigation, which is part of the Struggle for Survival curriculum (Reiser et al. 2001). The Struggle for Survival is a LeTUS (the Center for Learning Technologies in Urban Schools at Northwestern University) evolutionary biology curriculum, designed for use in middle school, inquiry-based science classrooms. Through a variety of activities and the use of a software database, the Galapagos Finches, (Tabak, I., Smith, B. K., Sandoval, W. A., & Reiser, B. J., 1996), students investigate the reasons that led to the death of many finches on the Galapagos island of Daphne Major during the late 1970's. Through the use of the Galapagos Finches software students collect data to support their hypothesis on why many finches died and why some survived during the crisis years on Daphne Major. The data reported in this paper were collected from one 8th grade urban class. As they were engaging with solving the Galapagos Finches investigation, students in this study also used the Progress Portfolio software to help them manage their investigation.

The groups case-studied were selected in consultation with the teacher, with the goal of obtaining data from students of varied academic ability (high, medium, low, as perceived by their teacher), so that we could begin to understand the range of what consists reflective inquiry. We collected several types of data for every day of each groups' computer-based investigation over a period of approximately six weeks. The discussion in this paper is based on the analysis of the students' videotaped conversations, as they are using the two software programs, the analysis of students' work on the computer using process video (that is, we obtained computer output in videotaped format of all the actions students took on the computer while using the two software programs), group interviews administered at the end of the Struggle unit, and an analysis of the artifacts from the Progress Portfolio and the Galapagos Finch software that students produced.

Data Analysis

The videotaped data were all digitized and transcribed, and then analyzed. Due to the scope of this paper we are not going to explain all the phases of this analysis in detail. Our coding scheme focused on identifying the reflective inquiry activities that students were engaging with and then trying to understand how the scaffolds in the Progress Portfolio might have contributed to these activities, by triangulating data from video observations, process video, each group's Progress Portfolio files, and post-investigation interviews. Based on the empirical data, these reflective inquiry activities can be seen as belonging to eight major categories, each one of which comprising of several sub-categories: 1) identifying important information, 2) developing hypotheses, 3) linking data to hypotheses, 4) organizing information, 5) self-monitoring, 6) self-evaluation, 7) planning, and 8) communicating with others, outside of the local group. The first three categories are core inquiry activities while the other categories are the metacognitive control mechanisms. We consider all of these categories to be pivotal aspects of our study of reflective inquiry, since we posit that such a metacognitive engagement may have an effect on the subsequent inquiry activities that the students engage with. These categories helped us identify interesting episodes in the data that focused on how the students engaged in reflective inquiry. We also looked at the process of students' inquiry, and how what they talked about or did in the Progress Portfolio influenced their subsequent course of action in their investigation. The analysis demonstrated that all groups of students were engaging with the reflective inquiry cognitive activities identified in the previous section. In the following section we will present our main findings from the analysis of these three groups about the role that the Progress Portfolio scaffolds can play in students' inquiry. Due to space limitations, in most cases we will present the final analysis of the data without discussing in detail the evidence that supports this analysis.

Findings

How students use the Progress Portfolio scaffolds

All pairs of students work with both software programs during each investigation session, alternating from the one to the other several times in each session. Typically, the groups may generate six to ten graphs in the Galapagos Finches software, from which they then select only some to store and annotate in the Progress Portfolio. Each group of students overtly engage in metacognitive activities such as self-monitoring, self-evaluation, and planning to varying degrees. Self-monitoring instances are those instances when students remind themselves of where they are in their investigation, or what steps they have or need to take next. An example of self-monitoring is one student asking the other at the beginning of the investigation "What's the question we need to answer again?" Self-evaluation was coded as those instances when the group compares their performance to some set standard, which includes an evaluative comment. An example of this might be one of the members of the group explaining

that their concern is that "We don't know how to support that idea." The set standard here is the realization that one needs to provide supporting evidence for their claims. Finally, one example of planning is the following statement: the group is working in the Progress Portfolio when they say "Ok, now let's go to beak length….it might be the one" and then move to the Galapagos Finches where they look at the finches' beak length. Figure one shows the frequency in which the three groups case-studied engaged in such activities, aggregated over their entire investigation. The important issue to note with this figure is that the groups do engage with these metacognitive activities that literature findings point to as influential in the success of a group's problem solving. One other important issue to observe is that the low ability group engaged in far more instances of self-monitoring and self-evaluation. This is congruent with the observation that this group started off with many hypotheses that were not supported by the data and the only way to be successful in their problem solving would be to change strategies as necessary until they find something that could be supported by the data. The literature on self-regulated learning emphasizes that self-monitoring and self-evaluation help students consider alternative paths and strategies, which in turn may assist them in their problem-solving process.

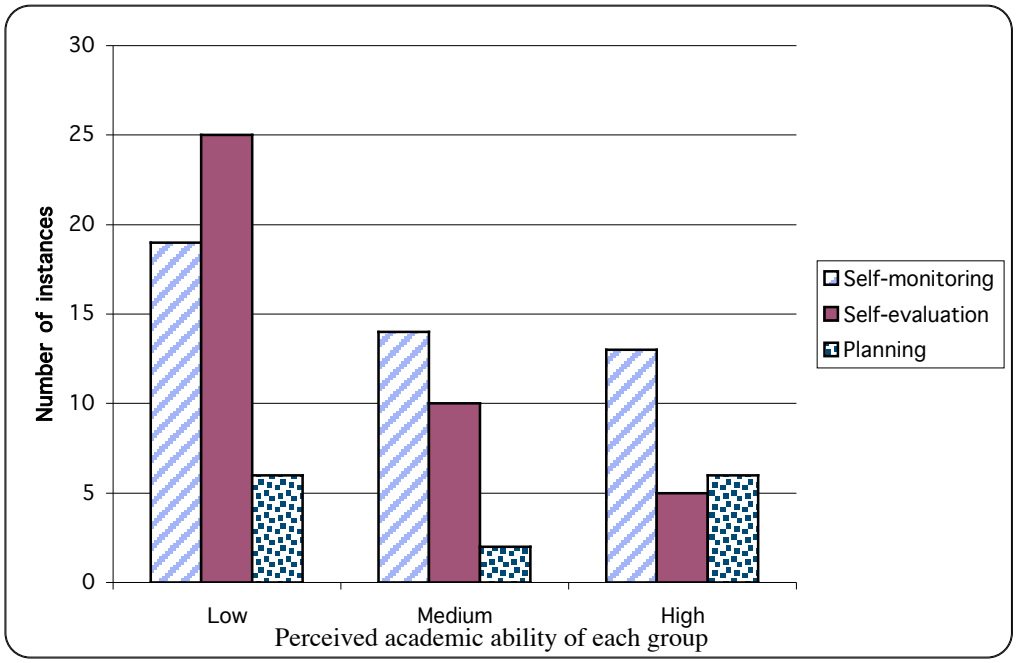

Figure 1: Frequency of students' engagement in metacognitive activities

In the following section we will discuss how the groups do their inquiry while using the Progress Portfolio prompts to reflect on their inquiry process.

Facilitating the organization and discussion of important inquiry information

In a typical investigation session students may generate anywhere from six to ten different graph comparisons in the Galapagos Finches software. Our analysis of what the students do once they transfer the data in their Progress Portfolio file (responding to prompts, drawing arrows and writing sticky notes to highlight the epistemic features of that information), and also of their discussions during the investigation about discarding information that they put in the Progress Portfolio but never end up using (for instance, students are saying things like "I'm throwing away gf1 [the profile of finch 1] --we never talked about it"), shows that students are being thoughtful in what they decide to capture and transfer to their Progress Portfolio file. All students explicitly acknowledge that they only moved useful information to the Progress Portfolio in their post-investigation interviews. In addition, this process of selection is further showcased by the numbers of graphs generated in the Galapagos Finches and then selected to be recorded and talked about in the Progress Portfolio: one of the three groups case-studied generated seventy graphs in the Galapagos Finch software but moved only seven of them to their Progress Portfolio file. In a similar way, the other two groups moved to their Progress Portfolio a) sixteen out of fifty-three, and b) seven out of twenty nine graphs produced in the Galapagos Finches.

Helping narrow down the scope of the investigation

Providing templates and prompts for the students to use as they engage in a complex investigation may assist them in understanding the task and narrowing down the scope of their investigation. As they report in their post-investigation interview, the medium ability group felt confused when they started investigating the Galapagos Finches software environment. Prior to their first day on the computer, they had discussed between them possible ideas about why the finches might be dying, but this did not seem to help them when they started working on the computer. When they begun exploring the data and realized that the hypotheses they had the day before were not supported at all by the data in front of them they became confused and, as they said, were unable to decide which new direction they should start exploring due to the large amount of data in front of them. They ended up deciding to work first with the KWD Progress Portfolio template (KWD stands for "What do you Know, what do you want to know, and what are you going to do about it?") on which they spent the next nineteen minutes. When asked specifically about the usefulness of each page they said that the KWD page helped them: "*Yeah, because, we first looked at the data and we got confused […] Like "what do you want to know"? We wanted to know everything cause at that point the profiles, totally confused us"*. Taking the time to articulate what they would like to know, as encouraged by the prompts in the Progress Portfolio, seemed to have had a positive contribution in helping them refocus their efforts. The fact that they found a way to escape the confusion and continue working independently comes in contrast to other times when the same group is seen asking the teacher more specifically for help and shows that engaging with the Progress Portfolio may have contributed in clarifying their ideas about other possible investigation paths to take.

Facilitating the development and articulation of hypotheses

The three groups case-studied engage in conversations about their hypotheses in the context of the Progress Portfolio. One group started the discussion in the Galapagos Finches, only moving to the Progress Portfolio when they thought they had a good hypothesis that was supported by data, whereas the other two groups engage in conversations about their hypotheses and evidence to support it only when they move to the Progress Portfolio. Even though these hypotheses were probably not conceived in the Progress Portfolio, the Progress Portfolio prompts invited opportunities for discussions and articulation of their ideas between the members of each group, something that research points to as a beneficial element in learning and understanding.

Developing hypotheses is an elemental aspect of inquiry-based science, which can serve as a point of departure for students' beginning investigation. Without the formulation of working hypotheses the investigation can easily become unfocused and students can get lost since working hypotheses can help narrow down the scope of the investigation and give students direction. In accordance to the literature findings, all data collected thus far indicate that students' metacognitive engagement differs according to their ability level. Two different patterns emerged in how the case-studied groups used the Progress Portfolio template to record their hypotheses at the beginning of their investigation. From the data analyzed thus far, the pattern displayed by the middle and low ability groups was very similar whereas the high ability group displayed a different pattern: the first two groups chose to discuss and co-develop their hypotheses in the Progress Portfolio for the first time, while the high ability group first developed multiple hypotheses in the Galapagos Finches and only moved to the Progress Portfolio to record the hypothesis they felt was most viable. Furthermore, the one of the two groups who chose to co-develop their group hypothesis in the Progress Portfolio stated in the interview that followed their investigation that taking the time to think and articulate written responses to the questions in the Progress Portfolio helped them narrow down the scope of their investigation and figure out the next steps in their investigation.

The groups started their computer investigation by exploring the Galapagos Finches environment with the goal of formulating their hypotheses in the Progress Portfolio template their teacher had designed for this purpose. Nevertheless, the high ability group spent the first hour of their first investigation day exploring in the Galapagos Finches program and discussed several hypotheses while doing so. After looking at a variety of data, they decided that the reason that so many finches were dying and some survived had something to do with wing length and beak length. Agreeing on this, they decide on the information they would like to transfer to their Progress Portfolio file to help them make that point, they take a snapshot of this information and paste it in a new Progress Portfolio data page. They end up capturing profiles of four different finches, which they organize in the Progress Portfolio. As they are doing this, they start discussing their hypothesis abut the finches' beak size; their discussion starts off by one of the students suddenly saying "*I want to…write this down…[what he is just about to say] I want to see what each finch is doing*"; they then engage in a discussion about their hypothesis which concludes by saying that "*If they*

[the finches] have a smaller beak it has more maneuverability to move around, to bend it, and to go do things faster. But if you have a longer beak, you don't have the maneuverability...of the small beak and you can reach into cactuses and take the seeds out. And if you have a small beak you cannot do that. And if you have a big beak you don't have the maneuverability. If you have a medium beak... But if you have a medium beak you can do both." As the conversation is concluding the other member of the group has moved to the template where they are expected to document their hypothesis and has written what the group had discussed above as their hypothesis. This episode shows how these students took into account the task set up, afforded by the Progress Portfolio template and the prompt "write your hypothesis" to discuss, co-develop, and articulate their hypothesis.

The Progress Portfolio template "Planning and organizing your investigation" asked students to list their hypotheses and provide data to support them. This template was in a table form with four columns each with the prompt "Write your hypothesis" as the header, whereas the prompts in each of the table rows were "Explain your hypothesis", "Status of hypothesis", and "Data Source". As the analysis of their discussion shows, students read aloud and discussed all of these prompts and this discussion was catalytic in deciding the next steps they took in their investigation. All three groups were seen reading the prompts and then engaging in brief evaluations of what they were doing, thinking about whether they had enough evidence to support their hypothesis, an important aspect of science that we would like students to pay attention to when engaging in such investigations. The following transcript is the conversation that happened between the members of the low ability group and shows how the Progress Portfolio prompts offered them an opportunity to think about and openly discuss issues of supporting their ideas with data. Prior to the conversation below, the group had typed and explained their hypothesis in the table cells with the header "what's your hypothesis?" and "explain your hypothesis". When engaging in the following conversation, they are reading the prompt that follows the two above mentioned prompts which asks them to list the data sources that support their hypotheses:

1	Jennifer:	It says "data source" (referring to and reading the prompt): We looked in the field notes and it said that most of the birds, they occasionally go and eat spiders.
2	Timothy:	I think because, the finches are dying because they are eating some poisonous food, and because all finches eating poisonous food. (While Timothy is talking he points to the Progress Portfolio part, where it says "hypothesis").
3	Jennifer:	Yeah, but that's the same thing.
4	Timothy:	Because in the field notes it said that all the finch eat different food.
5	Jennifer:	(Reading the prompt): "Are you going to keep this hypothesis?"
6	Timothy:	It depends on whether I find any new information.
7	They are now typing another hypothesis in the third column of the table.	
8	Timothy:	(Reading the prompt): Data source: It says field notes. We should look at other stuff too, besides field notes.
9	Jennifer:	Ok. Let's go.

As one can see from reading lines 1 & 2, the prompt "data source" serves to guide the group's conversation to discussing the source of their ideas ("we looked in field notes") while at the same time referring back to their hypothesis (line 2). Also the prompt "are you going to keep this hypothesis" (line 5), allows Timothy to make explicit that he understands that if he finds new information that contradicts what they have, he (they) might not keep that hypothesis. Finally, in lines 8 & 9 we see that the second repeat of the same prompt (data source) plays now a different role: the first time they encountered it (lines 1 &2) the group cites the evidence they have; the second time they encounter it the group is seen deciding that they need to look at different types of data for evidence, in addition to the ones they have (field notes). In the subsequent part of their investigation, they do go look for other evidence. This type of interaction is observed with the other groups as well; even though we have no evidence about the kinds of conversations these groups would engage in if they were doing the same investigation without the Progress Portfolio prompts, it is important to add that two of the three groups only had conversations about their hypotheses and the need to find supporting evidence in the context of the Progress Portfolio, while they were obviously engaging with responding to the prompts in place.

Supporting claims with evidence

The literature reports that students need to be scaffolded in understanding the need for supporting their ideas and constructing evidence-based explanations, and that the latter is often difficult for middle-school students. The Progress Portfolio templates used in this study attempt to encourage students to cite and think about evidence, since they enable easy linking of data pages to support students' arguments, and provide the ability to pictorially

record the data, along with the prompts asking them to explain how their evidence relates to their hypothesis. With all three groups case-studied we frequently see them concerned about having supporting data over the period of their investigation. This concern seems to relate to some extent to the Progress Portfolio task set-up. For example, as one of the groups is working in the Progress Portfolio, organizing and annotating data that respond to the question "why did so many finches die?", they engage in the following discussion:

1 Jim: OK, we're done. I answered the question.
2 Dina: You did? What did you write?
3 Jim: They died in 77, shortness of seeds in 77.
4 Dina: We need to show it.
5 Jim: I did show it right here, see. I'll show it right now.

As lines 4 and 5 point to, the students are concerned with demonstrating the evidence for their claim. Following this conversation, Jim adds sticky notes and arrows, emphasizing where the reader of their Progress Portfolio should look at to see evidence that finches died in 1977 because of a seed shortage. At another instance, one of the students in the low ability group states the following as they are working in the Progress Portfolio, and talking to the teacher:

Jennifer: We want to change our hypothesis.
Teacher: Oh, why?
Jennifer: Because we have no supporting evidence.

Prior to the above conversation, Timothy, the other member of the group had said while responding to a prompt asking them to write "what do you see in the data", "Let's do weight instead of beak. Apparently, we have no [incomprehensible] evidence." It is encouraging that all three groups were seen concerned about backing up their claims in the context of using the Progress Portfolio prompts. Just because they are concerned with that though does not mean that the evidence they provide is always appropriate. Even though all three groups came up with a causal explanation about why many finches were dying and only some survived, there are instances where one of the groups' explanation is conflicting, as on most Progress Portfolio pages they talk and provide evidence about the finch population beak length going up every year, especially during the crisis years, but on a couple other pages they state (without any real evidence) that the finches with the medium beaks are the ones that survived. These occasions are examples of the Progress Portfolio prompts needing to be supported by supplementary means of evaluating what the students have collected; one such support could be the teacher's feedback, either verbal or in the format of review at the end of the day with sticky note comments. The electronic format of the students' Progress Portfolio files facilitates easy review of their work at the end of the day, so that the next day the students can start thinking about their teacher's notes. [Nevertheless, this requires a significant amount of the teacher's time, especially as students may create twenty data pages or more by the end of their investigation.] The teacher in the study reported did take the time to post sticky note comments, which the groups took seriously into account. Students were observed working in the Progress Portfolio responding to those comments for most of the time after they read the teacher's comments, but a more frequent monitoring might be needed to make sure that all such issues with their investigation are addressed.

Conclusion

The data presented in this paper provide evidence on how the use of a cognitive artifact, such as the Progress Portfolio, may help students focus on the important points of their inquiry, such as the development and refinement of hypotheses. This explicit scaffolding of students to think about critical aspects of the learning task is an important affordance of the interaction between the tool and the students. Working in the Progress Portfolio appears to have served as a springboard to help think about possible starting points, (something that two of the three groups chose to do in the context of working with the Progress Portfolio templates), and offered opportunities to all three groups to extend their current ideas. This is an example of the role such a tool can play in problematizing the inquiry task, that is making students think about important concepts they might have otherwise overlooked (Reiser, 2002). On the other hand, as we are continuing with the analysis of the whole data corpus, which includes looking at reflective inquiry with and without the use of the Progress Portfolio, at different schools/classes and with different teachers, we are hoping to understand more about both the opportunities afforded by the use of the Progress Portfolio scaffolds, as well as the limitations/ challenges of the use of such tools in inquiry-based science.

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Acknowledgments

This research was funded by the National Science Foundation under grants #REC-9980055 to the KDI/ASSESS project, and #REC-9720383 to the Center for Learning Technologies in Urban Schools. The opinions expressed herein are those of the authors and not necessarily of these foundations. For additional information about the KDI/ASSESS project see http://www.letus.org/kdi.