Examining the Role of Explicit Epistemic Reflection in Promoting Students' Learning from Digital Text

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Abstract: This study examined whether and how epistemic reflection embedded in students' use of a digital tool influenced their learning using the tool. One biology teacher and his four classes of 8th graders (N = 100) participated in this study. Students used a digital text tool, VidyaMap, to learn about photosynthesis and energy transformation. Two classes were provided prompts for epistemic reflection. The prompts encouraged students to reflect on the epistemic role of the tool for inquiry. The other two classes served as comparison groups, and used the tool without epistemic reflection prompts. Quantitative analysis showed that the classes that received the epistemic reflection prompts outperformed the comparison classes in their learning. We also coded the levels of students' epistemic reflection and found that it was correlated with students' science learning from the tool. Qualitative analyses further suggested how students with high and low epistemic reflection scores differed in their inquiry using the tool. Implications of findings are discussed.

Introduction

Since Perry's work (1970), epistemic cognition, understanding of the nature of knowledge and knowing, has attracted much attention in research. Epistemology examines the origin, nature, methods, and justification of human knowledge (Hofer & Bendixen, 2012; Hofer & Pintrich, 2002). Over the years, researchers have adopted a psychological approach to examine individual's epistemology, focusing on what individuals believe is the nature of knowledge and knowing (Hofer & Pintrich, 1997; Khine, 2008). Accumulated evidence has shown the role of epistemic cognition in students' learning processes and outcomes (Cano, 2005; Mason, 2010; Mason, Ariasi, & Boldrin, 2011; Qian & Alvermann, 1995; Schommer, 1990). However, much of the research was based on self-reported questionnaire for examining students' epistemic understanding, which has been criticized for its decontextualized nature (Mason et al., 2011) and limited explanatory power (Sandoval, 2012). More recent literature has called for studying epistemic cognition from a situative perspective (Chinn, Buckland, & Samarapungavan, 2011; Louca, Elby, Hammer, & Kagey, 2004; Sandoval, 2012). The situated view argues that epistemic cognitions are situated and context-dependent (Chinn et al., 2011; Louca et al., 2004), and that they "emerge from and are linked to particular forms of activity" (Sandoval, 2012). Given the situated nature of epistemic cognition, it is possible that students possess certain epistemic ideas, but they are not activated in certain contexts (Louca et al., 2004), which may influence how they learn. Therefore, an important question to ask is, how can we design epistemic support to activate students' epistemic cognition, and will this support help students learn better? This study will address this issue in a context where digital tools are used.

With the widespread use of technology in education, digital tools are commonly used for supporting students' inquiry and learning. Many of these tools have been designed with epistemological underpinnings that may not be obvious to or taken up by learners. Therefore, students may not use the tool as intended, which might influence their learning. In this study, our aim is to examine whether engaging students in *epistemic reflection*, that is, providing students with opportunities to reflect on the epistemic role of tools used to support science inquiry, could improve their learning. We adopted the term epistemic reflection from Mason et al. (2011), who examined students' spontaneous thinking about knowledge and knowing. But here, we use it to refer to the intervention process of activating students' thinking about knowledge and knowing. In this case it is to explicitly engage students in reflecting on the epistemic role of a digital tool for their inquiry. Engaging students in such a process might influence how they actually engage in inquiry in that context, and therefore influence their learning. Our work builds on previous studies that emphasized the importance of making the epistemic aspects of students' inquiry explicit (Lin & Chan, 2018; Sandoval & Reiser, 2004; Schauble, Glaser, Duschl, Schulze, & John, 1995). For example, Sandoval and Reiser (2004) designed epistemic scaffolds to structure students' inquiry activities within ExplanationConstructor (an electronic journal that students used to record their investigations). Their aim was to help students attend to the epistemic features of scientific explanations, including articulation of coherent, causal accounts, and use of data to support causal claims. They found that such an epistemic tool was helpful for improving students' inquiry. Schauble and colleagues (1995) found that 5th grade students designed better experiments after instruction on the purpose of experimentation. These studies suggested the importance of making epistemic goals and epistemic aspects of students' inquiry explicit. The current study builds on this line of research. To help students attend to the epistemic features of the tool, we used explicit epistemic reflection prompts in an attempt to activate students' cognition about the epistemic role of a digital tool for inquiry, and examined its effect on students' learning using the tool.

The particular digital tool we focused on in this study is VidyaMap. VidyaMap uses both concept maps and text to facilitate students' navigation and inquiry (Puntambekar & Stylianou, 2005)[see Figure 1]. The concept maps display the connections between science ideas, which mirrors the interrelated structure of the science concepts and phenomenon. Underlying this design is the epistemic idea that scientific knowledge is coherent and connected. This epistemic feature of VidyaMap was designed to help students engage in deeper and more sustained inquiry, as the connection of concepts could be used to guide and expand students' inquiry by helping them generate more questions and leading them from one idea to another. However, *students may not understand this epistemic feature of the tool and the underlying design principles, and therefore may not use it as intended*. Therefore, we developed epistemic reflection prompts to activate students' epistemic awareness of this feature to see if it would affect their learning from their inquiry using the tool. To examine the effects of the epistemic prompts on students' learning, we also included a comparison group who were not given prompts for epistemic reflection while using the tool.

In addition to exploring the effects of epistemic reflection on students' learning from using VidyaMap, we examined whether and how the levels of students' epistemic reflection may be related to the depth of their learning. Previous studies have suggested that students' epistemic understanding is related to their conceptual understanding (Qian & Alvermann, 1995; Schommer, 1990), but many of them were based on a decontextualized questionnaire approach for examining epistemic cognition. This study will take a situated perspective to examine epistemic cognition by looking at students' reflections of the epistemic role of the digital tool for inquiry, and examine the relationship between epistemic reflections and student's learning from using the digital tool. We will also explore how students with different levels of epistemic reflection engage in inquiry using the digital text tool.

Three research questions are addressed in this study:

1) Does the process of engaging students in epistemic reflection improve students' learning when using the digital text tool?
2) What is the relationship between students' level of epistemic reflection and their learning?
3) How do students with different levels of epistemic reflection engage in inquiry using the digital tool?

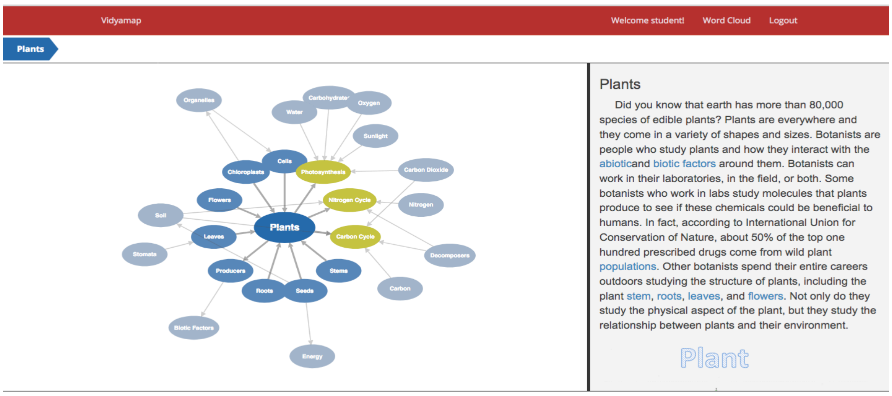

Figure 1. An example of a navigation page on VidyaMap

Methods

Participants and context

One experienced biology teacher and his four classes of 8th grade students participated in this study. Each of the four classes was randomly assigned to one of the two conditions: epistemic reflection condition and non-epistemic reflection condition. Students in two classes (n=49) were provided with epistemic prompts (epistemic reflection condition), and the other two classes served as comparison classes (n=51) (non-epistemic reflection condition). Despite the fact that the classes were randomly assigned to one of the conditions, each student was not randomly assigned to a particular condition, which made this a quasi-experimental design. This study occurred during students' regularly scheduled science classes in a Mid-sized Midwestern city in the U.S.A. The study was conducted within a larger research project that examined how engaging students in a curriculum focused on solving 21st century bio-engineering problems would help them learn science. In one of the units, *Make Your Own Compost!*, students needed to use information they learned about energy transformation, matter cycling, ecosystems, decomposition and human impacts on the environment to solve the challenge. Thus, all the participants were involved in solving a design challenge to reduce the amount of waste going into landfills by designing compost that breaks down quickly and contains lots of nutrients. Students worked in groups of three to four students throughout the unit and participated in cycles of inquiry which included research using simulation and physical experiments, as well as second-hand research (Palincsar & Magnusson, 2001) using a digital text tool, VidyaMap. Throughout the unit, every student wrote notes in his or her scientist's journal, which was a paper-and-pencil tool that included prompts associated with each activity, such as writing hypotheses, collecting data, interpreting results, and reasoning. The journal both served both as a scaffold, as well as a place for students to record their ideas.

Procedure

About halfway through the unit, students were engaged in a mini-unit to help them understand the role that plants play in the transformation of energy in ecosystems. Students were asked to: 1) brainstorm their ideas about what plants need to grow, which they recorded in their journals and served as prior ideas for our analysis; 2) write questions they had about plants' role in energy transformation in ecosystems; and 3) use VidyaMap to research their questions. Students' notes from their research on VidyaMap were recorded in their student journals and served as their post ideas for our analysis. It should be noted that all students had used VidyaMap before this session, and thus they were familiar with the concept map structure of the interface.

The prompts were given after students' brainstorming of ideas and before their generation of questions and use of VidyaMap. For the epistemic reflection condition, each student was provided with a worksheet containing three questions: 1) *You already have some experience with VidyaMap, what do you think about the role of the maps (left side of the screen) in VidyaMap? 2) Did the maps help you? What did they help you with?* 3) *How can the connections between nodes in the maps help you with your research?* They were first asked to reflect and write their ideas about these three questions on the worksheet. Then they were asked to discuss these questions in small groups for 10-15 minutes. Students were able to revise their responses to the questions based on their discussion. A similar procedure was followed in the comparison classes (non-epistemic reflection condition), except that we gave them a general prompt: *What do you want to learn from VidyaMap*?

Measures

Students' learning from text

To examine students' learning from text, we analyzed students' pre- and post- ideas in their journals. Students wrote what they knew about plants in their journals before their use of VidyaMap, these ideas were analyzed as pre-ideas. They also wrote what they learned after their investigation with VidyaMap in their journals. These responses were analyzed as post ideas. We analyzed these pre- and post-ideas with a coding scheme focusing on the extent to which the students discussed the concepts of photosynthesis and energy transformation. The concepts students learned from engaging in these photosynthesis activities were an essential part of the Compost unit, because students needed to understand the role that plants play in transforming energy and cycling matter in an ecosystem to solve the challenge. The coding scheme was inductively developed. For this rubric, the concept of photosynthesis included 6 sub-ideas and energy transformation included 2 sub-ideas, as Table 1 shows. We counted the number of sub-ideas included in each student's pre- and post-written responses according to the rubric. The total number of sub-ideas included in each response was summed to represent the thoroughness of their ideas about photosynthesis and energy transformation. Thirty percent of the students' journal entries from their VidyaMap session were individually coded by the first and second authors. Cohen's Kappa was $K = .77$, indicating good agreement. The first author coded the remaining responses.

Table 1. Coding scheme for pre- and post-ideas

Concept	Sub-Ideas
Photosynthesis (max 6 points)	included sun/sunlight, water, and oxygen as input for photosynthesis
	included oxygen as output for photosynthesis
	included glucose/chemical energy/food/carbohydrates as output for photosynthesis
	explained the role of stomata in photosynthesis

	explained the role of chlorophyll/chloroplast in photosynthesis
	explained the role of root/leave/stem in photosynthesis
Energy Transformation (max 2 points)	connected plants with sun/sunlight for energy transformation, or state that plants play an important role in energy transformation
	connected plants with the rest of the ecosystem (e.g., provide food for consumers)

*The maximum score that could be earned was 8.

Students' reflection on the epistemic role of VidyaMap

To examine students' epistemic cognition embedded in their epistemic reflection, we analyzed students' written responses on their prompts worksheet, *which served as both an intervention and a measurement*. We coded these responses according to their levels of understanding about the epistemic role of VidyaMap. For our purpose in this study, we described a more sophisticated epistemic reflection as one that showed a better understanding of the epistemic role of VidyaMap for sustained inquiry, e.g., how the connections between the nodes in the concept maps might help them expand their ideas for further inquiry. A less sophisticated reflection showed a more superficial understanding about the function of the tool, e.g., it provides content knowledge. Each student's responses to the three questions were grouped together and coded. Three levels of epistemic reflection were identified as follows in Table 2 below. Thirty percent of the students' epistemic reflection responses were individually coded by the first and second authors. Cohen's Kappa was $K = .69$, indicating good agreement. The first author coded the remaining responses.

Table 2. Coding scheme for epistemic reflection

Level of Response	Description	Student Example*
0	Unintelligible responses	*1) It's the food or (mabbs) to more of the plant parts.2) Yes it showed me what to do. 3) If you click it it tells you?*
1	Described VidyaMap as tool to find content knowledge and details	*1)I think they are really helpful when it comes to the research part of the project. It gives us the* ***background information****. 2)It helped me with* ***finding specific details****. 3)It gives us the* ***definition*** *of the role all of the objects …*
2	Described connections in VidyaMap as important, but did not discuss the role of connection for inquiry/understanding	*1) The role is to show how the* ***maps are all connected*** *and they all spread. 2) Yes helped me see that they are all connected to one [main] thing producers. 3) to show that they* ***are all connected to one thing****.*
3	Described importance of connections in VidyaMap for inquiry to include expanding ideas, leading one subject to another, spurring more questions, which were beyond finding information/answers	*1)It helps you find the [origin] of the node. 2)Yes, It helped us* ***get more questions and answers****. 3)It lets us know [there is****] more parts of it instead of just one answer****. ….It helps you realize that there are connections between them all.* ***Each thing leads up to another*** *+ back sometimes to one main thing. It really helped me* ***realize info[information], that I wasn't yet aware of.***

*We bolded words in students' examples to highlight key parts of response in relation to the rubric.

Small group inquiry during navigation

Students' small group discussions during their investigation on VidyaMap were qualitatively analyzed to understand how students with different levels of epistemic reflection may engage in inquiry differently using the tool. We selected two contrasting groups based on their epistemic reflection scores (one high and one low epistemic reflection group) as well as availability of video data. The groups' epistemic reflection scores were calculated by averaging the epistemic reflection scores of all students in the group. Contrasting cases analysis (Rummel & Hmelo-Silver, 2008) was conducted to examine their inquiry practice using the tool.

Results

Comparing students' learning gains between conditions

We first conducted a t-test to compare students' prior biology knowledge in both conditions (epistemic reflection vs non-epistemic reflection condition) using a content test to examine if there were significant differences between the groups. All students took the Compost content knowledge test before the start of the

Compost unit, which measured what they knew about energy transformation, matter cycling, decomposition, ecosystems, and human impacts on the planet. The test included 22 multiple choice questions and 4 open-ended questions. We found that students within each condition had similar levels of biology content knowledge at the start of the unit ($t = -1.197$, $p = .234$). By establishing that students in both conditions started out with similar levels of content knowledge, we could then assume that the results of our analyses were likely not due to differences in students' prior knowledge.

We then conducted an ANCOVA to examine if the students in the epistemic reflection condition had higher post-idea scores than the students in the non-epistemic reflection condition after controlling for their prior idea scores. The assumption of homogeneity was met. The result showed that the students in the epistemic reflection condition (adjusted mean = 3.26 ($SE = .282$)) had significantly higher post-idea scores than the students in the non-epistemic reflection condition group (adjusted mean = 2.36 ($SE = .279$)), $F(1, 94) = 4.98$, $p < .05$) when controlling prior idea scores. This suggested that students from the epistemic reflection condition learned more from VidyaMap than students from comparison condition.

The relationship between epistemic reflection and students' learning outcomes

To understand whether students' epistemic understanding of the online tool in their reflections was related to their learning, we conducted a correlation analysis to examine the relationship between students' epistemic reflection scores and their post- idea learning scores. The results showed that they were significantly positively correlated (r = .316, p <. 05), suggesting that more sophisticated epistemic reflection was associated with a better learning outcome.

Students' inquiry during navigation

To understand how epistemic reflection was related to students' inquiry and learning, we compared the discourse of two contrasting groups from the epistemic reflection condition: high and low epistemic reflection group. The average epistemic reflection scores of all groups ranged from 1 to 3. We chose the highest ($M = 3$) and the second lowest one ($M = 1.5$) as the contrasting groups as the video data of the lowest one was not available. The Critical Incident technique (Flanagan, 1954) was used to identify excerpts from the groups' discourse that best exemplified the different types of epistemic practice of the contrasting groups as they conducted inquiries on VidyaMap. Overall, we found that students' in the high and low epistemic groups engaged in qualitatively different inquiries, which aligned with their respective epistemic reflections. In the following, we present excerpts from both groups that illustrated how they differed in their inquiry practice. The following is an episode from the high epistemic reflection group:

S2: Like yesterday…We found energy transformation taking sunlight and converting it into chemical energy. So-
S1: How do they transform energy? How do they provide energy for the other animals?
S2: So we should go to photosynthesis right?
…
S2: [reading VidyaMap page] It says, uhm, the- there's sunlight needed to combine with the nutrients to produce sugars for the plants to grow.
S3: Wait!
S1: That's growth, that's not energy.
S3: [pointing to the VidyaMap page] What is that? What is that? Chloroplat- plast.
S2: Click on it.
S1: I did.
S3: Of the plant cells and the-
S2: Oh it makes cell membranes like, right there there's one in the map.
S3: Ok. So, this thingy is- oh yeah that's the one I was talking about! The one that turns the plants green.
…
S2: Mhmm. But we know- we have to know… why do they transform, energy? So we gotta go back to producers.

This excerpt shows how this high epistemic reflection group decided their navigation direction based on their prior understandings and questions they wanted to know, and how they made use of the epistemic feature of the tool (connection of concepts) to expand their ideas. As the excerpt shows, while S2 was reading aloud about the process of photosynthesis on VidyaMap, S3 noted a related concept (chloroplast) from the visualization of the concept map on VidyaMap, which prompted the group to learn more about chloroplasts.

Later the group was wondering how and why plants make sugar. While S1 was navigating, S2 noted some related information on VidyaMap:

> S2*:* [pointing to VidyaMap page] *Right there. It says um photosynthesis is the ability to convert sunlight into carbon and sugars-* ((continues reading text from VidyaMap))
> S4: *(inaudible)*
> S2: *For energy.*
> S1: ((reading quietly))
> S2*: Go to carbohydrates*
> …
> S2: [talking to S3] *What do you think?*
> S3: *Well I just read that um energy cannot be created or destroyed so plants can't create energy instead they (transform) the energy.*
> S2: *From the sun light, chemical energy. Perfect. …..* ((writing notes and thinking aloud)) *Plants can't create energy but it is transformed-*

This excerpt showed how this high epistemic reflection group navigated to different related concepts guided by their *emerging* questions, and how they connected each other's ideas (S2 built upon S3's ideas), and came to understand the relationship between plants and energy transformation.

In contrast, the low epistemic reflection students did not use any questions to guide their inquiry, even though they were asked to do so. They often simply opened a VidyaMap page, one student read aloud, and the rest of the group followed and recorded the information in their journals. For example, in the beginning of a session, the group opened a page on producers:

> S1: [reading a VidyaMap page] *Plants use the nitrogen and the carbon, well the plants, take, in, carbon and water, and nitrogen that is found in the water, they break down the nitrogen so that other plants can use it.*
> S2: *So what are we writing down?*
> S1: *Take, taking –*
> S2: *Carbon –*
> S1: *Water. Water slash…*
> S2: *Carbon then what?*
> S1: *Carbon, and turn the, turn the nitrogen into usable nitrogen. Carbons into, turn the nitrogen atoms…into usable nitrogen…for other animals. And turn, carbon…into, into food and oxygen.*

After a while, another student learned something from another VidyaMap page, and read aloud "*Plants are able to make their own food, cause that's, that's what they do*." He jotted down these notes, and everyone else in the group also recorded this information in their journal. At times, one student even explicitly told everyone to copy the information he found:

> S3: [pointing to a graph in a VidyaMap page] *So does everyone write down these four things?*
> S4: *Yes.*
> S3: *Have you?*
> S1: *Two of them.*
> S3: *Write it down.*
> S4: *Come on dude.*
> S1: *Okay ((mumbling)).*
> …
> S3: [Reading a VidyaMap page] *So six carbon dioxides and six water, plus sunlight…is that equal? One carbon, one carbohydrate and six oxygen. Yeah it does. So write everyone, write this down. Write that equation down. Six, so write underneath your papers…*
> S4: *That means you too XX,*

As these examples show, the high epistemic reflection group used VidyaMap as an epistemic tool to support and expand their question-driven inquiry, and they actively connected their previous ideas as well as each other's ideas for constructing new understanding. However, the low epistemic reflection group merely used VidyaMap as a tool to provide information and did not capitalize on the epistemic features of the tool to help them connect and expand their ideas. Their navigation on VidyaMap was fragmented. They neither connected their search with any research questions nor to their previous ideas. They just copied what was written on VidyaMap and did not process nor connect each other's ideas. Such differences in inquiry practice between these two groups were aligned with the difference in their epistemic reflection.

Discussion

In this study, we examined the role of embedded epistemic reflection in students' learning from digital text. Drawing from the previous research emphasizing the situated nature of epistemic cognition (Chinn et al., 2011; Sandoval, 2012), we designed explicit epistemic reflection prompts to activate students' cognition about the epistemic role of an online tool for inquiry and examined its impact on students' learning and inquiry using the tool. We specifically addressed three questions: 1) Does the process of engaging students in epistemic reflection improve students' learning when using the digital text tool? 2) Is there a relationship between students' levels of epistemic reflection and their learning from using the tool? and 3) How do students with different levels of epistemic reflection engage in inquiry using this tool?

In traditional classrooms, science has generally been presented as a collection of unrelated facts and ideas. VidyaMap was intentionally designed to display the connections between science concepts and ideas in concept maps. These maps can be used by students to help them to see how science concepts are related and to support their navigation in the tool for sustained inquiry. However, this epistemic feature is not always obvious to students. Our study showed that having students explicitly reflect on the epistemic role of the tool better promoted their learning when using it.

Research over the past few decades has been focused on understanding the nature (e.g., dimensionality) of epistemic cognition and its relation to other constructs. Few studies have examined how epistemic support could be designed in a certain context, and how it may impact students' learning. Our study was situated in a collaborative learning environment where a digital tool was used. Our findings suggest that helping students understand the epistemic nature of the tool by providing reflection prompts may be a promising way to promote students' inquiry and learning. This finding aligns with previous studies (Sandoval & Reiser, 2004) that emphasized the importance of scaffolding the epistemic aspects of students' inquiry. It also sheds light on a new way to provide explicit epistemic support in a context where a digital tool is used to impact students' learning.

To further understand the relationship between students' understanding of the epistemic role of the tool and their learning, we conducted a correlation analysis to examine the relationship between the students' epistemic reflection scores and their post- science ideas. Consistent with the previous research (Mason et al., 2011; Qian & Alvermann, 1995; Stathopoulou & Vosniadou, 2007), we found that these two variables were positively correlated. This result confirmed the importance of helping students engage in epistemic reflection to support their learning.

In examining how students' epistemic reflection might influence their inquiry and learning, we focused on how two contrasting groups with high- and low-level epistemic reflections pursued their inquiries using VidyaMap. We found that the group with a higher-level epistemic reflection attended more to the epistemic role of the tool, and used the connection of nodes to expand their inquiry. They also connected what they knew, what they wanted to know, as well as to each other's ideas during their discussion. In contrast, the group with lower-level of epistemic reflection did not attend to the epistemic feature of the tool, and simply used VidyaMap as a tool to provide content knowledge. This result showed that students' understanding of the epistemic features of the tool aligned with their use of it. This is consistent with the previous studies on the relationship between epistemic cognition and learning process (Cano, 2005; Cho, Woodward, & Li, 2017). Many of these previous studies are based on questionnaire measures, our study provided further evidence by examining epistemic cognition from a situated perspective and illustrated how students' epistemic reflection might be related to their inquiry and learning while they used VidyaMap. It is possible that our epistemic prompts activated students' cognition about the epistemic role of the tool, which influenced their inquiry during navigation, and therefore their learning using the tool. Future research could further examine this relationship and test it in a different context.

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