Analyzing Collaborative Knowledge Construction in Secondary School Biology

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Abstract: This research investigates student collaboration in a high school biology curriculum that was based on the Knowledge Community and Inquiry (KCI) model. Using co-design, the researchers collaborated with three high school science teachers to design a curriculum where 112 grade-ten biology students collaboratively developed a community wiki about Canadian ecozones and biodiversity issues. Students then used the wiki as the primary resource for a subsequent inquiry activity. This paper analyzes students' contributions to the knowledge base, test performance, and student satisfaction to evaluate the efficacy of the KCI model. A new method of analysis for collaborative wiki artifacts was developed to measure student interaction in the wiki. We found that students who were higher contributors to the knowledge base performed better on a post-test than students who were measured as low contributors. Our findings suggest that the KCI model is a promising mechanism for supporting both collaborative and individual learning.

Introduction

Increasingly, scholars are emphasizing the importance of preparing students for the complex problems of a "knowledge society" (Drucker, 1959; Bereiter, 2002). Such 21st century skills are important for students to become productive citizens in a technological and knowledge-oriented society (Lemke, Coughlin, & Reifsneider, 2009). Such skills cannot be taught in isolation; rather, they must be learned in the context of a knowledge community where individuals collectively pursue the advancement of ideas. Many educators have noted the mismatch between conventional school curriculum and the needs of citizens in a knowledge society (Tapscott & Williams, 2006; diSessa, 2000). While schools struggle to raise student achievement on basic skills, scholars have identified a full spectrum of cognitive and metacognitive skills that are not being addressed, including inquiry, critical thinking, design and collaboration (Slotta & Linn, 2009). Thus, the traditional forms of lecture and homework that still predominate in today's classrooms are not desirable models for the design of technology-enhanced learning (Collins & Halverson, 2009).

The domains of science and technology are particularly reliant on high levels of knowledge work, yet in classroom settings teachers routinely employ rote learning in an effort to cover the mandated curriculum content (Slotta & Linn, 2009). This is particularly the case in secondary school science, which covers more topics than any other subject, thus resulting in textbooks that have been described as being "a mile wide and an inch deep" (Schmidt, McKnight, & Raizen, 1997, p. 62). Secondary teachers are responsible for teaching specific content matter, making it difficult to design learning activities where students can pursue a deep understanding of science topics. All science lessons must fit within a tight schedule of content coverage, with outcomes that are assessable by conventional measures. The fast pace of most science courses leaves teachers little or no time to ask their students "big-picture" questions, or engage them in personally relevant topics.

This paper begins by considering the established research traditions of knowledge communities and scaffolded inquiry, as well as a recent pedagogical model that describes how these two traditions can be blended to create engaging new curriculum for secondary science students (see Slotta, 2007; Slotta & Peters, 2008). We discuss the important innovation of co-design (Roschelle, Penuel, & Sechtman, 2006), which offers a means for creating such curriculum in a way that meets teachers' expectations without undermining the researchers' objectives. We discuss an eight-week design study where a technology-enhanced curriculum was co-designed according to the Knowledge Community and Inquiry model. In our analysis, we evaluate students' contributions to the community knowledge base, the effects of such contributions on test performance, and student satisfaction with the curriculum unit.

Theoretical Framework

A number of promising instructional approaches have already shown to engage students in deep collaborative inquiry. In the research program called Fostering a Communities of Learners (FCL), Brown and Campione (1996) scaffolded student learning within a peer community. The key components of FCL – research, information sharing (jigsaw), and consequential tasks (performing) – provide structure and support for students' collaborations within the learning community. When combined, these components form an effective instructional strategy that fosters critical reflection and deep understanding of disciplinary content. An important characteristic of FCL activities is that they are independently purposeful, yet they cohere to form a functional system. Although FCL is scripted, it must be emphasized that simply following a series of steps is not enough – teachers must understand the goals and philosophies that underlie the approach.

An important theoretical contribution of FCL is the notion of *diverse expertise*. In their classroom implementations of FCL, Brown and Campione (1996) found that students came to highly value the contributions of their peers. These contributions were not always about content, they were often related to using the computers or managing the group (Collins, Joseph, & Bielaczyc, 2004). This observation solidified the importance of information sharing for fostering a sense of community among learners. The students also offered suggestions for refining the design of FCL (Bielaczyc, 2006), such as recommending that information sharing occur sooner in the process rather than at the very end of the project. This suggestion resulted in an innovation called *crosstalk*, which involves students presenting their preliminary findings to the entire class. Crosstalk became a mechanism for a peer-review of ideas that would often result in students pursuing a new line of inquiry (Bielaczyc, 2006).

Another important consideration in the research literature is that of scaffolded inquiry. Researchers have developed a number of prominent pedagogical approaches that provide students with rich collaborative inquiry activities, many of which include technology-enhanced tools and materials (e.g., Linn & Hsi, 2000; Slotta, 2004; Songer, 2006). Broadly speaking, inquiry learning is an instructional approach where students research and investigate some phenomenon before making inferences about it (Kuhn, Black, Keselman, & Kaplan, 2000). For some educational researchers, the goal of inquiry learning is to teach students to work in ways that are similar to the way real scientists work. Students pose questions, formulate hypotheses, and then design investigations to test those hypotheses (White & Frederiksen, 1998). For other researchers, the experimentation cycle is just one of many possible inquiry patterns (Linn & Eylon, 2006). In all models of inquiry, the teacher does not assume the role of "sage on the stage" (King, 1993), but that of a facilitator who guides students in leading their own investigations (de Jong & van Joolingen, 1998). Students engaged in inquiry activities learn domain-specific content while developing their reasoning skills (Hmelo-Silver, Duncan, & Chinn, 2007) and their ability to understand and apply scientific principles and concepts (Schwab, 1962).

Both inquiry learning and knowledge communities emphasize the importance of collaborative knowledge construction. Here, collaboration refers to the coordinated efforts resulting from "a continued attempt to construct and maintain a shared conception of a problem" (Roschelle & Teasley, 1995, p. 70). Fischer, Bruhn, Gräsel, & Mandl (2002) describe four characteristics of collaborative knowledge construction: (a) individuals bring their prior knowledge to the learning situation, (b) there is a cause for a learning partner to share that knowledge, (c) a consensus is reached about the content or given facts, and (d) individual perspectives are integrated into a common understanding of the task or problem. This form of learning, in which students become productive knowledge workers, citizens and lifelong learners (Stahl, 2000), always occurs in a social context, either face-to-face or computer mediated. The essential element is the provision of a shared space for individuals to engage in social negotiation.

The two research traditions of scaffolded inquiry and knowledge communities provide mechanisms for deeply engaging students in science learning. However, despite widespread enthusiasm, these approaches have yet to make strong headway in science classrooms, as researchers have yet to determine how they can promote new cultures of learning while remaining sensitive to curriculum standards: What types of pedagogical and technological innovations are required to transform classrooms into learning communities? How can these innovations be designed? What supports do teachers need to enact new approaches in a manner that does not undermine the theoretical commitments of the design? These are questions that need to be addressed before inquiry-oriented instruction can pervade secondary school science curricula.

Knowledge Community and Inquiry

In an effort to make headway on these problems, Slotta (2007) has developed the Knowledge Community and Inquiry (KCI) model which combines collaborative knowledge construction with scripted inquiry activities to target specific curriculum learning objectives (Figure 1). The model begins with a collaborative knowledge construction activity where students explore and investigate their own ideas as a community of learners, creating knowledge artifacts that are aggregated into a communal knowledge base. An important component of collaborative knowledge construction is that learning activities (such as inquiry-type investigations) must be guided by the community itself through the knowledge construction process (Scardamalia & Bereiter, 1996). Common themes, ideas or interests should emerge, reflecting the "voice" of the community. The instructor must listen to this voice and respond by designing activities that reflect students' interests. The latter process is critical, but also challenging to execute, since the design of any activity must also address the content expectations and learning goals of the curriculum.

It is no easy task to design activities that respond to community interests while addressing learning goals and adhering to time constraints. In the KCI model, scripted activities are co-designed by teachers and researchers only after the knowledge construction phase is complete, resulting in new activities that build upon the themes that were identified within the knowledge base. Students then work independently or collaboratively on the scripted activities, drawing on knowledge elements from the community knowledge base, producing new contributions to that knowledge base, and completing inquiry tasks that are directly connected to assessable content learning outcomes. KCI attempts to support the development of such curriculum by working closely with teachers to develop a carefully controlled flow of collaborative knowledge construction and scaffolded inquiry activities that are specifically designed to address the mandated curriculum.

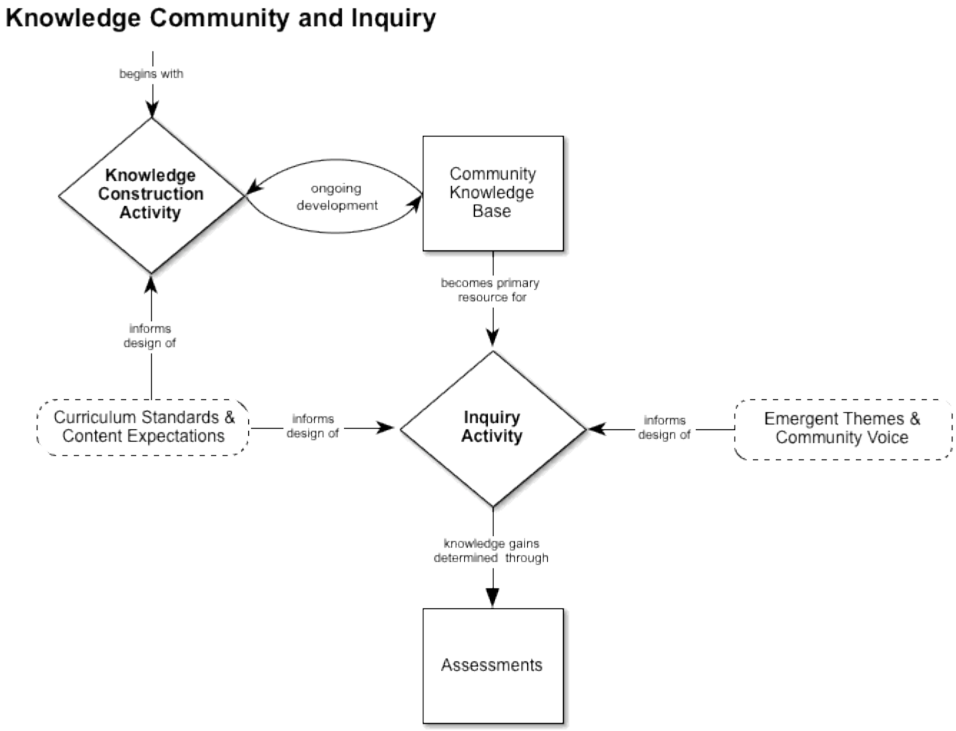

Figure 1. Flow diagram of a Knowledge Community and Inquiry curriculum.

Methodology

The research discussed here was the second iteration of a design-oriented study that implemented the KCI model. Design research (Brown, 1992; Collins, 1992) was an appropriate methodology for this study as it supports multiple investigations across a number of contexts (McCanliss, Kalchman, & Bryant, 2003). Design research can be characterized by its iterative design cycles and formative research in authentic settings such as a real classroom (Edelson, 2002). Another important method used in this study was co-design (Roschelle, Penuel, & Shechtman, 2006), where teachers and researchers work in close partnership when designing all curriculum materials and activities. Since it was important that our biodiversity unit target the curriculum content expectations, the teachers' input was essential for creating relevant and ecologically valid materials.

Participants and Data Sources

Participants included 112 grade ten biology students and three experienced science teachers. The co-educational school involved in this study provides specialized curriculum for high-achieving students in grades 7 through 12. Initially created as a laboratory school, this unique institution prides itself on new and innovative classroom practices. Admission to the school is competitive and based on students' score on the Secondary School Admission Test (SSAT), with 98% of new admissions being accepted from grade 6 students. The school population is ethnically diverse, with the majority of students coming from middle to upper-middle class homes. The school has a strong commitment to the liberal arts and sciences curriculum, and students are expected to fully engage in their academic program. There is a strong emphasis on community, and individual acceleration and early course specialization are discouraged. Assessment is ongoing throughout the school year and consists of formal progress reports and performance improvement plans.

Design and Procedure

The teachers began the Biodiversity lesson by placing students into one of eight Canadian biome groups. Working in these groups, students could choose a geographical region from Canada for which they would create a wiki "Ecozone Page". A template was used to scaffold students to include specific biology content and to help them set up their wiki page. While it was important to preserve the open-ended feeling of collaborative editing that typifies wikis, it was equally important to our project that we provide students with a simple, structured way to create wiki pages that scaffolded their treatment of science concepts. We therefore created a new hybrid wiki environment that improved control over student accounts, groups, editing permissions and other features. This environment includes a special "New Page" web form (developed using Ruby on Rails) that collects metadata (e.g., with check boxes and text fields), and then generates a new wiki page with pre-specified headers to help scaffold students' wiki entries as well as the specified authoring and access permissions (see Figure 2).

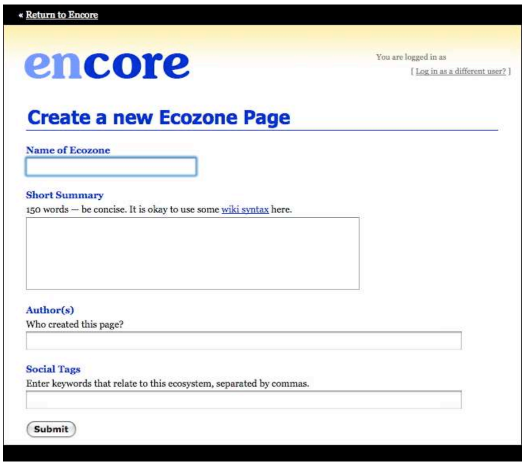

Figure 2. "New Ecozone Page" script.

Students in all four classes contributed to this same wiki repository, adding to and editing their peers' ecozone pages. After the knowledge construction activity, students were tested on their knowledge about Canadian biomes and ecozones. After working on the ecozone pages, students worked in pairs to create another wiki article about an issue or problem that posed an environmental threat to a Canadian region. Students could draw on their expertise by writing about an issue from the same ecozone they had written about in the first activity. Because biodiversity issues are not restricted to one ecozone, and to encourage synthesis of the wider knowledge base, students were asked to make connections between the different regions. Students were also asked to link to their peers' wiki pages wherever possible when referencing them in their biodiversity issue page.

Data Sources and Analysis

Data for this study were drawn from the revision logs of students' contribution to the wiki resource, pre and post-test scores and student interviews. Content analysis was performed on a subset of students' wiki edits to gain insight into their authoring practices, and to determine the level of collaboration that was occurring. The pre and post-tests were used to gauge the effects of wiki authoring on students' test scores. Interviews revealed students' satisfaction levels with the wiki curriculum, including their perspectives of the co-authoring process. The use of multiple methods when studying collaboration is desirable since it provides a more complete picture of student engagement and interaction (Hmelo-Silver, 2003; Naidu & Järvelä, 2006).

Since there are no accepted guidelines for analyzing wiki contributions, we developed a method of content analysis to capture students' knowledge contributions to the wiki. To begin, we defined a unit of analysis for studying the wiki revision logs. The wiki technology employed in this study labels all contributions to the wiki as "changes"; however, this characterization is imprecise as it suggests that only a single change is occurring. We instead labeled such changes as individual "transactions", since it allows for multiple codes to be assigned to a particular section of the wiki (e.g., adding text, deleting text or moving text). Figure 3 is a screen shot of a revision history comparing two versions of a wiki page, and shows why this kind of segmentation (which is labeled as a single change by the wiki software), is inadequate for analysis purposes. Here, we can see two transactions: T1 and T2 (labeled as such on Figure 3). The upper portion of T1 (red text) shows a section of text as it appeared before the revision, and how it appeared afterwards (green text). The student who completed this transaction deleted some text from a paragraph (highlighted in dark red with strikethrough), and added new text (highlighted in dark green and bolded). In T2, the student added new text without altering any existing text. Referring to the content in this way enabled us to code wiki interactions without being overly reductionist in terms of the student's editing process, and permits a finer-grain analysis of wiki content.

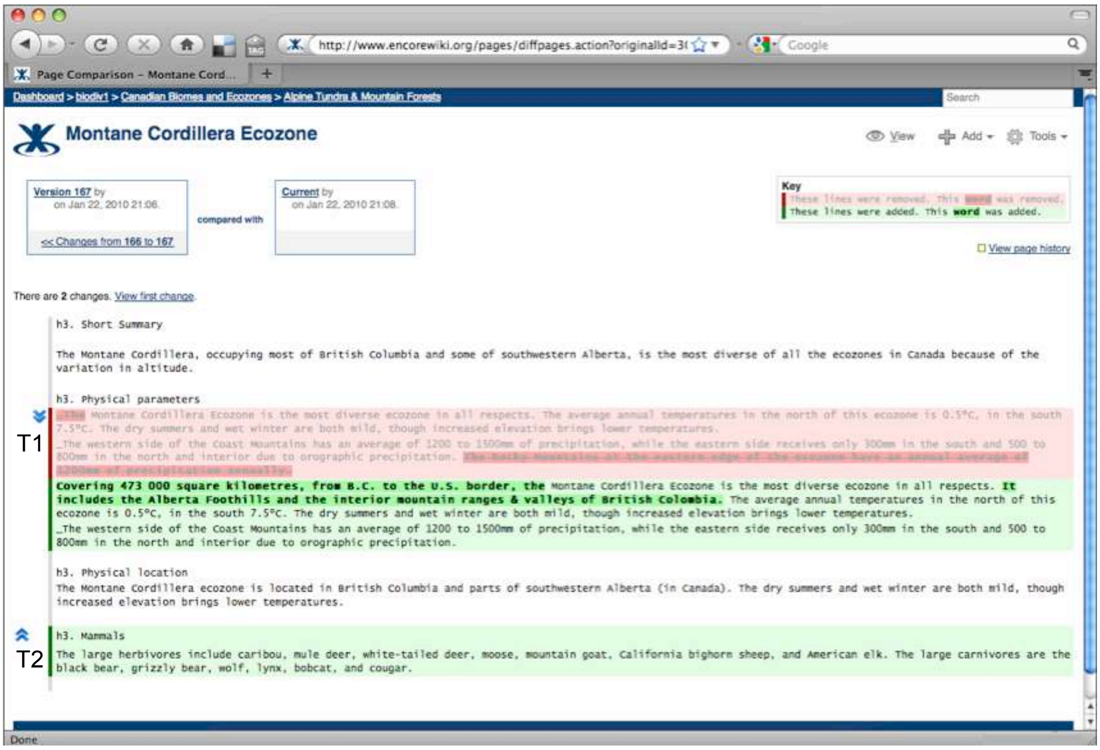

Figure 3. Screen shot of a revision history comparing two versions of a wiki page. In this comparison there are two "transactions". The first transaction (T1) contains text that was deleted and added into existing text. The second transaction (T2) contains newly added text.

We then developed a coding scheme to analyze the wiki contributions of a subset of students, coding all the transactions they made to every version of every wiki page. For the coding procedure, we first coded for "transaction type" (move, add, delete or format), then for "content type" (text, image, internal link or external link). Since substantive contributions would likely be written in prose, only text-based transactions were coded further – as either belonging to peer or self. If the edit was made to a classmate's text it was coded as peer, if it was made to one's own text it was coded as self.

Results

Students were actively engaged in the construction of the knowledge resource within the wiki, creating 31 ecozone and biome pages, and 47 biodiversity issue pages that showed an average contribution of more than 1500 words per student (M = 1651.55, SD = 1700.40). Prior to analysis, each wiki page was run through Copyscape©, a web-based utility that compares web documents to check for instances of plagiarism. We found no cases that warranted concern. In the following sections we present our findings for performance gains, the collaborative knowledge construction activity and student satisfaction.

Knowledge Construction Activity

To analyze how students were collaborating in the wiki, we applied our coding rubric to a subsample of students (n = 8) to learn about their editing practices when co-authoring their knowledge artifacts. Overall, the students contributed an average of 38 transactions (SD = 20.26), with high variability levels between students. Of these transactions, an average of 4.62 were images, 1.25 were internal links and 3.37 were external links. The total number of text-based transactions was 269 (M = 33.63, SD = 12.93)

We were interested in finding out how many of these text transactions involved *other* students text. That is, how often were students editing their own text, opposed to that of their peers? Of the students surveyed, the total number of self-based text edits was 151 (M = 18.78, SD = 8.87) and the total number of peer-based text edits was 118 (M = 14.75, SD = 9.44). The overall percentage of self vs. peer edits was roughly equal: 56.13% and 43.87%, respectively (see Table 1).

Table 1: Total text-based transactions per student: self and peer.

	Total text edits		
Student	**Self**	**Peer**	**Total**
Nick	21	15	36
Nathan	22	31	53
Patricia	27	12	39
Marion	34	9	43
Dave	7	18	25
Karen	14	23	37
Wendy	15	10	25
Brian	11	0	11

Performance Gains

We were interested in the effect of the knowledge construction activity on student test performance. We used only the test scores of two classes (n = 50) that were taught by the same teacher. We then placed these students into one of two groups based on their total number of text edits: "low contributors" and "high contributors". Students in the low contributing group were below the median for total words edited, and students in the high contributing group were above.

To find out if wiki contribution levels had an effect on test performance we conducted pre and post-tests. The difference in pre-test scores between the low and high contributing groups were not statistically significant ($t(48) = 0.2429$, $p = 0.809$), as shown in Figure 3. We did, however, find a significant difference between the two groups on a post-test ($t(50) = 4.68$, $p = <.0001$). Although this finding does not provide unequivocal evidence of higher learning gains for students who contribute more to the knowledge base, it does suggest that students who are more involved with the knowledge construction process are also engaging more with the subject content, resulting in higher test scores.

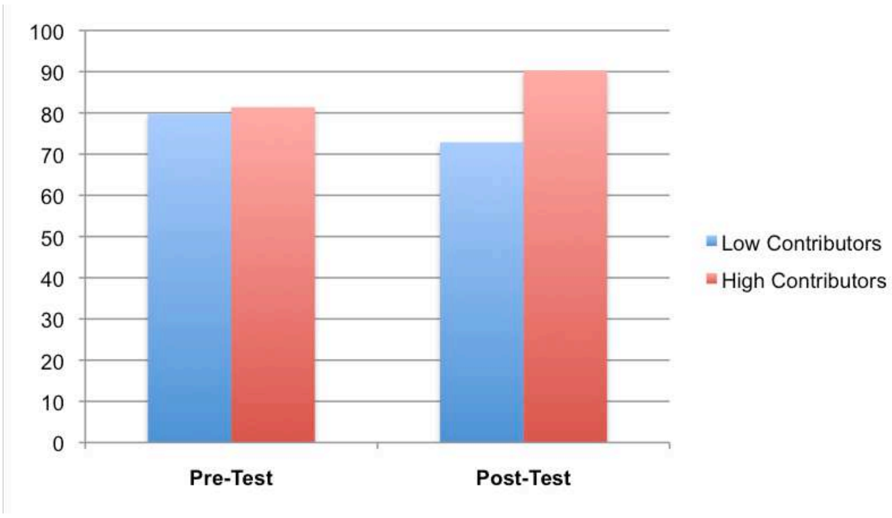

Figure 3. Test Scores from Low and High Contributing Students.

Student Satisfaction

Student interviews were conducted in the beginning, mid, and end-point of the study. A total of twelve students participated in the interviews. Participants were interviewed in pairs in an informal environment, usually during the lunch break or after school. Since the students had never used a wiki before, we were interested in their perspectives of creating a wiki in their science class. All students responded that building a knowledge base was a fun and novel way to learn biology. One student, Marge, described her perspective of the unit as follows:

> I really enjoyed it because, like, I've never built a wiki site before and it was really cool because we actually got to make a webpage in a way – and I think it was a really interesting way of learning about Canadian biodiversity without just going on other peoples sites and memorizing all the information. Because here, I guess when you actually put the effort in

> creating a website you learn a lot more about it, or the subject itself, then when you just read it in a book – because when you're creating a site you have to do the research and then decide what information you need and what information you can leave out because it's either not relevant or it's too complicated. But in the long run you do the elimination process with the information that you get, so it's really interesting and makes you learn stuff.

Other students commented on the authoring process of their collaborative knowledge construction activity. For example, some students were against the idea that students could make deletions on their wiki page. They felt it was preferable for their classmates to leave comments or suggestions, but not actually edit the original text. They felt this would give them the opportunity to refute changes made by others, and avoid what they described as "wasted work". According to one student: "I don't agree with people making deletions right away on your own thing. I think it's better that they leave a comment and say 'you could just do this' but you don't actually change the original text." Other students, however, felt comfortable about their classmates making changes to their wiki articles. In Jason's words:

> Well, I don't really mind [people editing my ecozone page] as long as I know that everything is completely recorded in the editing history, but I guess if it was just easier to undo the changes, like a bit more immediate, then it wouldn't bother people... but I guess when you're posting something to a wiki you have to know that someone else is going to make changes, so you just have to be okay with that and move on.

Overall, the students enjoyed making wiki artifacts as part of their biodiversity unit, and felt confident about using their peers' work as a resource for later activities. Since the wiki environment was new to students, however, future implementations of this activity would need to consider the social aspects of wiki authoring such as accepted norms for editing, work distribution and possible role assignment.

Discussion and Conclusion

Although still ongoing, the findings from this research provide support for the Knowledge Community and Inquiry model as a mechanism for engaging students in collaborative inquiry. The blended use of wiki-based knowledge construction and scripted inquiry activities enabled students to make productive use of their co-constructed community resource. Through co-design, we were able to establish a successful research partnership with teachers, resulting in curriculum materials in which the teachers had a strong sense of ownership. We see this partnership as a positive step towards the "hybrid culture" described by Bereiter (2002), in which researchers and teachers rely on each other when working towards an educational objective.

This research also raises new questions concerning collaborative practices in a wiki environment. For example, despite the relative success of the knowledge construction activity, we still know little about students' individual practices when working in a wiki: Why do some students contribute more than others? Are all wiki transactions of the same educative value? And what are the optimal conditions for encouraging students to work with the content contributed by their peers? These questions open up an important dialogue for further investigation – and characterization – of collaborative knowledge construction and inquiry.

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