

Digital Curriculum in the Classroom: Authority, Control, and Teacher Role

<http://dx.doi.org/10.3991/ijet.v10i6.4825>

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Abstract—With greater online access and greater use of computers and tablets, educational materials are increasingly available digitally, and are soon predicted to become the standard for science classrooms. However, researchers have found that institutionalized structures and cultural factors in schools affect teacher uptake and integration of technology. Findings are sparse that detail the complexities of how teachers actually incorporate technology in their teaching as they negotiate the introduction of a new and potentially disruptive innovation. With respect to a digital curriculum in particular, teachers can be unclear about their role vis-a-vis the curriculum, as the "computer" potentially becomes an alternative source of authority in the classroom, and this can mean that the teacher is no longer in control. This paper reports on the implementation of two units of an innovative environmental science program, *Biocomplexity and the Habitable Planet*, as a digital curriculum. We discuss some of the lessons learned about the mix of challenges, anticipated and unanticipated, that confronted four high school teachers as they implemented the curriculum in their classrooms. We suggest that developers and users of digital curricula pay particular attention to how they envision where the authority for teaching and learning in the classroom should reside.

Index Terms—Authority, digital curriculum; high school science instruction; teacher orchestration

I. INTRODUCTION

Many sectors of the education community have pointed to the promise of technology for improving science education, e.g., [1][2], and call for better technology use [3][4]. The various goals for technology use in the classroom articulated by Kleiman over 10 years ago are still relevant. These include motivating students, broadening curriculum objectives, and offering "education for the 21st century" [5]. Greenhow, Robelia, and Hughes [6] describe a vision for 21st-century competencies that include multimedia work by project-oriented teams, and point out that teachers will be expected to model and facilitate such competencies in various ways.

Educational materials are increasingly available digitally, and digital materials are soon predicted to become the standard for science classrooms [7][3][4]. States such as California, that are required by law to provide textbooks, have recommended that districts consider adopting digital textbooks wherever possible [8]. The Federal Communications Commission and the US Department of Education recently partnered to produce the Digital Textbook Playbook, created by a partnership of educational institutions [9], which is intended to help school districts in the U.S.

navigate the challenges associated with the shift to digital curricula.

Digital classroom materials can range from simple PDF conversions of print materials, to carefully designed web-based curricula with innovative and creative features such as on-demand supports and customized features based on student needs. However, such materials require de-novo design or the substantial redesign of existing print materials.

Teachers play a central role as adapters and implementers of digital learning materials, and some have been in the vanguard of experimentation with new technology. Teachers can effectively facilitate students' use of simulations, digital labs, and educational games to support curricular goals as well as differentiated learning [10], but much remains to be understood about ways that teachers can learn to work with digital tools that have both content and a designed pedagogy of some sort.

This teacher-tool collaboration has been explored from various points of view. For example, researchers have found that the institutionalized structures of schools are often incompatible with the enactment of digital literacies [11]. Drayton, Falk, Stroud, Hobbs, and Hammerman [12] point to the importance of school cultural factors in affecting teacher uptake and integration of technology. Zhao, Pugh, Sheldon, and Byers [13] summarize two main factors that seem to affect the degree of teacher implementation of technology: teachers who "consciously use technology to further their goals" tend to use technology more positively, while technology is difficult to implement if the technological innovation differs widely from prior teacher practice. In fact, some have found that teacher adoption of technology innovations can have the effect of reinforcing established pedagogical practice while, for others, the classroom use of technology has been transformative [14]. Zhao, Pugh, Sheldon, and Byers [13] point to a conspicuous lack of research attention to the complexities of teacher-tool collaboration. They cite studies that "tend to neglect the messy process through which teachers struggle to negotiate a foreign and potentially disruptive innovation into their familiar environment" (p. 483).

In initial experiences with a digital curriculum, teachers can be unclear about their role vis-a-vis the curriculum, as the "computer" potentially becomes an alternative source of authority in the classroom [15][16]. In contrast to a print text, which typically presents pedagogy, e.g., suggested class structures, questioning strategies, etc., in the front matter, to be taken up - or not - by the teacher, a digital curriculum can present process as well as content "inline." Because of this, the digital material can create

more potential "interferences" with or redundancies to the teacher's role, for example, in task-setting, setting tempo, and even sometimes validation of student work.

In addition, the question of authority or voice in the classroom is larger than the issue of "teacher control" [17][18]. The student's understanding of science, and standing in relationship to it, is shaped by whose voices are heard and respected in the classroom, how students are organized to participate in class activities, and what sorts of tasks are typical and valued [19]. Another critical aspect is what sources of content are seen as sanctioned and to be relied upon for use in argumentation [20][21]. Hawkins [22] described the teacher, the student, and the content matter or natural phenomena under investigation in the classroom, as the key voices in classroom discourse. Curriculum and other mediating materials can play a role by reinforcing one of the voices other than the teacher's, or by representing an independent voice to be considered in relation to the rest [19][21]. Therefore, as with so many digital tools, teachers are typically faced with a complex interpretive and practical challenge in understanding the intent of the curriculum, the affordances of the digital environment, and the environment's degree of alignment with his or her pedagogical philosophy and curricular goals. For optimal design of such tools, research on how teachers negotiate this challenge can be an important resource to designers and teachers.

"Orchestration" is increasingly being used as a metaphor to describe learning environments that are enhanced by technology [16][23]. In particular, orchestration involves the complex interplay of contextual factors, teacher pedagogical commitments, student expectations and classroom pressures that influence classroom implementation of technology. Dillenbourg [16] categorizes the continuum of activities that populate classroom life, in the context of a discussion about why technologies are under-exploited in schools. The two categories that concern us here are *core activities* and *emergent activities*. Core activities are predefined by the curriculum itself, but with adaptations defined by the teacher, while emergent activities are contingent, usually upon previous phases of learning [16]. Examples of core activities in the *Biocomplexity* curriculum are readings, investigations, and student assignments that involve analysis of provided data, or answering "making sense" questions. Examples of emergent activities are applying information from readings to make further sense of data, working as a group to draw up and iteratively revise a group project, and discussion to come to consensus about interpretation of graphs.

This exploratory study addresses the issue of teacher authority in the classroom when a digital text is employed for instruction. We explore the challenges a small sample of teachers confront as they negotiate their role vis a vis the authority of the curriculum. Specifically, we address the following research questions:

1. What are teachers' expectations with respect to their role in the classroom when introducing a digital text? How do they see their role, and the role of the text?
2. How do teachers support student collaboration when using a digital text?

II. BACKGROUND

We recently completed an NSF-funded project to transform two units of an innovative high school curriculum,

Biocomplexity and the Habitable Planet,¹ with Universal Design for Learning (UDL) scaffolds and multimedia resources. The *Sprawl* and *Arctic* units were chosen because these two units proved to be the units most frequently chosen for implementation by field test teachers in the print version.

The *Biocomplexity* curriculum engages 11th and 12th grade students in understanding "the complex fabric of relationships between humans and the environment" [24] by incorporating an integrated framework to study the myriad relationships and reciprocal interactions that link human economic and social systems to natural systems of the planet. The curriculum consists of student-centered investigations designed around cases in urban, agricultural, tropical and polar systems that explore complexity at all spatial and temporal scales. It builds on ecology, environmental science, human ecology, geography, economics and anthropology, and helps students understand environmental land and resource use challenges increasingly confronting society. Students are challenged to gather evidence and marshal arguments in support of possible case solutions. This approach is becoming more urgent given the global scientific challenges of human resource use, and is increasingly being deployed, e.g., [25]. The four units are designed to stand alone as replacement units in advanced courses, or to be implemented as a yearlong capstone course.

The pedagogical model that underpins the curriculum is one of problem-based learning in teams, in which students are engaged in solving complex, authentic problems that cross disciplinary boundaries. For example, in addressing the challenge of suburban sprawl, students consider the costs represented by the loss of agricultural land, changes in biodiversity, choices represented by different kinds of suburban design, and social impacts of living in sprawling suburbs. To do so, they draw from cross-disciplinary resources such as agricultural ecology, conservation biology, social sciences, economics and urban design. Each unit frames a problem, provides appropriate resources such as investigations and readings, and creates organizational structures that support student work. This approach supports learning as a process of knowledge creation [26].

To shift the print curriculum into a digital version we used the toolkit developed by CAST² in collaboration with Education Development Center and the University of Michigan. This enabled us to embed Universal Design for Learning (UDL) features [27] such as highlighting, text-to-speech and speech-to-text features, a digital multimedia glossary, and "smart image" features. In addition, based on feedback on the print version from field test classrooms, we developed new multimedia resources to target critical junctures in the curriculum, to further focus on critical new science findings related to the core ideas, and to provide support around implementation of advanced ecological sampling techniques.

The curriculum needed extensive redesign for the online platform. Changes included differentiating the readings, adding extensive content that described each

¹ Currently in press as *Environmental Science and Biocomplexity*, Its About Time publishers.

² CAST is an educational research and development organization that works to expand learning opportunities for all individuals through Universal Design for Learning Principles (www.cast.org).

visual, and expanding the glossary to support UDL features such as an audio option and visuals to support text definitions. In addition, it was necessary to alter the flow and order of readings and activities, based on the assumption that students would work through the materials as encountered sequentially online. So, for example, while the reading and investigation components were presented separately in the print curriculum, they were interwoven in the digital version.

This was done for two reasons, one, so that relevance of each to the other were more closely presented, and two, so that students began each class with active engagement in discussion, or investigation. This meant that the kind of orchestration that a teacher might exercise in this respect became scripted into the text. We, and they, did not anticipate how this design would shape the teachers' assumptions about their role in implementing the curriculum, as we will show.

III. METHODS

Our study reports on qualitative data drawn from eight days of classroom observation in two classrooms, as well as interviews of 4 teachers and students from 2 classrooms, and review of teacher implementation logs.

A. Participants

Four teachers used all or parts of two digitally redesigned units with their students. Names of teachers and students are pseudonyms. Teachers and their students were:

- Mr. Richerson, a teacher at a private Catholic school for boys in Louisiana who used the entire *Sprawl* unit with a class of juniors and seniors, supplemented by many additional components, over the course of a year. He had previously implemented the print version of the unit.
- Ms. Quaid, a public school teacher in Pennsylvania who used the entire *Arctic* unit in a Biology 2 class with high level seniors. She undertook to implement one large section of the unit using the digital version. She had also previously implemented the unit.
- Ms. Carracio, an urban Massachusetts public school teacher who gave her honors Environmental Science class (almost all seniors) the final *Challenge* section of *Sprawl* during their last week of school, serving as a final performance assessment for her yearlong course. Students also completed the *Suburban* design section of the unit, since it covered material essential to the challenge that they had not covered in their course.
- Ms. Tang, an urban Massachusetts public school teacher, who used the *invasive species* section of *Sprawl* with her 9th grade honors class for three days.

Teachers' experience teaching high school environmental science ranged from five years (Ms. Tang to thirty years (Ms Quaid). All four teachers traditionally used prescribed textbooks in their environmental science classrooms. They were all comfortable with the use of technology in the classroom, supplementing textbook readings with multimedia resources, either those supplied with the curriculum or that they provided themselves. All valued field trips and other hands-on experiences, although they

also stressed the challenges of covering the specified material in the time available.

Informed consent was obtained from teachers and students included in the study.

Before implementation, the project provided written teacher instructions in the form of a Teacher Guide. For Mr. Richerson and Ms. Quaid, a two-hour Skype session to review the special UDL features for teachers and students was conducted. We made the assumption that this was sufficient professional development since both teachers had previously implemented print versions of the curriculum. Ms. Carracio, on the other hand, reviewed the digital text on her own first, and then had a two-hour face-to-face orientation with the TERC developers, and a two-hour one-on-one orientation to the UDL features with a CAST developer.

Neither Ms. Carracio nor Ms. Tang had previously implemented the *Biocomplexity* curriculum. Ms. Tang had no orientation, since she planned to use only a small segment of the curriculum in collaboration with two other teachers at her school, and therefore had less control over what she was able to do. She ended up simply using the unit as a resource for students, but not as the primary mode of instruction.

B. Instruments

Teachers and students were asked questions about their experiences with the digital materials, in formal interviews or focus groups as well as more informally during observation visits.

Observation protocol: Observers took informal notes during observation sessions, paying particular attention to teacher moves, level of student engagement, ways in which teacher and students were interacting with the digital environment, and the quality of teacher and student talk.

Teacher interview protocol: Teacher interviews were semi-structured. Teachers were asked what they liked and disliked about the curriculum, what features of the curriculum were helpful, and what their perceptions of implementation were overall.

Student Interview protocol: Semi-structured interviews with a sample of 3 students from one of the classes were conducted towards the end of the teaching sequence. The teacher selected high achieving students who had been most engaged with the curriculum and the materials. Students were asked what they liked and disliked about the curriculum, whether they thought they looked at the world a little differently now as a result of what they had done and learned, as well as what features of the digital environment they found helpful, and the extent to which they had used them.

Implementation log: Teachers noted what section of each lesson was implemented and to what extent.

C. Data collection

All three of the project researchers were involved in data collection. The first two authors are experienced education researchers; the third author is an experienced evaluation researcher who was external evaluator to the project. Of the total of eight days of classroom data collection, Karp observed for 2 days in Mr. Richerson's classroom, and Puttick, Drayton and Karp observed for a total of 6 days in Ms. Carracio's classroom. Karp conducted infor-

mal focus groups with Mr. Richerson's students after observing in his classroom, a final focus group interview of three of Mr. Richerson's students, and an interview of Mr. Richerson. Karp interviewed all four teachers. Puttick conducted a follow-up interview with Ms. Quaid, and Puttick and Drayton a follow-up interview with Ms. Caracio.

D. Data analysis

All interview and observation notes, focus group interview notes, and implementation logs were initially reviewed several times by all three of the project researchers to identify emergent themes [28]. We refined our interpretation and identified additional themes during regular meetings of project researchers. Interpretations were further refined as writing and analysis proceeded; final themes are shown in Table 1. Review of the implementation logs indicated that teachers implemented all components of the materials that they had intended to implement.

TABLE I.
THEMATIC CATEGORIES

Themes	Description
Goal(s) for implementation	Teacher describes goal for student learning, or for classroom outcomes, through implementation of the curriculum
Teacher role	Teacher expresses perception of his or her own role in the classroom
Curriculum role	Teacher statement reveals some aspect of the perceived role (expected or actual) of the curriculum
Student engagement, learning	Teacher describes some aspect of perceived student engagement or learning in the classroom
Instructional strategies	Teacher expresses perception of instructional strategies needed, or instructional strategies deployed
Curricular affordances	Teacher describes some aspect of their perception of the affordances of the curriculum

IV. RESULTS AND DISCUSSION

Integrating technology is not an easy task for teachers who have to cope with increased complexity in preparing lessons and managing the classroom. In doing this, teachers must take into account several features going beyond familiar formats and routines in a "traditional" environment [29], and create learning situations for which the teacher's choice of tools is tactical, strategic and also epistemological [12][30][1]. In addition, teachers must also confront the consequences of their choices with respect to their role and their authority in the classroom.

Teachers interviewed reported that they liked the content of the *Biocomplexity* curriculum and found it to be an excellent source or support for the topics central to their courses. They also agreed that the online format was straightforward and easy to use. However, none of the teachers had any prior experience teaching with digital curriculum materials. They all struggled to understand their role as teacher, as we describe below. The sections below present and discuss results in relation to the two broad areas under which our questions fall, namely, authority, and the nature of science as socially mediated.

A. Role of the teacher in orchestrating activities

A print text is a familiar feature of the classroom. It is an object that typically makes obvious its role as a source of information and questions related to the text. A digital curriculum – or at least the *Biocomplexity* digital curriculum – is more than that. Like a print curriculum, it also incorporates lab instructions, worksheets, and additional resources such as [links to] videos and animations. However, unlike most print curricula, a digital text can constrain the placement of these resources to *specific* places and contexts. It provides explicit guidance to students for when to work together and when to work alone. It also includes a place to post homework, online fields for student responses at prescribed junctures (e.g., "check your thinking" questions for reading comprehension, and "making sense" questions for student writing to support deeper understanding), and features that further support student comprehension of the text (e.g., glossary, highlighting, rich visual support for text comprehension). In addition, the system's power to collect, display, and interact with student work in digital form constitutes an important value for the teacher's work. While a teacher using a print text can (and does) enact these and other features of the digital environment in various ways, the digital system reifies specific ways of conducting this wide range of operations. As a result, the designer of the curriculum presents a default design for the classroom using it (if it is used "with fidelity"). Therefore, as a "voice" in the classroom, the digital text can exert a rather more active and formidable role than a printed text, since it can potentially support much of what the teacher used to be responsible for in orchestrating classroom activities. Tasks familiar to every teacher include making explicit the relationship between learning goals and outcomes, providing verbal prompts for student sense-making in the form of questions or additional information, or engaging students in "warm-up" activities such as brainstorming or overviews at the beginning of class. These are all things that teachers – not the text – ordinarily orchestrate and typically experiment with while exercising discernment during their daily classroom practice [12][31].

The digital curriculum also includes several features designed explicitly as teacher supports. These include a whiteboard to post and project student responses to the whole class, check boxes for students to indicate completion of individual tasks which the teacher can monitor, and the capacity to respond to individual student work in students' digital notebooks. In addition to the novelty of built-in digital supports for the teacher, the *Biocomplexity* curriculum – both print and digital – presents several challenges to teachers in implementation: It is [a] case-based, [b] not basal but upper-level, [c] contains challenging science and a socio-ecological approach new to many teachers, and [d] contains many UDL features that are unfamiliar to teachers and students.

It is therefore perhaps not surprising that all of the teachers struggled to understand their role in relation to this new platform in the face of such complexity. They all needed guidance and time to figure out their role when teaching with the digital materials. At first they expected the materials to largely take the place of the teacher, freeing them to focus only on technology issues. There were online supports and guidance for teachers, which only some of the teachers made use of, and owing to the design

of the digital environment, some had trouble finding all of them.

Furthermore, even in schools with excellent technology infrastructure and support, set-up always required more time that teachers or designers anticipated and there were still problems getting everything to work consistently for all students. A digital curriculum, especially if it is Web-delivered, is a multi-layered environment, and may prevent students and teachers from satisfactory use by dysfunction at any of these layers (servers, Internet provider, in-school hardware or software, condition or number of computers available, and so on). While these difficulties are easy to dismiss as local, accidental factors, technical problems are a persistent and inherent feature of teaching and learning with such complex tools [12].

It is not clear from our data whether the size and length of the curriculum makes a difference or not to teachers' assumptions about their role. There is a considerable difference between drop-in sections of a unit, such as Ms. Carracio used, versus an entire unit, such as Mr. Richerson implemented. However, in both cases, teachers were confronted with an unfamiliar role. As we analyzed their stories, we observed how authority in the classroom shifted over time, in very different ways.

Although Ms. Carracio, an experienced teacher, had not taught *Biocomplexity* nor used an electronic curriculum before, she determined from the beginning that the standards and practices she had set in place before would be the norms of the classroom during the trial. She had a clear picture of what she wanted from the students as a final project. And so, in setting up the task, she played a critical role in defining it. She provided detailed guidance by, for example, reminding students to check off completed work, reminding students that they could see transcripts of audio sections, and suggesting they use the highlighting feature to pick out key ideas in readings.

She was also attracted to the opportunity that the focus on collaboration offered her students. When we first began to discuss the possibility of her piloting the curriculum, she remarked:

I've been looking for a way to get away from more lecturing and do more inquiry.

However, in spite of this, and although she had reviewed all the materials, she had not anticipated the shift in authority and the shift in roles that would transpire in the classroom. After a day or two, she reported the impression that she wasn't doing anything but monitoring their work, saying:

I felt like they didn't need me. I think I have to explore what is my role. There are courses on how to use technology in the classroom. I haven't taken them. I use technology, I use a projector, I have them go online. I now see there's a lot more to it... . What do I do, keep circling like a shark? Is that my role, just an auxiliary? I didn't expect to feel so useless.

At the same time, she valued the way students were working collaboratively together, and commented on the degree to which they were engaging with the task:

They are so self-sufficient. I don't know what to do with myself.

Three days into their work, she had decided that she needed to give them more structure. At the end of the

lesson on day 3, she told one observer that she had figured out what she wanted the students to do, commenting:

Maybe I'll start with a discussion of how it's going tomorrow.

She began class by projecting the table of contents of the unit, and directing them about what pages to read. She talked them through three illustrations of neighborhoods of different designs, drawing their attention to the differences in housing density, spacing of lots, areas of green space, etc. Next she wrote a list of tasks on the board, in the order in which the students needed to engage with the materials. She talked about the optimization table by projecting a sample that she had completed herself, and drawing student attention to how the table is set up to explicitly require a justification for each element of their proposed plan:

It [the table] has a good structure and will guide you so you don't get lost. It might help you realize if something (part of your design) can't be justified, needs to be changed.

Ms. Carracio had realized by this time in implementation that, although earlier she hadn't known "what to do with herself," she needed to exert control of the student experience, and play an active role in, at a minimum, pointing out the activity structure that was inherent in the digital curriculum. She was still in charge, and making pedagogical decisions. She wanted to shape the experience through whole class discussion (both to inform herself as the teacher responsible for their learning, and as a benefit to students), as this was clearly a tool she has relied on before and used to effect.

From this point on, she also provided feedback on the quality of students' work, evaluating their understanding and skills, for example, telling a pair of students that they need to be more specific about what kind of settlement(s) they wanted to include in their plan. When they appeared not to know what she was talking about, she did not give them the answer but instead told them: "*You will understand what I mean after you read it.*"

Ms. Carracio continued to adapt the student experience of the digital curriculum to their (and her) needs, but still vacillated between feeling that she had only an auxiliary role, and playing an active role in shaping the kinds of seeing and expressing that her students did, and the evidence of their learning that would be displayed in the class later [1]. So, for example, students were not sure they would finish in time, and were concerned about the extra reading. Ms. Carracio advised them to adapt, encouraging them to skim it and just use it as a reference. She also encouraged students to draw their plan on paper first, then transfer it into the drawing tool. She was aware of some of the limitations of this tool, as well as the learning curve for students to use the tool well.

On the final day, when students made their presentations, Ms. Carracio was very active. She asked clarifying questions, and asked students to justify their statements and choices in coming up with their final land use plan. She also elaborated on topics she felt had not been emphasized enough, and brought in additional facets that complicated the land use decisions that had to be made.

We should note that students were required to work in pairs because of the lack of computers at Ms. Carracio's school. This was a departure from her more usual practice of having students mostly do individual work except in

labs. As we've already described, she highly valued, and was somewhat surprised by, the result. An experienced and reflective teacher, she confided to a researcher:

It's going pretty well. I was worried about it at first. It's perfect for this time of year.

This time of year was May, towards the end of the school year, and just before final exams, when she least expected her students to be focused and engaged. Like many teachers, she knew that student attention required more active management at this time than at any other time of the year.

Mr. Richerson and Ms. Quaid, both of whom had implemented the *Biocomplexity* curriculum before in the print version, were eager to use the same units in their entirety again in the digital version. However, they both came to the realization that they would have to reevaluate their expectations with regard to the role of the curriculum and the autonomy of the students. In an interview, Ms. Quaid described how she had expected to play a smaller, more supportive teaching role than usual. This is how the interviewer noted Ms. Quaid's description of her experience:

At first, she thought her students would read the material by themselves, work with partners, and teach each other, and she would play a support role only, being more hands-off. She realized she needed to give more guidance, and ended up teaching the same as with hard copy materials, helping them focus, direct them, point out essential questions to answer in reading, explain the reading a little, etc.

Like Ms. Carracio, Ms. Quaid was also a veteran teacher who knew the subject well, and had taught it before. She described a lot of "downsides," with the digital text, but acknowledged that they may be "generational issues." For example, she told us:

The pages have too little information on each one before you have to click, which makes it harder to manage. I'd prefer to see everything together.

This may indeed be a generational issue, since best practices of web design indicate that scrolling should preferably be minimized [32], and we undertook extensive redesign to reduce the amount of text on each page. Ms. Quaid also told us that she writes faster than she types, therefore, she found that giving electronic feedback was frustrating, and much easier and quicker with pencil.

These frustrations finally culminated in Ms. Quaid choosing not to finish the digital section of the unit, but reverting to the hard copy. Upon reflection, she realized she preferred to use technology/digital formats only as a support for print materials. Based on her observations of her students, she concluded that the online format was best suited for strong students who could work independently. She reported that most of her students preferred the print version as well.

Mr. Richerson had also piloted the original print version previously, and he also expressed a strong preference for the paper copy of the book by the end of the year. He initially expected that the curriculum alone would support the students' work, and that students would complete all of the course work during class time. Perhaps because of this expectation, he did not communicate the overall structure of the unit to the students, nor that they were intended to accumulate information and understandings from the

activities along the way to help with their final project. In addition, he was initially confused about the layout of the materials, and did not look at the teacher support materials until we learned about his confusion and drew his attention to them.

His class was an elective, filled with seniors and some juniors who did not expect to work hard. In the past, the course has consisted of extensive field trips, with little or no homework. He was very disappointed with the quality of work and effort put into the class (although he reported that other teachers were also frustrated with the academic achievement of many of these same students). Mr. Richerson came to the conclusion that he had to re-evaluate his teaching with the electronic curriculum, because most of the students had trouble with task management and quality of work when supported only by the curriculum itself.

Monitoring student progress through the curriculum became challenging, especially since the digital environment – at least as construed in this project – did not support students who had poor organizational skills, in spite of the fact that check boxes were provided for students to indicate when they had finished a section so their teacher could quickly track their work. Mr. Richerson found that some students never marked their progress, and others figured out how to falsely indicate completed work. Thus, ensuring quality control of student work and providing feedback were also a challenge.

After a couple of months, Mr. Richerson eventually decided he needed to revert to the way that he had always taught. He thus re-asserted his "authority" as teacher in the classroom, telling a researcher:

What I as teacher will have to do, corral them into – "This is what we are doing with it, this is what you will have to do, develop a case, build a plan, give us your assessment and evaluation of sprawl and your case." ... I'll have to revisit the challenge tomorrow in class. I might even share with them some of the frustrations inherent in the curriculum, putting the challenge first, set the roles out for them...maybe they will say okay, this is what we'll have to do, give them a deadline. [...] [It's] important for the teacher to stress focus and goals, not just turn them loose.

Despite this refocusing, managing the flow of class work continued to be problematic. Mr. Richerson finally ended up continuing to use the digital curriculum, but as a framework within which he interspersed many field trips, PowerPoints, videos, and field observations. As he noted in a final interview:

Here [Louisiana] sprawl and environmental degradation are huge issues - BP, Katrina, flooding, logging, wetlands being filled in to create development instead of preserving. So I tied all that in together. I used the threads of the chapters from the curriculum to bring [these issues] in. They did the lesson and then I would supplement it with stuff pertinent to this area.

It is interesting to speculate how the authority of the digital curriculum might have been sustained, had his students been at an advanced level– the type that he and Ms. Quaid felt would benefit most from the self-paced engagement they had originally expected from students using the digital curriculum. However, it appears that Mr. Richerson plans to continue to use the curriculum in the manner that he ended up developing for himself, since he

liked the way it anchored the material he wanted to cover in his environmental science course. He put it this way:

From my standpoint, the online curriculum was great. I want to continue to use it. I found I could copy everything and make a printed copy. I have the old [print] curriculum, and I plan to use it. Next year I'll have 27 environmental students. [...] [I'll] build my own curriculum. Sprawl curriculum is so rich with all the topics I cover, I will use that as the base platform, to throw in those other things.

In appropriating the curriculum to use as his own, he even re-evaluated the order of the sections. In this way, his “authority” – though very different from the way he originally envisioned it – was reasserted.

It was clear that each teacher at some point had to stop and take stock of how things were going for their students and for themselves. This sort of re-evaluation is typical as teachers try out and get to know any new curriculum, whether or not the content itself is familiar to them already. This typically involves teachers building familiarity with the curriculum contents, extending their content knowledge, understanding the logistics and values of the curriculum, and building pedagogical content knowledge. However, new curricula do not necessarily challenge the teacher’s understanding of their basic role in the classroom, as *Biocomplexity* did.

Developers of digital curricula have a responsibility to make this challenge clear. At a minimum, a discussion of this issue could be placed in the front matter or introduction to the materials, as we have done. Alternatively, since the digital medium presents an obvious just-in-time opportunity, the need for particular types of teacher orchestration could be pointed out at critical junctures in a digital teacher version of the curriculum. However, there is a caveat to this approach. Having to learn and manage the explicit “orchestration technology” can potentially introduce a new complication for the teacher.

B. *Science is socially situated*

The electronic environment was also problematic for teachers with respect to classroom culture. There is an unspoken parallel that persists between an individual laptop or mobile device and a textbook or worksheet. They are not at all equivalent, but the construal of a computer or a piece of software as a strictly individual tool is in tension with the building of class culture among all the individuals in the class. A persistent design question for us was, How do we relate what feels like a very individual-based experience (each student engaging with the curriculum at his or her computer) to our conviction that science learning is best and richest when it is a socially situated experience [33]?

As curriculum developers, we originally designed a large portion of project-based work to be done in small groups or teams. This is a common characteristic of modern science classrooms. For example, according to the recent Horizon Research study [34], high school teachers report that small group work is used at least once a week in 80% of classrooms. The print curriculum had been developed carefully with attention to how the work of each team would inform and complement that of other teams, so that the whole class was engaged in sense-making, grounded in their own team's work on a common challenge. Using the print text, teachers were able to regu-

larly ensure that developing student products were shared across groups as they were tasked with developing and sharing interim reports for discussion by the whole class.

As we transferred the curriculum from print to digital, we tried to ensure that, to the extent possible, the features that supported collaboration were transferred. For example, explicit directions were described for students, such as, “As a group, address the Making Sense questions at the end of the investigation.” However, the digital environment did not include dedicated spaces to support collaborative work as other digital environments have done [35][36]. Because the digital environment was still primarily a research tool for investigating the efficacy of UDL instructional principles, this capacity had not yet been developed at the time we created the digital curriculum. As a result, the curriculum put an additional onus on the teacher to orchestrate student collaboration. Collaboration was thus reliant on his or her pedagogical style and capacity, and required active management to arrange the students’ task to accommodate this goal. This could mean tracking where students were in their process, rearranging them away from computers for discussion, and then having them return to computers to write up their notes.

Sun and Looi [37] describe a digital environment that supported student collaboration, in which the teacher sets up groups of 4 students digitally, each on his or her own computer, which displays the 4 individual workspaces of the students simultaneously, as well as a shared workspace and a chatbox that allows more than one student to draw or edit a joint model at one time. The teacher orchestrates student tasks through an authoring tool, can monitor the work of groups simultaneously, and offer feedback in real time or asynchronously. The authors report promising success in terms of student learning, and state that teachers expressed an “overall positive attitude” (p. 87). However, one wonders about the level of complexity that deployment of the digital tool added to the teachers’ task as she monitors the whole class digitally, responds digitally to their work in real time, and at the same time manages the other activities of the classroom, for example, managing student social interactions, or adapting to contingent events. This issue calls to mind Dillenbourg’s assertion that the “balance of control” of regulation of the classroom system is a key factor in dictating the level of deployment of technology in schools [16]. In short, even when supports for collaboration can be built into a digital tool [37], the issue of orchestration in the classroom is still one of “tensions and contradictions” [23].

As already described, in Ms. Carracio’s classroom, the lack of computers meant that students worked in pairs to complete their work online. Ms. Carracio liked the encouragement for students to work collaboratively, and also appreciated the chance for her students to be more self-sufficient as learners, reporting that:

They collaborated even more than I could have imagined they would. I saw some great cooperative learning going on.

A researcher, observing Ms. Carracio’s students working in pairs wrote in her observation notes:

The students talked a lot (and also talked across teams), and this helped them compare notes, think more deeply, and engage their imaginations in the work more. Altogether better than one-to-one... Class much noisier today. Teacher likes the collaboration that this supports.

Another observer noted:

Motivation and engagement of the students is impressive...I hear several substantive conversations...and debate...

Nevertheless, the intended design of the curriculum, where the work of each team would inform and complement that of the other teams so that the whole class was engaged in sense making grounded in their own team's work on a common challenge, was not realized to any great extent. Teachers did sometimes use the feature that enabled them to anonymously project student answers to a particular question, and two expressed specific appreciation for this ability to highlight high quality work, but did not use this to support whole-class meaning-making and debate, as had happened in the text-only field test classrooms. While sharing of student work and student ideas is certainly a basis for supporting science as socially situated, the (limited) ability of the tool to support student collaboration via sharing artifacts with the class for discussion did not result in that outcome. Instead, on occasions when teachers did use this feature, it functioned in a way to support the teachers' settled practice, and gave them authority to define what the desired student outcomes should be.

Likewise, in the other classrooms, the teacher had to make decisions about how to support the group work, and solve the logistics of sharing products. In Mr. Richerson's classroom, students worked alone at computers, with occasional small group discussions. They only collaborated on tasks associated with the Challenge (not including field work and offline investigations) at the end, when assembling their land use plan in groups. Collaboration to make sense at interim stages, carefully designed, was not realized. In addition, Mr. Richerson's students would have liked a way to share their group plan. Although they could post individual efforts online, they needed to use emails and jump drives to share their emerging group plan so as not to have to duplicate the team plan on each computer. This placed an additional technological burden on the teacher to manage and track.

Providing a digital environment that requires student placement in groups, and providing some tools to support collaboration does not necessarily give the teacher sufficient "authority" to orchestrate social meaning-making. Although the students in one classroom were working in groups, their teacher regimented their tasks with the result that student autonomy in sense making was not authentic. This may have been due to unfamiliarity with how this new tool was supposed to work, and therefore a reasonable reaction to a new curriculum. However, as a design challenge then, digital instructional materials should strive to include careful construction of features that support not only student collaboration, but also a student experience that provides them with the capacity to enact socially situated sense making, and provides teachers with the capacity to orchestrate them. This is particularly important in science.

V. CONCLUSION

Since the teacher sample was very small, and all of the teachers lacked prior experience with digital curriculum implementation, our study has limited capacity for generalization. However, the data we present in this limited exploration of the use of a digital curriculum are sugges-

tive on several points. First, teachers' expectations of where authority for teaching and learning in the classroom would reside presented them with a mix of challenges, anticipated, and unanticipated. They expected at first that the digital curriculum would "teach" the students, and discovered soon after implementation began that this was not the case.

In a teacher-centric classroom, the primary voice of authority is that of the teacher. The teacher may be aided by a text, but if the scientific authority is being questioned, typically the teacher's voice overrides that of the text [38]. In such a classroom, the objective is, of course, for students to learn material determined by the curriculum, mediated by teacher and other resources. Students understand, however, that their task is to satisfy the teacher according to whatever criteria she or he has set.

On the other hand, if the text comes to play a more central role as the voice of authority, students may be empowered to have a dialog with the text, and potentially with the teacher too. While the teacher's role is to help students navigate or interpret the text to make meaning, students can also call upon the text to point out contradictions to what the teacher may say, thus challenging his or her authority, e.g., Tan [39]. In this scenario, dialog can happen, which means that students can engage in some inquiry. The teacher and text are allies, but the fact that they are somewhat independent power centers in the classroom confers more authority on students too.

In a project-oriented classroom, the project and associated resources become additional voices of authority to those already described above [40]. Project-oriented classrooms diversify whose authority – whose voices – count. The teacher becomes a co-inquirer with his or her students, and together they reach out to other authorities.

From the perspective of authority then, *Biocomplexity* was an interesting case. With teachers setting out unsure who was in charge, it was not clear how student sense making would be negotiated. On the one hand, if the teacher plus the curriculum were setting the stage, the teacher could listen, respond, and facilitate active engagement. On the other hand, if the teacher were to cede authority to the computer, students would need to draw on their own resources to make sense and "extract" meaning from the curriculum. Essentially, the expertise of the teacher would be neutralized. The teachers in our study recognized this, and responded in different ways.

Mr. Richerson "transformed" the curriculum into the anchor for what turned out to be a yearlong course. The curriculum provided a story through-line for his class that provided coherence to many of the other topics and activities that he considered important. Most important, since he judged that his students did not have the organizational skills to navigate the digital environment, Mr. Richerson's repurposing of the unit was also important for keeping this particular class of students engaged. Ms. Quaid, on the other hand, finding that her assumption that her role would be peripheral was faulty, made the decision to go back to the print curriculum, essentially taking back control in the classroom. Ms. Carracio did not cede authority because she maintained her standards for the class, but she discovered as she was floating that her students were doing all of the work. She struggled with this unfamiliar role, but in the end she waited until students made their presentations to become more collaborative with the curriculum.

By the end of the experience she had renegotiated her role and asserted equal authority with the curriculum by actively managing classroom discourse when students were presenting their plans.

We suggest, then, that developers of digital curricula – and teachers who use them – pay particular attention to how they envision authority being conferred in the classroom as curricula are enacted. Teachers and students should expect the issue of where authority resides to arise as they shift to teach and learn while relying on digital curricula, and will need help in negotiating it. Our study points to the value of further research on where authority resides as teachers transition more and more to using digital texts. Where does authority reside while teaching with digital curricula? What kinds of supports are needed to help both teachers and students in negotiating it?

Second, we suggest that the use of digital texts, like any innovation in the classroom, will require patience and experimentation on the part of the teacher, and support from the administration as he or she negotiates how to become familiar with the “foreign and potentially disruptive innovation” [13] it entails. As Drayton and colleagues [12] observe, every move to experiment and change practice will require an intellectual and sometimes emotional adjustment by the teachers, as Ms. Carracio clearly expressed in the first couple of days of implementation. Looi and Song [41], likewise, emphasize that orchestration is a critical aspect that designers must take into account. Further, core activities and emergent activities [16] require different preparation and planning by teachers. Adapting core activities in a digital curriculum requires familiarity with the materials' content, the technology, and ways of student engagement required, facilitated, or impeded by the digital environment. Adapting emergent activities requires teacher interventions at both the level of the individual student – knowing about student progress – and at the level of the whole class – orchestrating class discussions. Both ultimately require teacher control. We echo Zhao, Pugh, Sheldon, and Byers [13] in asking for much more attention to be paid to the complexities of teacher-tool collaboration. In what ways does a digital curriculum place additional demands on teachers as they familiarize themselves with this innovation? Does it differ from the implementation of any other classroom innovation? In what ways?

Third, teachers need to review the information provided by developers, and preferably also examine the unit in order to explicitly identify the specified activity structures built in to the curriculum, and check for alignment with their own pedagogical commitments, instructional goals and preferred ways for students to work together in the classroom. Decisions about this question are complicated by the persistence of the “teacher centered classroom” as the fundamental paradigm [12], given the expectations about roles – for students as well as the teacher – that this entails.

Finally, the importance of collaboration in the classroom to support “scientific discourse” has been an important goal of science education reform in the U.S. over the past several decades [42][43]. This, of course, requires students to work in pairs or teams. While work in teams reinforces the traditional use of “lab teams” for practical work, other types of collaborative work, for example, on a team write-up, or, as in *Biocomplexity*, a team response to a land use challenge, require more careful thought and

planning. The use of a digital curriculum can challenge the paradigm of collaboration, thus further complicating the kind of planning the teacher must do. Moreover, it intensifies the importance of clarity about authority for the content, processes, and evaluation of learning in the classroom: Who is doing the learning? Whose questions are being explored? What characterizes good performance or understanding, and whose standards are to be met? These issues, endemic to any classroom in which authority is shared [44], are all the more important with respect to a digitally mediated curriculum. To us, this was the most crucial issue, and, as such, warrants much more attention. How does the teacher foster a view of science as a socially situated activity when students engage with material online, use digital tools to record their work, and receive digital feedback from their teachers?

In summary, we suggest that realizing the full potential of a digital curriculum to support students' capacity to enact socially situated sense-making, and teachers' capacity to orchestrate this, will likely require dedicated design of digital curricula. In addition, it will require more explicit information and professional development about the teaching challenges that we have highlighted here. Finally, more extensive and iterative design research will be necessary in classrooms where such curricula are tested.

ACKNOWLEDGMENT

We thank the teachers who participated in this study for welcoming us into their classrooms. Comments from J. Miller, I. Baker and J. Foster improved the manuscript.

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This work was supported in part by the National Science Foundation (NSF) under Grant 0628171 and 1020089. The NSF is not responsible for any conclusions and opinions expressed by the authors in this work. Manuscript received 22 June 2015. Published as resubmitted by the authors 15 November 2015.