Technology, Pedagogy and Education

ISSN: 1475-939X (Print) 1747-5139 (Online) Journal homepage: https://www.tandfonline.com/loi/rtpe20

Integrating a space for teacher interaction into an educative curriculum: design principles and teachers' use of the iPlan tool

Miray Tekkumru-Kisa & Christian Schunn

To cite this article: Miray Tekkumru-Kisa & Christian Schunn (2019): Integrating a space for teacher interaction into an educative curriculum: design principles and teachers' use of the iPlan tool, Technology, Pedagogy and Education, DOI: 10.1080/1475939X.2019.1595707

To link to this article: https://doi.org/10.1080/1475939X.2019.1595707

Published online: 15 Apr 2019.

TECHNOLOGY, PEDAGOGY AND EDUCATION
https://doi.org/10.1080/1475939X.2019.1595707

Integrating a space for teacher interaction into an educative curriculum: design principles and teachers' use of the iPlan tool

Miray Tekkumru-Kisa [a] and Christian Schunn [b]

[a]School of Teacher Education & Learning Systems Institute, Florida State University, Tallahassee, FL, USA; [b]Department of Psychology & Learning Research and Development Center, University of Pittsburgh, PA, USA

ABSTRACT

Implementation of reform curricula requires teachers to adopt new approaches to teaching. Research has provided promising results about the influence of educative curriculum on teachers' learning and instruction. However, this approach generally focuses on teachers as isolated learners. Using a design-based research approach, the authors developed a web-based tool, *iPlan*, which provides access to educative curriculum materials in an online interactive learning platform. iPlan encourages social interaction among teachers, in particular their modifications and reflections on teaching with the curriculum materials. The authors describe design principles, assessing successful and unsuccessful aspects of the resulting platform through semi-structured interviews with teachers within the context of implementation of a high school biology curriculum. Analysis of the interviews revealed which structures of this online platform were used by the teachers, as well as why and how they were used. The study provides implications for designing educative and online systems for teacher learning.

ARTICLE HISTORY
Received 15 January 2018
Accepted 3 February 2019

KEYWORDS
Educative curriculum; online teacher learning; design-based research; teacher learning; reform curriculum

Science education research and practice in the United States has been challenged by especially ambitious instructional reform policies put into play in 2012 (National Research Council, 2012; NGSS Lead States, 2013). Most prominently, the vision aims to move science teaching away from a focus on many discrete facts covered at a superficial level to a focus on a smaller number of disciplinary core ideas that can be explored in depth (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). Providing opportunities to engage in scientific and engineering practices (e.g. asking questions, arguing from evidence, modelling) as they explain phenomena or solve problems has become more crucial in facilitating students' learning in science classrooms. Undoubtedly, these reform policies require substantial instructional changes for most science teachers (National Academies of Sciences, Engineering, and Medicine [NASEM], 2015). As one tool for change, well-designed reform-based curriculum materials in science can anchor instructional shifts in the classroom (Schneider, Krajcik, & Blumenfeld, 2005). Particularly important are educative curriculum materials – that is, curriculum materials designed with features to support teacher learning (Ball & Cohen, 1996; Davis & Krajcik, 2005).

Educative curriculum materials are often considered an efficient and scalable tool for change (Ball & Cohen, 1996) and have been shown to impact teachers' instructional practices (e.g. Arias, Bismack, Davis, & Palincsar, 2016; Cervetti, Kulikowich, & Bravo, 2015). However, as indicated by Loper, McNeill, and González-Howard (2017), most of the research on educative curriculum materials has focused on text-based supports provided for teachers. Considering that teachers' learning is social and distributed across people and tools (Putnam & Borko, 2000), online learning

CONTACT Miray Tekkumru-Kisa mtekkumrukisa@fsu.edu

environments for teachers will likely provide further support that is needed given the scale of change called for in these ambitious reforms (Moon, Passmore, Reiser, & Michaels 2014; NASEM, 2015). As discussed by Dede, Ketelhut, Whitehouse, Breit, and McCloskey (2009), online learning environments are considered to have more potential for scale in comparison to most face-to-face interactions designed to support teachers' learning.

This article presents a successful implementation case of a science curriculum aligned with the current instructional reforms in the USA and incorporated three novel aspects for student learning as envisioned in these new reforms: (1) the new curriculum provided opportunities for students to make consistent use of the scientific practices (e.g. make predictions, develop and revise models); (2) students were supported to develop a deep understanding of core science ideas (in this case, integrate biology and mathematics ideas in genetic inheritance); and (3) students applied these ideas to solve an engineering problem (i.e. made use of the engineering practices), so students' whole experience in the curriculum was framed as figuring out how to solve an authentic problem. For the effective use of this reform curriculum, the changes required of both students and teachers were large. Teachers were particularly challenged by the integration of biology with mathematics through students' engagement in a wide range of scientific and engineering practices (Cox, Reynolds, Schuchardt, & Schunn, 2016) and developing responsive instructional practices to support students' high-level thinking and sense making (Tekkumru-Kisa, Schunn, Stein, & Reynolds, 2017). Therefore, it is evident that teachers implementing this new curriculum would need support for learning and instructional improvement.

To support teachers' effective implementation of the curriculum and at the same time support their learning, many educative aspects were embedded into the curriculum materials. To further support scaling up these efforts and improving the support structures designed for teachers' learning, the educative curriculum materials were transitioned to an online platform, called *iPlan*, which creates a web-based community of learners among teachers implementing the reform-based curriculum materials. Follow-up studies with teachers using iPlan showed gains in their students' learning. Specifically, in one condition that involved *no* face-to-face professional development for the teachers (i.e. teachers only having access to the online iPlan tool), students showed large gains in understanding of biology content relative to traditional instruction (Schuchardt, Tekkumru-Kisa, Schunn, Stein, & Reynolds, 2017). This result, found in struggling urban public school classrooms, is particularly promising for the large-scale reform agenda. It provides evidence for the success of the iPlan tool and motivates inquiry into its use by the teachers, which is the focus of the current study.

Purpose of the study

Our goal in this study was to describe specific design features of iPlan and identify the ones that were (or were not) taken up by teachers with the reasons for the uptake. Teachers' decisions for accessing certain educative features of curriculum are important given the goal of maximising the effectiveness of educative curriculum materials (Loper et al., 2017). Thus, the first research question that guided our investigation was: (1) What are the features of iPlan that were (or were not) taken up by teachers and why? The design of the iPlan tool was informed by theory and so there were structures which were intentionally embedded in iPlan for specific purposes. Thus, to systematically examine the features taken up by teachers, we focused on the specific features of iPlan that were designed to address particular problems of practice associated with implementing reform-based curricula in science classrooms at scale. In particular, we examined the ways in which features of the iPlan tool supported: (i) teachers' understanding of the key foundations of the curriculum designed to support students' learning, and (ii) teachers' interacting and collaborating with each other for successful implementation of an innovative curriculum in science. Therefore, the second research question was: How did teachers use iPlan features which were designed for (i) the transparency of the intent of the materials for students' learning and (ii) facilitating online communities of practice?

Theoretical framework

Educative curriculum

Curricula can have a direct effect on what teachers do at scale. However, curriculum materials need to be developed by placing teachers' learning at the centre of these development efforts (Ball & Cohen, 1996). This consideration is the heart of the educative curriculum materials, which are intended to provide support for teacher learning (Davis, Palincsar, Smith, Arias, & Kademian, 2017).

In our project, we draw on the situative perspective on cognition and learning (Greeno, 1997; Greeno, Collins, & Resnick, 1996) to design for and examine teacher learning. There are several conceptual themes that are central to this perspective including that cognition is (i) situated in particular physical and social contexts, (ii) social in nature, and (iii) distributed across people and tools (Putnam & Borko, 2000). As discussed by Fishman, Davis, and Chan (2014), educative curriculum materials situate teacher learning within their instructional practices. Moreover, social supports for teachers are important for facilitating their learning and can aid them in constructing, distributing and sharing expertise (Fishman et al., 2014).

One consideration in the design of educative curriculum materials is how and what teachers read, and where they focus (Beyer, Delgado, Davis, & Krajcik, 2009; Remillard & Bryans, 2004). This is particularly important considering the recent research findings which have shown positive influence of educative curriculum materials on teachers' instructional practices (e.g. Arias et al., 2016; Cervetti et al., 2015) and student learning (e.g. Arias, Smith, Davis, Marino, & Palincsar, 2017; Schuchardt et al., 2017). It has long been understood that educative curriculum materials can be more effective when they are used in conjunction with other forms of support for teachers (Davis & Krajcik, 2005). For example, Forbes and Davis (2007) recommended the formation of materials-based teacher communities. Davis, Smithey, and Petish (2004) discussed principles underlying one such design for new elementary science teachers. In a different study, Fishman and colleagues (2013) examined the effectiveness of online learning communities structured around a specific curriculum for teachers' and students' learning. These communities of practice are created as a supportive group of professionals with common goals and interests that learn together (Wenger, 1998; Wenger, McDermott, & Snyder, 2002). Given the potential of online learning communities for creating rich opportunities for teachers' learning that are scalable and accessible to large numbers of teachers (NASEM, 2015), we brought together educative curriculum materials and online learning environments in our design of the iPlan tool to facilitate science teachers' learning.

Online learning communities

The term 'community of practice' is defined as 'a group of people who interact, learn together, build relationships, and in the process, develop a sense of belonging and mutual commitment' (Wenger et al., 2002, p. 34). In these communities, the members (a) are mutually engaged in an activity, (b) are held together by a joint enterprise, and (c) have a shared repertoire of customs for practice (Bannister, 2015; Wenger, 1998). Therefore, considering that knowledge is co-constructed and distributed across members of a community, a communities of practice framing is consistent with the situated theories of learning, where learning is viewed as a property enacted by individuals over time in shared practices and in interaction with each other rather than a property of individuals and representations in their heads (Bannister, 2015; Hoadley, 2012).

Technology has affordances that allow fostering communities of practice because technology can provide a platform to store and control information in a variety of formats, it can scaffold process and shift the user's social context by providing an opportunity for interactions across distance, location and time. Online learning communities are groups of people that gather in an online space to learn together (Frumin et al., 2018; Hoadley, 2012). Many online learning communities are considered as communities of practice (Wenger et al., 2002). Researchers have highlighted how online environments can enable more control to the learners (Song & Hill, 2007), promote interaction among the teachers (Pawan, Paulus, Yalcin, & Chang, 2003) and allow teachers to communicate across time and space (Dias, 1999). In a recent literature review, Macià and García (2016) identified several practices identified by authors as developed in the online communities and networks that they studied, including community members asking questions to each other for help and sharing teaching materials and resources.

In this view, learning is conceptualised as change in participation in a community of practice. Learners enter a community and begin to participate in practices in tangential ways and gradually, they take up more and more of its central practices (Bannister, 2015; Hoadley, 2012; Wenger, 1998). While the current study did not focus on the change in participation, it was the overarching goal in the design of the iPlan tool. We, as tool designers, used these theories to develop a platform for community of practice, which is constituted of a group of science teachers implementing our curriculum materials. According to Hoadley (2012), typically technology's role is investigated in supporting community (i.e. communication) rather than the practice. Through an analogy, he clarified this distinction as:

> an online discussion board might be used to support hobbyist quilters worldwide. In that case the technology is supporting the communication among quilters, but presumably does not support the quilting itself. On the other hand, if the quilters used software that helped them lay out a quilt design in advance, that would be an example of technology supporting the practice. (Hoadley, 2012, p. 295)

Considering this analogy within our study context, the currently studied tool was designed to support both the communication and the practice. There are different ways in which technology can support either the formation or the continuation of a community of practice in which intended learning takes place. These include linking others with similar practices; providing access to shared repositories (i.e. information used by the community in its practices); supporting conversation within a community by providing tools for discussing with others; and providing awareness of the context of information resources (Hoadley, 2012).

All in all, technology has affordances to foster community of practice. These affordances can enable supporting key aspects of functioning of a community of practice, as stated by Hoadley (2012), including connections, conversations, content and information context. By examining specific design features of the currently studied tool that provide access to educative curriculum materials within a collaborative online learning environment for teachers, this study reveals which aspects of this support system for teacher learning were taken up by teachers and why. These findings can contribute to designing innovations for supporting online communities of practice and provide implications for how to better support teachers during the enactment of innovative and reform-based curriculum materials.

Methods

Context

This study, which focuses primarily on the design and use of the iPlan tool, was situated within a larger project focused on the design of STEM units that aimed to teach rigorous mathematics tied to big ideas in biology in high school science classrooms. These units were four- to five-week-long replacement units aligned with the vision of the recent instructional reforms in the United States. They have the potential to engage students in scientific and engineering practices and disciplinary ideas as students are trying to solve design problems. Since they are developed as replacement units, teachers would implement these units instead of their typical way of teaching the focal content covered in the units. Here, we focus on the implementation of one of these units across two groups of biology teachers implementing in two consecutive waves with two slightly different versions of iPlan.

The four-week-long genetics unit, which we focused on in this study, was framed within a large design challenge for students to help an imaginary local zoo to develop a plan to breed rare geckos. Figure 1 provides a graphical representation of the genetics unit – the figure was also integrated into iPlan for teachers' access – depicting what students would learn in each task and how what they would learn is connected with the next task and the larger design challenge.

The unit's tasks were designed to enable students to learn how genetic information is inherited (i.e. inheritance of genotypes; Figure 1 lower left) and expressed (i.e. presentation as phenotypes; Figure 1 upper right). The new US science standards' emphasis on greater depth, connections to mathematics, and engagement in scientific and engineering practices were all incorporated into the design of the unit. The curriculum also embedded reform-based instructional approaches and strategies of group work, coordination of multiple representations, eliciting and using student ideas, using rigorous instructional tasks, and productive whole-class discussion. Thus, the unit differs from typical curriculum materials in inheritance in many ways; this topic, usually conceived of as Mendelian genetics, typically involves memorising simple scripts like completing a Punnett Square (i.e. no conceptual connections to mathematics, memorisation of key genetics terms and rules presented in the textbook, lectures and worksheets rather than learning through engagement in the scientific practices, no inclusion of engineering approach/practices). Therefore, the unit creates many opportunities for deeper student learning, and thus the strong documented student learning gains from this unit (Schuchardt & Schunn, 2016) might not be surprising.

The unit also requires major changes in teaching relative to typical ways of teaching this content and high school biology more generally. For example, according to the results of the 2012 National Survey of Science Education, only 18% of high school classes require students to supply evidence in support of claims and only 8% of them have students represent and/or analyse data using tables,

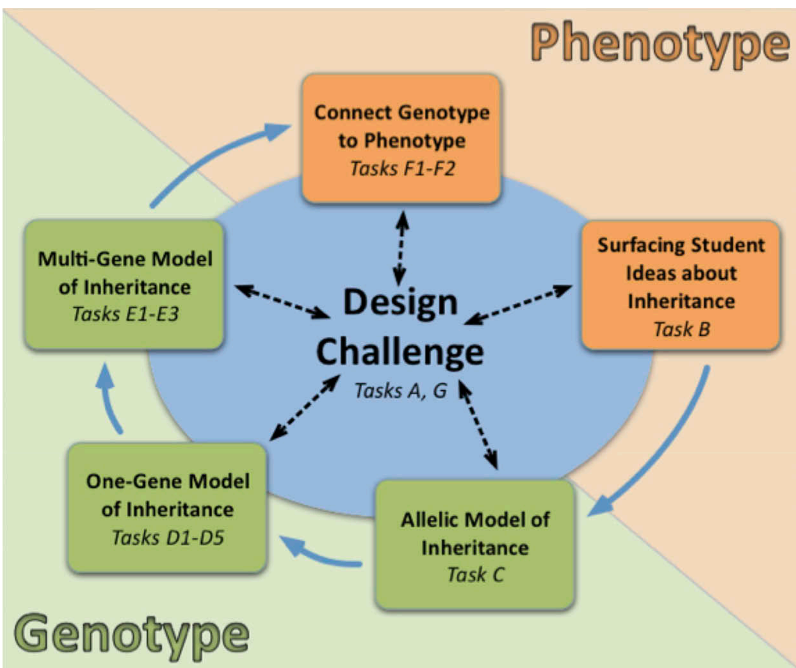


Figure 1. Conceptual arc of the genetics unit.

charts or graphs in all or almost all science lessons (Banilower et al., 2013). However, teaching the genetics unit requires frequently engaging students in these kinds of activities.

Further, the unit was implemented in widely different contexts, from predominately high-need schools with many students at risk for failing science and mathematics coursework to well-supported schools with many students on track for completing advanced coursework in mathematics and science by the end of high school. Therefore, it was likely that each teacher would need to customise the curriculum to the unique needs of their students. These are inherently the primary challenges of implementing ambitious reform curricula at scale (i.e. large changes relative to prior teaching and large customisation to local needs). The educative curriculum materials had many features designed to support these two challenges. The iPlan tool extended these features to support teachers' implementation and appropriation of reform-based approaches in science classrooms.

Study design and participants

The design and study of the iPlan tool was grounded in a design-based research approach that aims to study teacher learning through systematic design of supporting tools and environments for teachers (The Design-Based Research Collective, 2003). As Cobb, Confrey, DiSessa, Lehrer, and Schauble (2003) stated: 'Design studies are typically test-beds for innovation. The intent is to investigate the possibilities for educational improvement by bringing about new forms of learning in order to study them' (p. 10). Following this approach, to bring about new forms of teacher learning, iPlan integrated online interactive features with static educative curriculum materials and was designed through a rapid prototyping process to support teacher learning. Throughout this process, both authors of this article were the primary developers of iPlan and played an active role in its design and systematic investigation.

The initial prototypes of the iPlan tool involved the larger curriculum project team working closely with an educational software design group with prior experience in developing educative curriculum materials. This involved specification of theory-informed features of iPlan informed by situative theories on learning that we discussed above and building them into an online platform to foster a community of practice among the teachers using the curriculum materials that we developed. Once we developed a usable prototype version of iPlan, a group of biology teachers used and provided feedback on it. The iPlan prototype was then revised based on this input of the teachers, the larger curriculum project team and the educational software design group.

We then conducted a study to understand the functionalities within the full version of iPlan. In the first round, three high school biology teachers voluntarily participated in the study as part of implementing the genetics unit with the support of iPlan. Through interviews at the end of their implementation, teachers provided insights into their use of iPlan, its affordances and challenges. After some minor revisions, iPlan was used again the following semester this time by 10 teachers during their implementation of the same curriculum. Again, after implementation, teachers were interviewed regarding their use and perceptions of the system. In this article, we focus on the data from these two rounds of data collection about teachers' use of almost similar versions of the iPlan tool and also articulate the design features of iPlan in connection with the patterns in teachers' use. This analytic approach evaluates whether the features of iPlan that were designed to address certain problems of practice were in fact taken up by the teachers as intended, testing the underlying theory of action. It provides a worked example for designers and researchers of educative curricula, unpacking the details in a theoretical way of an overall tool that was successful for producing strong learning outcomes for students in the era of ambitious instructional reforms in science education in the United States (Schuchardt et al., 2017).

Combining across two groups, the participating teachers taught across a broad range of grade levels with students that differ in their achievement levels and socio-economic status (e.g. from classrooms with almost all students being from race and/or ethnicities traditionally under-represented in science and being eligible for free/reduced lunch, to classrooms in which less than 5% of students were eligible for free/reduced lunch). Table 1 provides details about the teachers and their focal classrooms which were used for the data collection purposes.

iPlan: educative and interactive learning platform for teachers

As discussed earlier, the iPlan tool was designed to incorporate the affordances of educative curriculum materials and online learning environments for teachers' learning. So, it was designed to support interactions among the teachers as well as serve as a resource that provides access to the curriculum materials with educative features. Regarding the educative nature of the curriculum materials embedded in iPlan, a representative set of the genetics curriculum materials were analysed for educative aspects using the criteria for educative quality by Beyer and colleagues (2009). These analyses revealed that curriculum materials address all three domains of knowledge in Beyer et al.'s criteria: Pedagogical Content Knowledge (PCK) for science topics, PCK for scientific inquiry, and teachers' subject matter knowledge (Schuchardt et al., 2017). These analyses provided justification for the claims about the educative nature of these materials. In what follows, we unpack the key features of iPlan in greater depth to illustrate how it was designed to foster a learning-oriented community of practice.

Macro view and micro view of tasks in iPlan

Each task in the curriculum has a macro and micro view in iPlan. The macro view (Figure 2) provides an overview of the task. This feature of the iPlan tool is consistent with one of the techniques used to foster how technology can support formation of a community of practice (i.e. providing awareness of the context of information resources). Providing context of the information available to the teachers in iPlan, the macro view includes a verbal task description, and helps to situate the task within the larger curriculum via the unit diagram presented in Figure 1 with the rest of the tasks in grey and two sections called 'Why this task now' and 'Moving on from here'. It is considered as the 'skeleton' of the task since the macro view provides the necessary information that can help the teacher develop an overall idea about the focus of the task and where it is located within the conceptual arc of the unit. The macro view also shows which physical resources are needed for implementation to assist with physical preparation work. To support conceptual understanding of the overall task goals, finally, it also lists the specific content goals, and relevant scientific and engineering practices.

Table 1. Information about the participants.

Teacher (pseudonym)	Years of experience teaching	Classroom type & grade level	Achievement level[a]	School type	% Free or reduced lunch[b]
Amy	11+ years	*Not available*	*Not available*	Public	25–50
Julia	11+ years	*Not available*	*Not available*	Private	<25
Sara	11+ years	*Not available*	*Not available*	Private	25–50
Grace	11+ years	AP Bio, 12	Mix of levels	Public	25–50
Emily	11+ years	General Bio, 9	Mostly low	Public	> 75
Andrew	3–5 years	College Prep, 10	Mostly high	Public	> 75
Jacob	11+ years	Honors Bio, 9	Mostly high	Public	25–50
Maria	11+ years	Honors Bio, 9	Mostly high	Public	< 25
Zoey	< 1 year	Honors Bio, 9	Mostly average	Public	< 75
David	11+ years	General Bio, 9	Mostly high	Public	< 75
Nathan	11+ years	General Bio, 9	Mostly low	Public	< 75
Allison	11+ years	Honors Bio, 9	Mix of levels	Public	< 75
Caleb	11+ years	General Bio, 10	Mostly average	Public	25–50

[a] Reported by the teacher by selecting one of the following: (i) mostly low achievers, (ii) mostly average achievers, (iii) mostly high achievers, and (iv) a mixture of levels.
[b] School-level data.

Select Unit / Task C: Gecko Breeding Results (Genotype)

Task Overview Task Segment

TASK C
2 Class periods
6 Discussions

Gecko Breeding Results (Genotype)

Task Description

Students begin to explore inheritance at the genotype level by examining two contrasting sets of PCR results.

Resources

C.1: PCR Data

https://sites.google.com/site/geckozoomvideo/resource

http://prezi.com/z2jcv8i6vqpv/?utm_campaign=share&utm_medium=copy&rc=ex0share

Task C Worksheet p1-2.pdf

C.2: Develop Rules of Inheritance

Task C Worksheet p3.pdf

C.3: Summarize Inheritance Rules in Scientific Terms

Task C Worksheet p4.pdf

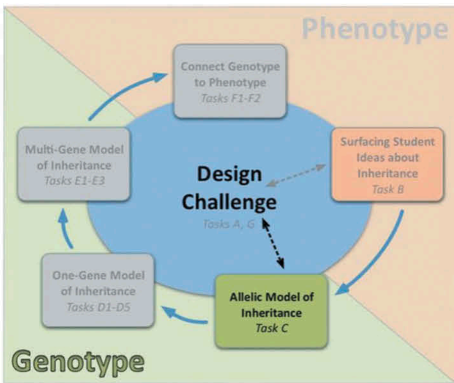
C.4: Connection to Design Challenge

Task C Worksheet p5.pdf

Breeding Design Worksheet.pdf

Quiz 1- after Task C.pdf

Situate this Task into the unit



Why this Task now?

The PCR results enable students to further explore the question from Task B, "How can two similar looking parents have different kinds of offspring?" This task challenges the novice idea that offspring may differ from parents because of chance and builds the foundation for the inheritance model by demonstrating that there are rules governing the way genes are inherited. Students derive the rules of inheritance by identifying patterns in the PCR data and generating rules to describe those patterns.

Content Goal

Biology

- The basic allelic rules of inheritance include the following:
  - Each organism has two versions (alleles) of each gene.
  - One version of each gene comes from the male parent and one comes from the female parent.
  - Offspring can only get what the parents have to give.
- Scientists use specific terminology to communicate about inheritance (e.g., alleles, genes, chromosomes, DNA).
- There are different levels within an organism.
- PCR data represents information about an organism at the DNA level.

Practice

NGSS Science Practice 4: Analyzing and Interpreting Data

"A major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence." (NGSS, 2013)

Students will analyze and interpret data by
- observing PCR results of two different gecko matings,
- comparing and contrasting the results to make sense of the two matings, and
- interpreting the PCR data to derive rules of inheritance.

Common Core Mathematical Practice 7: Look for and Make Use of Structure

"Mathematically proficient students look closely to discern a pattern or structure."

In developing their inheritance rules, students will:
- recognize that there is a predictable pattern in the data, and
- generate rules to describe the pattern.

Moving on from here

In Task C, students derive the inheritance rules by describing the inheritance patterns they see in the PCR data. They can now refine their ideas about inheritance to include a reliable description for what offspring will inherit from parents (one allele from each parent and only what the parents can give) and what genetic information each organism should have (two alleles). Students can also refine their initial breeding designs to emphasize gecko genes as well as gecko traits. Three questions relevant to their design challenge work emerge:
- How do the inheritance rules connect to the biological mechanism of gecko offspring generation?
- How can we predict what offspring a particular set of gecko parents might produce?
- How are gecko appearances connected to gecko genotypes?

Figure 2. Macro view of the tasks in iPlan: components of the macro view as presented in this figure: Task description; Resources; Situate this task into the unit; Why this task now; Content goals, biology and mathematics; Practices, scientific and engineering practices and/or mathematical practices; Moving on from here.

The micro view (see Figure 3) zooms in on the details of task implementation in the classroom. Therefore, it can be said that the micro view can serve as shared repositories (i.e. information used by the community in its practices) that teachers can access to implement curriculum materials, which is another technique to foster community of practice within an online platform. The micro view of the task scaffolds teachers in enacting the task by providing: (1) brief reminders of the purposes/instructional goals; (2) tips for effective implementation; (3) possible students' ideas that may come up during the implementation of the task; and (4) instructional practices that they may want to adopt while teaching. Thus, the micro view includes many pragmatic details, such as amount of time, class grouping (i.e. whole class, small group or individual work) and even particular questions that could be asked of students. But the overall learning goals and functionality of particular task components were always made salient. Cut-out images from student materials with short attention 'call-outs' and strict word-count budgets were given to each component to promote teachers reading the materials without being discouraged with the text length and also to ensure that teachers could quickly refer to the materials during instruction if needed.

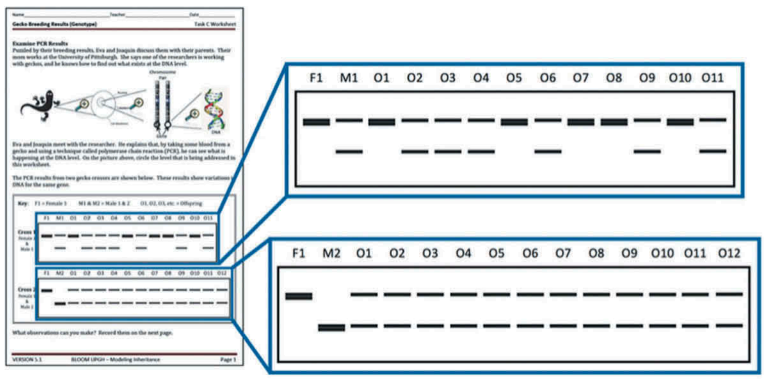
Four different icons were created for the micro view to highlight especially critical information in consistent ways across the larger set of materials. As illustrated in Figure 4, these are important, target, revisit and information icons. The *target icon* was designed to support teachers' thinking about how deeply students should progress conceptually by a certain point of a given task; initial implementations of the unit had shown that teachers often struggled in deciding how much conceptual progress on a big idea had to be made before going on to the next phase. The *important icon* was created to give teachers access to the developer's rationale for suggested teacher or student actions that are important for effective implementation. Important science ideas to revisit in later portions of the unit were presented with the *revisit icon*. Lastly, any supplemental information that teachers may or may not be familiar with but can find useful was presented with the *information icon*. In sum, the micro view was designed to provide suggestions and guidance for effective enactments, with purposes made salient to the teachers to support productive modifications in tasks during their enactment across different classroom contexts.

Interactive features of iPlan

There are also other ways in which technology can support either the formation or the continuation of a community of practice that were integrated into the design of the iPlan tool. These include linking others with similar practices and supporting conversation within a community by providing tools for discussing with others. The discussion space and the implementation notes in the iPlan tool were designed to serve these functions to foster communication among members of the community.

Two high-level problems of practice provided a starting point for our thinking about a system of support for teachers through iPlan, which then led to a set of design solutions embedded into the design. In other words, many features of iPlan were developed to address these anticipated problems of practice that teachers may experience. In what follows, we describe how we attempted to address these problems of practice in the design of iPlan.

Transparency of the designers' thinking. Teachers often modify curricular materials to provide certain learning experiences for their own students in their own contexts (Beyer & Davis, 2012; Brown & Edelson, 2003; Remillard, 2005). How can we help teachers see the intent of curriculum designers so that the modifications made for each classroom's unique context can maintain the rigour intended for students' learning? Prior research on educative curriculum materials emphasised providing rationales for teachers about why particular instructional approaches are pedagogically and scientifically appropriate (Ball & Cohen, 1996; Beyer et al., 2009; Davis & Krajcik, 2005). We believe that it is important to engage teachers in the ideas underlying curriculum designers' decisions and suggestions. This can help teachers to understand how and why to implement the curriculum in certain ways and be mindful of these reasons while adapting the materials into their own teaching context. Table 2 provides structures built into iPlan to support the transparency of the curriculum designer's intent for students' learning in the design of the materials.



Observations	Inferences
All the offspring in cross 2 have the same PCR.	All the offspring in cross 2 look like a blend of the two parents.
In cross 1, some offspring PCRs match the mom's and some match the dad's. In cross 2, none of the offspring PCRs match either parent.	In cross 2, offspring 1, 5, 7, 8, and 10 are boys because their PCRs look like the dad. The others are girls. In cross 2, all the offspring are girls.

Guiding Students to Consensus: Whole Class [10 min]

Purpose: To enable students to agree on a list of PCR observations that they will use to develop rules of inheritance in Segment C.2.

- Teacher asks students for observations.
- Class decides whether each contribution is an observation or inference.
- Teacher records the observations on chart paper for use in generating the rules of inheritance.

Monitoring Student Thinking: Small Groups [10 min]

Purpose: To use data to refine ideas about inheritance.

- Teacher hands out page 2 of Task B Worksheet.
- Student groups examine mating results and write responses to worksheet questions.
- Teacher gets ready for whole-class discussion by monitoring how students explain the mating results and noting unwarranted assumptions students make about the data. For example, students may claim that, in the first mating, half the offspring are normal and half are blizzard. There is no evidence in the pictures to indicate quantity.

Important

Monitoring for ideas during group work can help you structure the class discussion to maximize student-to-student interaction. For example, try to identify groups with contrasting wrong ideas (see examples below). During the discussion, invite those groups to share and encourage the class to ask questions and offer feedback.

Sample Student Responses	Category of Student Idea
"All the normal offspring are girls and the boys are rare because they are blizzards."	Offspring will look like the parent of the same gender.
"In the second cross, the blizzard was worn out. The normal Female 2's genes became more dominant."	A parent's ability to transfer features or the strength of the features themselves are weakened with repeated matings.

Guiding Students to Consensus: Whole Class [20 min]

Purpose: To reach a consensus that there must be hidden factors within the parents that account for the mating results.

- Teacher invites groups to share their answers.
- Students ask questions and decide whether they agree or disagree with each group's interpretation or explanation of the data.
- Teacher charts student ideas about the mating results and, as necessary, guides students to focus on the data and whether or not it supports their ideas.
- Students compare charted ideas and develop consensus on how to explain the data.

Target

Students should recognize the following:

1. Parents that look the same do not always produce the same offspring.
2. Offspring appearance cannot always be predicted based only on parental appearances.
3. There must be hidden factors within the parents that determine what kinds of offspring they produce.

Figure 3. Micro view of tasks in iPlan. Description of the components of the micro view presented in this figure: Example responses addressing the question in the task; Suggestions for teacher and student actions for certain parts of a task tied to purpose driving these suggested actions; Important icon that highlights why and how teachers are recommended to use certain practices; Sample student ideas and possible interpretations; Target icon that highlights the conceptual ideas that students should start driving.

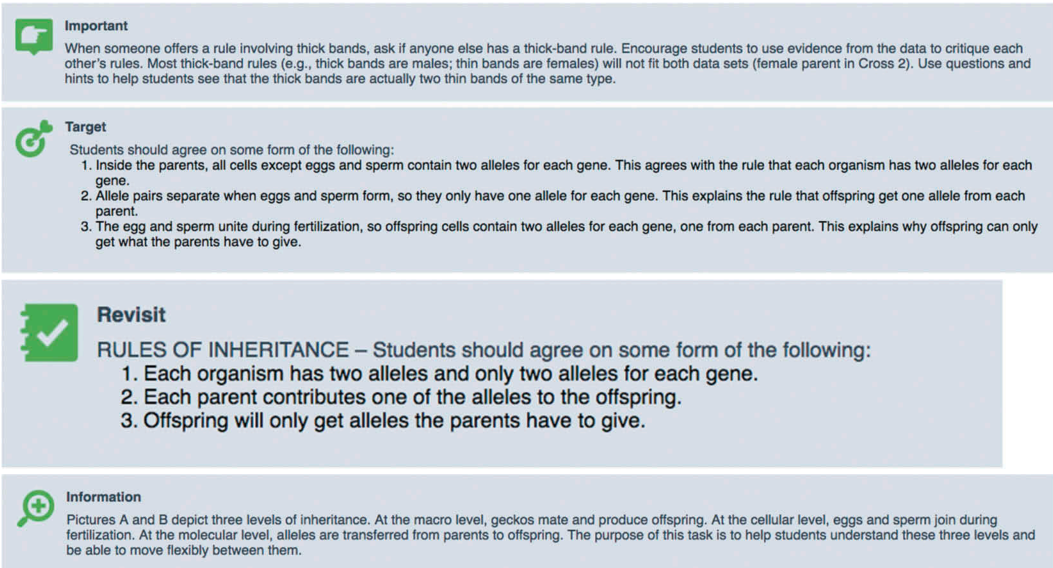


Figure 4. Examples of four different icons presented in the micro views of tasks.

Although perhaps more convenient for reprinting student materials, these features were relatively similar to what was included in the print version of teacher materials. iPlan also had a number of features that address the second problem of practice that we will discuss below in more detail and were more unique to web-based teacher materials that were meant to support teachers' sharing and learning with other teachers.

Building a community of practice. Reform curriculum materials like the one that we developed can undoubtedly be used by teachers in different contexts and settings. As a teacher is working alone, (re)designing or implementing the curriculum materials, they develop new understandings about students' learning and ways to support them; they also begin to adopt new instructional

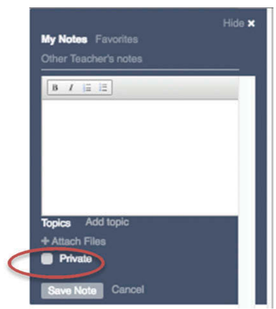
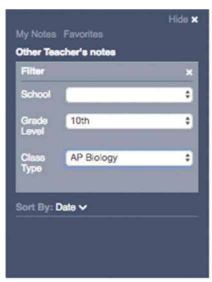
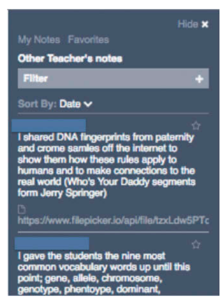
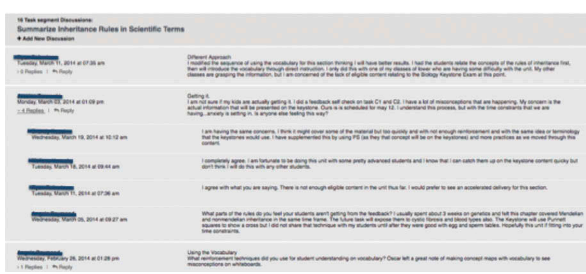
Table 2. iPlan features for the transparency of the design thinking.

Structures and Functionalities Embedded in iPlan	Examples
Important icon in the micro view presents why teachers are recommended to implement certain things in certain ways. These include certain teaching practices that they are recommended to adopt or the importance of engaging students in the scientific practices.	*When someone offers a rule involving thick bands, ask if anyone else has a thick band rule. Encourage students to use evidence from the data to critique each other's rules. Most thick band rules (e.g., thick bands are males; thin bands are females) will not fit both data sets (female parent in cross 2). Use questions and hints to help students see that the thick bands are actually two thin bands of the same type.*
Purpose statements in the micro view present the goal for each sequential event during the enactment of the task to clarify what different parts of the task aim to accomplish.	*Purpose: To help students understand that, to learn about hidden factors, they need to explore inheritance at the gene/DNA level.*
Why this task now in the macro view provides a rationale for situating the current task within the conceptual arc of the unit. Rationale involves explanations about the conceptual ideas from previous task upon which more conceptual ideas will be built.	*The PCR results enable students to further explore the question from Task B, 'How can two similar looking parents have different kinds of offspring?' This task challenges the novice idea that offspring may differ from parents because of chance and builds the foundation for the inheritance model by demonstrating that there are rules governing the way genes are inherited. Students derive the rules of inheritance by identifying patterns in the PCR data and generating rules to describe those patterns.*

practices that can facilitate effective implementation of reform curricula. However, teachers implementing (or planning to implement) a shared set of curriculum materials across schools, districts or states would undoubtedly have a lot to learn from one another. How can distributed expertise be leveraged to share and support innovations? Online learning environments offer one platform for teachers to share successes, as well as co-construct and transfer learning (Zygouris-Coe & Swan, 2010). iPlan works by creating a web-based community of users by giving implementing teachers access to peer resources. The web-based community extends across space (geographical boundaries) and time (teachers can access discussions and implementation notes from others even if they are not implementing at exactly the same time). Table 3 provides features built into iPlan to support building an online learning community among teachers.

As presented in Table 3, these features were built into iPlan both to locate expertise and knowledge building in the participating teachers with an encouragement to share and to support learning interactions between the teachers for knowledge building.

Table 3. iPlan features related to building a learning community.

Design rationales	Structures and functionalities embedded in iPlan	
Locating expertise and knowledge building in the participating teachers with an encouragement to share	Implementation notes: iPlan provides space for teachers to take notes about the lesson implementation (e.g. lesson planning notes, reflection, modifications, reminders etc.). Teachers can make their implementation notes available for other teachers' access by unclicking the 'private' at the bottom of their notes.	
Supporting learning interactions for knowledge building	Teachers can access to other teachers' implementation notes and search for implementation notes of teachers teaching in classrooms similar to their own contexts.	 
	iPlan allows dialogue with other teachers and developers within discussion sections.	

Data collection and analysis

Interviews with the teachers at the end of their implementation of the genetics curriculum constituted the main data source for this study. In both rounds of data collection, we used a similar interview protocol, although with additional questions in the second round of data collection, and so combined them in our analysis. Questions targeted the features of iPlan and the ways in which they supported teachers' implementation of the curriculum. For example, one of the questions was: Were there particular sections of the iPlan tool that helped you to understand not only what we wanted you to do but also the reason for why we recommended you to do certain things? In another question, which was more about the interactive aspects of iPlan, we asked: As you know in the discussion space, teachers can post their questions and comments and have discussion with other teachers as well as curriculum developers. What kind of things did you generally post? Did you read other teachers' comments? Why? Was it helpful? In what ways? These semi-structured interviews were conducted by three different members of the research team. Interviews were 40 minutes to 75 minutes in duration and video-recorded for the data analysis purposes. We also conducted observations in the classrooms of all the teachers, read many of the contents of their posts and contributed materials. A systematic analysis of those data is beyond the scope of the current study, but they were generally consistent with the interview responses. As mentioned earlier, both authors of this article were the primary designers of iPlan and played an active role in its systematic investigation. Thus, they spent a significant amount of time speaking with a range of people that interacted with iPlan, observing and tracking teachers' interaction with the tool to fix technical as well as substantial issues related to its use. This enabled them to become oriented to this phenomenon of interest and also rise above their preconceptions about its functionality. All of these play a role contributing to the credibility of the findings (Lincoln & Guba, 1985) based on the interviews.

In our analysis of the interviews, we focused on the teachers' responses to the questions that were specifically related to how teachers used iPlan and the ways in which they found different features beneficial (or not) and the reasons for why. We read through these responses and identified the parts relevant to the goals of this research: (i) Which structures within iPlan did teachers find the most and the least helpful; (ii) Why did they find them helpful/unhelpful; and (iii) How they used the specific aspects of iPlan designed to address the challenges discussed above. Thus, the goal of our analysis was not only to identify what worked for teachers but also why. Finally, we identified the patterns across teachers, creating representations of the overall patterns with detailed examples from individual teachers' comments (Miles & Huberman, 1994). As we will summarise in the findings section, interviews with the teachers provided insights into the ways in which they used iPlan and the structures embedded in it.

Findings

In what follows, we present the findings organised around the research questions. Addressing the first question, we will first present features of iPlan that were (or were not) taken up by teachers and the reasons why. Then, addressing the second research question, we zoom into how teachers used the specific features of the iPlan that were designed (i) for transparency of the curriculum designers' intent, and (ii) for promoting online communities of practice, and the affordances and challenges of these features.

What features were (un)helpful?

Regarding the usefulness of iPlan features, we had asked the first group of users of the full version of iPlan – Amy, Julia and Sara – how they used the macro and micro views of the tasks during their implementation of the genetics unit. For both Amy and Julia, the macro view provided an overall idea about the task, although they spent more time studying and using the micro view. Amy said she primarily used a given macro view only once, when entering a task for the first time. In contrast to Amy, Julia said she used the macro view in her weekly planning and then daily to 'refresh her mind'. She said:

> In the mornings, I just kind of look over again to remind myself what is going to happen… Thursday and Friday are usually my planning days. I decided what are we going to do for the week; so, I would probably look over it then to give myself an overview. In the morning, it is just to refresh my mind.

Similarly, Sara said that she liked the way the overview page is laid out, 'What it is that I will be doing? This is your task description. Where is this in the big scheme of things?' Therefore, all three teachers' use of the iPlan macro view reflected the designers' intent, even though the exact details of use and their purposes varied. The macro view seemed to serve as a skeleton for the lesson, as we intended, by providing the necessary information for teachers to develop an overall idea about the focus of the task.

The micro view was also generally viewed as helpful. When asked to describe how she used iPlan, Julia stated that different parts of iPlan were helpful at different times. She emphasised the importance of the targets icon in the micro view for her teaching of the genetics unit. She said, 'The target is extremely important.' When she was asked what she would suggest to a teacher who does not have time to read everything in iPlan, she said:

> Go to the task page. Read the targets that tell you where you want them [the students] to be by the time you are done. I will definitely read the targets. If you are really pressed for time, I would read the targets.

As reflected in Julia's comments, the target icon seems to serve the purpose as intended by the designers; it helped her to understand how much conceptual progress on a big idea that students needed to make.

Ten biology teachers, who implemented the genetics unit the following semester with the full iPlan tool, were asked to specify one to two features of iPlan that they consistently found the most and the least useful, and the reasons for why. Table 4 provides insights into these teachers' use of iPlan.

Table 4. Teachers' use of the structures embedded in iPlan, sorted from more helpful to less helpful structures.

Structures embedded in iPlan	Found by teachers the most useful	Found by teachers the least useful
Micro view	Emily, Allison	
• Instructions & guidelines	Andrew, Zoey, Nathan, Caleb	
• The icons	Allison	
o Revisit icon	Grace, Zoey	
o Target icons	Zoey, Nathan	
o Important icon	Nathan	
• Purpose	David	
• Time frames	David	Nathan, Allison
Macro view		
• Task description	Jacob	
• Resources in the macro view	Maria	
• Content goals	Grace, Maria*	Caleb
• Why this task now		Maria
• Scientific and engineering practices & mathematical goals		Emily, Jacob, Andrew
Discussion and implementation notes	Emily, Jacob	
Implementation notes	Andrew, David	Zoey, Allison
The calendar		David
Graphical representation of the unit		Emily, Maria

*She only focused on the macro view during this part of the interview and was not prompted about the micro view.

As shown in Table 4, eight out of ten teachers found the micro view overall (Emily and Allison) or specific features of the micro view (David, Andrew, Zoey, Nathan, Caleb, Grace) the most useful. Most of them found it helpful because it provided details about how exactly to implement the tasks, which is consistent with the intent of the designers. Emily said, for instance, 'Directions told me what exactly students were supposed to be doing at a specific time.' Similarly, Nathan said:

> The procedure, how to do it. It gave me an idea what I should do first, what I should do second. I think, this is really important for the first time around, because I was in the dark. Giving me the sequence and telling me what is important is really important especially for the first time around.

Moreover, four of the teachers specifically indicated how useful the information provided in the boxes with icons was. Nathan, for instance, said about the important icon, 'it helped me zoom in where I needed to zoom in to get to the end goal'. Grace said the revisit icon guided her about where she was going. Considering that the icons were designed to orient teachers' attention to critical information in consistent ways, their use by the teachers was again as intended by the designers.

While three of these teachers found the macro view to be helpful, several specific macro view features were not considered helpful. As described previously, this unit was an integrated STEM unit; that is, it was designed around an engineering design challenge to teach rigorous mathematics tied to big ideas in biology in high school science classrooms. Some of the reasons for why teachers found the goals and practices not useful reflect the challenges of teaching such integrated units in science classrooms. For instance, Caleb said, 'I don't think I focused as much, specifically on the mathematics because I am a biology teacher.' Similarly, David said that he did not focus much on the engineering practices 'because of the fact that I was focusing on biology. I understand that engineering was part of it. I did not play up the engineering part of it much.' He continued and added, 'We kind of went over math a little but I expect my students to know most of the math about probability from their other classes.' A closer look into the reasons for why teachers did not find some of the structures in iPlan helpful seems to be related to their decisions about what to teach/cover while implementing the genetics unit. Engineering and math were not considered as necessary to emphasise by Caleb and David, and so, they did not see the features of macro view that provide this information as helpful.

Interestingly, while four of the teachers found the discussion and/or implementation notes the most useful, two of the teachers found them the least useful. Teachers finding the implementation notes useful were mostly using them to compare their experiences with the other teachers teaching the same curriculum. For example, Emily said that by reading other teachers' notes, 'I was prepared for what other teachers experienced. A lot of the times, I would look at those retrospectively as well to see whether they experienced the same thing that I did.' Similarly, Andrew said he used the implementation notes to see concerns and issues that other teachers run into. Jacob said, 'It was helpful to see what other teachers had done, their suggestions.' Like others, David said, 'I would look at the other teachers' classroom notes and see what worked in their class and what did not work in their class.'

However, both Zoey and Allison did not find other teachers' notes useful. Allison said:

> The implementation notes did not work for me. I liked to read them but when it comes to the make up of their classes and my classes, their implementation notes would not have been beneficial to me. It was kind of a waste of time.

Providing a different complaint, Zoey said:

> A lot of the discussion was these teachers were consistently talking about how these students were struggling in their notes. There were not really solutions. Very often I found it more helpful to go over and physically talk to another teacher, who was working on it then using the implementation notes and the discussion.

Both of these teachers' feedback indicates that they indeed read others' notes but did not find them beneficial because of the relevance of the ideas considering their own classroom context.

These concerns would be less of a concern if there were more notes posted by more teachers teaching in different contexts, a limitation that we take up in the general discussion.

All in all, our analysis of what teachers overall found to be the most or the least useful revealed that teachers focused on different structures of iPlan depending on their needs and contexts. However, there was not a specific iPlan structure that the majority of the teachers consistently found the least beneficial. These patterns are promising, especially if we consider our overarching goal as supporting teachers' learning at scale for which it is important to design tools and environments to support teachers from different contexts and with different needs. Next, we zoomed in on teachers' use of the iPlan structures that were specifically designed to: (i) ensure transparency of the designers' intent, and (ii) promote online communities of practice.

Transparency of the designers' curriculum intent

Three structures were built into iPlan to support the transparency of the curriculum designers' intent for students' learning: the important icon, the purpose statements in the micro view and the why-this-task-now section in the macro view of the tasks. One way to check whether these structures served their purpose was to ask teachers whether iPlan was helpful for communicating the 'why' for them. Thus, in the interviews, we asked teachers whether there were particular sections of the iPlan tool that helped them to understand not only what we wanted them to do but also the reasons for why we recommended them to do certain things.

Table 5 provides the structures in iPlan that the teachers across both waves of data collection identified as providing them with the reasons for why to do certain things. Out of 13 teachers, nine of them provided a response for this question (excluding Sara, Andrew, Zoey and David, who did not respond to the question or pinpoint a particular iPlan structure). Zoey said that nothing major stuck out in her head but at the same time commented, 'For some of the tasks, there seem to be enough information for why or for exactly what we were doing', while this was not the case for some tasks. The remaining nine teachers identified specific iPlan structures that supported their understanding of reasons for why to do certain things.

A majority of teachers (i.e. Amy, Jacob, Grace, Nathan and Allison) identified the icons (and their underlying content) as providing the rationale for why to do certain things in certain ways. Amy said:

> You will never find a unit that tells you the why except here. I think every aspect of it. I mean the whole thing to me is the why. I love the targets. To me that is like a great why. Target was the most why. The bubbles were ways to get there.

Why this task now was one of the most frequently cited structures that helped teachers to feel like, 'Oh this is why I need to do this, or why students need to learn this.' For instance, Emily said:

Table 5. Structures embedded in the iPlan that teachers reported provided them with the 'why'.

Structures embedded in iPlan	Teachers (total n = 9)
Why this task now?	Emily, Jacob, Caleb, Julia
Other teachers' notes and/or comments	Emily, Grace, Jacob, Nathan
Target icon	Amy, Jacob
Important icon	Grace, Nathan
Icons (generally)	Allison
Purpose	Julia, Grace
Content goals	Julia
Moving on from here	Julia
The final task in the unit	Emily
Instructions & information in the micro view	Maria

> What are they supposed to get out of this? What is the point? Or is there something else that I can add to scaffold, especially for the lower-level students? Sometimes it was after [the lesson], if I had a complete disaster in the lesson, I might look back and go back: What were we supposed to do?

Interestingly, one structure that we, as curriculum designers, did *not* intend for this purpose was frequently cited by teachers as being useful for communicating them the 'why': other teachers' notes or discussion comments. Emily, for instance, thought that sometimes other teachers' comments gave her hints.

Finally, Julia's interview comments provided a useful insight into why it is important to provide teachers with a rationale rather than just a script to follow. She said that since iPlan provides the rationales for why to implement the tasks in certain ways, she did not need to be provided with a procedure to follow. Specifically, she said:

> I felt like I did not really need to read a script because I did not really understand the reasoning. I understood the reasoning enough that I kind of did not read all of the little: Teacher should say this… I did not read all of that because I understood the reasoning.

Online communities of practice

In our interviews with teachers, we also examined the ways in which teachers used the implementation notes and the discussion space. Our analysis revealed the affordances and challenges of these iPlan structures focused on building an online community of practice. Table 6 provides a summary of what did or did not work for teachers regarding the implementation notes and the discussion space, focusing on affordances and challenges expressed at least by two teachers. Some of the teachers used the implementation notes and discussion comments interchangeably during their comments as they were primarily referring to other teachers' posts. Thus, some of the reflections may apply across both.

One of the core functionalities of the implementation notes was the inclusion of a space for teachers to take notes about the lesson implementation (e.g. lesson planning notes, reflection, modifications, reminders etc.), which then can be shared with other teachers. Based on the analysis of the interviews with the teachers across both waves of data collection, more than half of them found one of the affordances of the implementation notes as being able to take notes about what worked, what did not work, things to remember etc. Consistently, almost half of the teachers found having a record of things for the next time teaching the same curriculum as beneficial.

Table 6. Teachers' reflections on their use of implementation notes and the discussion space.

What worked?	What did not work?
Implementation notes	
• Taking notes after the lesson: What worked, what did not work, what to change, things to remember etc. (Julia, Amy, Sara, Emily, Grace, Andrew, Nathan) • Having a record of things for the next time teaching the same curriculum (Julia, Amy, Andrew, Nathan, David) • Reading other teachers' notes (Julia, Emily, Grace, Andrew, Nathan, Maria)	• Others' notes did not really help (Amy, Zoey, Nathan, Allison) • Printed materials and took notes on printed materials or worked on other print materials (Amy, Grace, Zoey, Allison, Maria) • Feeling intimidated from others' notes or not feeling comfortable sharing (Emily, Jacob, Caleb) • Not knowing what to post (Caleb, Maria)
Discussion space	
• To check whether other teachers have similar experiences in their classrooms, seeing what others do, asking questions etc. (Julia, Amy, Jacob, Emily, Andrew, Nathan, Caleb, Maria) • To answer others' questions, to respond to others' concerns etc. (Andrew, Jacob, Julia)	• Reading negative comments, complaints, unconstructive criticisms etc. (Emily, Grace, Zoey, Allison) • Posting but not receiving a response (Julia, Emily, Maria) • Having face-to-face conversation, instead, is easier/more convenient (Amy, Zoey, Allison) • Not having enough teachers interacting at the same time (Amy, Caleb)

To promote knowledge building among teachers with an encouragement to share, the implementation notes feature had an ability to share (or keep private) one's own individual notes. As shown in Table 6, while some teachers found it helpful to read other teachers' implementation notes, some teachers did not find it helpful. Andrew for instance thought that other teachers' implementation notes provided an alternative. He said:

> I wanted to avoid any mistakes. I did look at the other teachers' implementation notes just to see the problems that they were running into, what things they were doing differently to improve it, and then I applied it to my groups of kids.

On the other hand, several teachers did not find them helpful since some of the teachers' notes were from classrooms with different student composition from their own. For instance, Zoey said:

> I read a few but I did not find them helpful at all just because my students are different. A lot of implementation notes seem to be for students of much higher level than my students. So, things that other teachers may have done for that higher level, I knew, wasn't just going to work for the lower level students that I have.

Similarly, Emily said:

> Sometimes I felt like a little intimidated putting implementation notes on. I felt like when you read some the other teachers' notes, I feel like they are going well above and beyond where I can possibly go with my students.

It appears that many of the teachers did not use the search option of the implementation notes, which allow searching for notes by school, grade level and class type; since there were only a few participants, iPlan was not populated with many notes by teachers from different contexts.

There were some other challenges expressed by the teachers in writing and sharing implementation notes, including not feeling comfortable with sharing with other teachers that they don't know or feeling intimidated by others' notes, as expressed by Emily. For example, Jacob said, 'I was a little bit nervous about once or twice when I posted saying: Is this a typo? I didn't want to look stupid.' With the similar concerns, Caleb said:

> I hate posting online. I am always very hesitant to put anything in print electronically for some reason because I try to think 4000 ways that it could be read; I don't want to appear stupid. I don't want to appear like I don't know what I am talking about. So, I am very hesitant to post anything publicly unless forced to.

While not knowing what to post was a challenge for two of the teachers, several of them expressed that they prefer working with print materials. Five of the teachers told that they printed the materials and took notes on them when needed.

Discussion space was another platform to support learning interactions among the teachers through dialogue, both with other teachers and with the curriculum developers. The majority of the teachers considered the ability to check what other teachers are doing and to ask questions or respond to others' concerns as among the affordances of the discussion space. Nathan said, for instance, 'When I heard that other people were confused or having problems that was a little reassuring that it wasn't just me.' Others' comments seem to have supported Maria in preparation for challenges of implementation. She said, 'I would look at them before I would do something. Again just to prepare myself just to maybe we might come into a glitch or something like that.'

However, challenges of the discussion space were also expressed by several teachers. A more frequent one involved reading negative comments that were posted by other teachers. For example, Grace said:

> As I went further through, there seems to be that the comments tended to be more instead of how to make it work, what was wrong and that bothered. The comments that why this did not work were not useful to me. If something did not work but they offered a solution, it was helpful.

These comments by the teachers suggest that they prefer going into the discussion space to learn with and from other teachers. Perhaps, having more comments posted by a larger number of participants could have increased the variation of the comments posted by the teachers. Consistently, two of the teachers highlighted the limitation of not having enough teachers interacting at the same time in the discussion space. Finally, some teachers indicated their preference to have face-to-face conversations with their colleagues rather than the online ones like in iPlan.

Discussion and conclusions

This article focused attention on specific design features of an online tool that combined affordances of educative curriculum materials and online teacher learning communities, and the analyses identified the features that were (or were not) used by the teachers. Our analysis, overall, revealed that teachers used different structures of iPlan depending on their needs and contexts. While there was not a specific iPlan structure that the majority of the teachers consistently found the least beneficial, there were some features that the majority of the teachers found more beneficial such as the micro view. Our analytic approach also allowed us to evaluate the research-informed features of iPlan that were designed intentionally to address certain programmes of practice such as supporting teachers' understanding of the key foundations of the curriculum designed to support students' learning. Thus, the findings provide a worked example for designers and researchers that aim to support change in student learning outcomes through engineering teachers' learning.

Given the ambitious nature of recent instructional reforms and the inherent scale required to successfully implement these reforms, designs for teacher learning that can reach out to many teachers in meaningful ways have gained importance. Curriculum is often seen as a tool to influence practice on a large scale. Similarly, there has been a growing attention to online learning environments. Dede and colleagues (2009) described the promise of online professional development strategies to facilitate changes in teachers' learning. That being said, the current evidence base for online programmes designed to support science teachers is thin (Moon et al., 2014; NASEM, 2015). By bringing together educative curriculum materials and online learning environments within a new tool (i.e. iPlan), the study offered an exploration of a set of research-informed support structures for online communities of practice around an innovative curriculum aligned with the reform vision that can be adopted by other curriculum designers to test in new settings.

Just as we assumed that teachers would need to adapt the curriculum to their context, teachers needed many different supports for their implementation and learning. On the one hand, one might consider our designs to have been only moderately successful in that no feature was strongly endorsed by all or nearly all of the teachers. On the other hand, one might argue the overall design was successful in that teachers generally felt supported in that they each found a few aspects of the system to support their needs. Like others (e.g. Brown, 2009; Remillard, 2005), we believe that teachers will use curriculum materials in different ways to adapt them to their own context, and so, given the diversity of teachers and teaching contexts, multiple forms of support are likely to be needed. In fact, differential use of educative features was revealed in prior research too (e.g. Beyer & Davis, 2012). Consistently, one of the design principles for educative curriculum materials proposed by Davis and colleagues (2017) is:

> Different teachers will need and take up different kinds of educative features (in terms of substance and form). Teachers' variable uptake will be based on the needs they perceive in themselves (e.g., their knowledge of content, assessment, or reading strategies) and their students (e.g., their typical content struggles). Therefore, designers should develop a constellation of educative features that have the potential to meet these various needs. (Davis et al., 2017, p. 301)

Our design approach was consistent with this design principle in that the educative features of iPlan seem to meet various needs, particularly in regard to the focal problems of practice that we discuss in this article. Moreover, our prior research findings showing strong student learning outcomes even with only iPlan support provide some evidence that the overall design was successful.

While it is important to design for meeting various needs, it is also important to monitor teachers' use of different educative features because they can allow us to tailor support provided to teachers. Eventually, using educative supports in different ways would lead to different learning outcomes for teachers. As underscored by Davis and Krajcik (2005), 'the effectiveness of any educational intervention depends on how the opportunity is used by the individual' (p. 4). For example, a study of middle school science teachers by McNeill (2009) revealed variation in how teachers utilised educative features of the curriculum materials, which then resulted in differences in enactments and student learning outcomes. Our study revealed challenges with teachers' use of one of the structures that we built into iPlan to facilitate teacher interaction and learning from each other: discussion space. A number of teachers felt that there was not content by teachers from similar contexts. In other words, this study revealed one of the challenges of the online learning community, which was a critical mass problem or the lack of scale. With not every teacher commenting, reflecting or modifying every task, the comments/variations/reflections on a given task would not include a broad cross-section of teachers within such a small implementation community. In general, in online content distribution schemes, the number of consumers of content will exceed (often to a large ratio) the number of providers of content (e.g. number of blog post readers to blog post writers). In an implementation with hundreds of teachers, we suspect this particular problem would either have gone away or at least have been less problematic. However, this prediction would depend upon the effectiveness of the search features, and thus is a topic for future research that can focus on larger group of teachers' use of iPlan.

Another factor underlying the limited interaction among teachers in the online discussion space might be related to not having a facilitator. The importance of facilitation in online learning environments for teachers was emphasised in prior research (Dede et al., 2009; NASEM, 2015). Lack of feedback was also found to be a limitation for sustained interactions (Barab, MaKinster, Moore, & Cunningham, 2001). Solely creating an online platform for connecting teachers is insufficient; a skilled facilitation could change the interactions about the participants. In our project, we assigned some of the experienced teachers an active participants role; they posted more frequently in the online discussion space and addressed other teachers' questions. They, in some way, played a facilitator role by modelling an active participant role in the online space. However, their role was not to support teachers' learning by posing more targeted questions or eliciting contributions from other teachers to focus on and improve their practices. The role of such informal facilitation can be explored further in future research.

Future research should continue to explore the dynamic relationship between teachers and curriculum materials. For example, Arias et al. (2016) found that teachers found certain types of educative supports to be more helpful in comparison to others, but they also used different educative features in different ways. Building on that idea, Marco-Bujosa, McNeill, González-Howard, and Loper (2017) found that while some teachers use curriculum materials as a resource to support student learning, others actively engaged in their own learning while using and adapting the curriculum to their own unique context. When we look at the patterns that we observed in our study about teachers' interaction with different structures of iPlan, we saw a range in teachers' interactions with the features of iPlan, which were designed to facilitate online learning communities among teachers. While some teachers thought other teachers' notes and discussion comments provided them insight about the rationale for implementing certain things in certain ways, other teachers did not find them helpful at all. Our intent of adding these interactive features to iPlan was to provide an opportunity for teachers to use each other and their contexts as additional resources for learning. It would be helpful to explore further how and why collaborative structures built around educative curriculum materials to support teacher learning are taken up differently by teachers teaching in different contexts and having different needs and how their use of these collaborative structures influenced their appropriation of certain instructional practices.

The study also has some limitations that should be considered while interpreting the findings. While the sample size is relatively larger than typical qualitative studies of teachers' use of educative curriculum materials, a larger sample size would provide further insight particularly into teachers' interactions with the iPlan features. Moreover, our data source was limited to the interviews with teachers. Even though these interviews with teachers were sufficient to understand what they say about how they used iPlan, additional data sources could have been used to track teachers' actual use of curriculum during their enactment. Regardless, given the goal of this study, to discuss design features in iPlan and teachers' use of these features, the findings elucidate the ways in which teachers interacted with these structures in iPlan. Finally, this study is on teachers' use of iPlan features, not on the change in participation of the iPlan members. Our next steps would involve exploring the relationship between teachers' use of iPlan and their instructional practices aligned with the intent of the curriculum materials.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the National Science Foundation under the Grant [DRL-1027629].

Notes on contributors

Miray Tekkumru-Kisa is an Assistant Professor in Science Education in the School of Teacher Education at Florida State University (FSU). She holds joint appointments at the Florida Center for Research in STEM (FCR-STEM) and at FSU-Teach Science and Mathematics Teacher Preparation Program. Dr Tekkumru-Kisa's research focuses on designing for and studying teacher learning, and instructional quality for ambitious and equitable teaching in science classrooms.

Christian Schunn is a Senior Scientist at the Learning Research and Development Center and a Professor of Psychology, Learning Sciences and Policy, and Intelligent Systems at the University of Pittsburgh. Dr Schunn directs a number of research projects studying expert engineering and science teams, and building innovative technology-supported STEM curricula.

ORCID

Miray Tekkumru-Kisa http://orcid.org/0000-0003-0641-7491
Christian Schunn http://orcid.org/0000-0003-3589-297X

References

Arias, A. M., Bismack, A. S., Davis, E. A., & Palincsar, A. S. (2016). Interacting with a suite of educative features: Elementary science teachers' use of educative curriculum materials. *Journal of Research in Science Teaching*, *53*, 422–449.

Arias, A. M., Smith, P. S., Davis, E. A., Marino, J. C., & Palincsar, A. S. (2017). Justifying predictions: Connecting use of educative curriculum materials to students' engagement in science argumentation. *Journal of Science Teacher Education*, *28*, 11–35.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is: Or might be: The role of curriculum materials in teacher learning and instructional reform? *Educational Researcher*, *25*(9), 6–14.

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 national survey of science and mathematics education*. Horizon Research, Inc.

Bannister, N. A. (2015). Reframing practice: Teacher learning through interactions in a collaborative group. *Journal of the Learning Sciences*, *24*, 347–372.

Barab, S. A., MaKinster, J. G., Moore, J. A., & Cunningham, D. J. (2001). Designing and building an on-line community: The struggle to support sociability in the inquiry learning forum. *Educational Technology Research and Development*, *49*(4), 71–96.

Beyer, C. J., & Davis, E. A. (2012). Learning to critique and adapt science curriculum materials: Examining the development of preservice elementary teachers' pedagogical content knowledge. *Science Education*, *96*, 130–157.

Beyer, C. J., Delgado, C., Davis, E. A., & Krajcik, J. (2009). Investigating teacher learning supports in high school biology curricular programs to inform the design of educative curriculum materials. *Journal of Research in Science Teaching*, *46*, 977–998.

Brown, M., & Edelson, D. (2003). *Teaching as design: Can we better understand the ways in which teachers use materials so we can better design materials to support their changes in practice*. Design Brief. Evanston, IL: Center for Learning Technologies in Urban Schools.

Brown, M. W. (2009). The teacher–tool relationship: Theorizing the design and use of curriculum materials. In J. T. Remillard, B. A. Herbel-Eisenmann, & G. M. Lloyd (Eds.), *Mathematics teachers at work – Connecting curriculum materials and classroom instruction* (pp. 205–222). New York, NY: Routledge.

Cervetti, G. N., Kulikowich, J. M., & Bravo, M. A. (2015). The effects of educative curriculum materials on teachers' use of instructional strategies for English language learners in science and on student learning. *Contemporary Educational Psychology*, *40*, 86–98.

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher*, *32*, 9–13.

Cox, C., Reynolds, B., Schuchardt, A., & Schunn, C. D. (2016). How do secondary level biology teachers make sense of using mathematics in design-based lessons about a biological process? In L. Annetta & J. Minogue (Eds.), *Connecting science and engineering practices in meaningful ways* (pp. 339–372). Heidelberg: Springer.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher*, *34*(3), 3–14.

Davis, E. A., Palincsar, A. S., Smith, P. S., Arias, A. M., & Kademian, S. M. (2017). Educative curriculum materials: Uptake, impact, and implications for research and design. *Educational Researcher*, *46*, 293–304.

Davis, E. A., Smithey, J., & Petish, D. (2004). Designing an online learning environment for new elementary science teachers: Supports for learning to teach. In *ICLS '04. Proceedings of the 6th international conference on learning sciences* (pp. 594–594). Santa Monica, California, June 22–26, 2004. International Society of the Learning Sciences.

Dede, C., Ketelhut, D. J., Whitehouse, P., Breit, L., & McCloskey, E. M. (2009). A research agenda for online teacher professional development. *Journal of Teacher Education*, *60*, 8–19.

Dias, L. B. (1999). Integrating technology. *Learning and Leading with Technology*, *27*, 10–13.

Fishman, B. J., Davis, E. A., & Chan, C. K. (2014). A learning sciences perspective on teacher learning research. In K. Sawyer (Ed.), *The Cambridge hand book of the learning sciences* (2nd ed., pp. 707–725). Cambridge: Cambridge University Press.

Fishman, B., Konstantopoulos, S., Kubitskey, B. W., Vath, R., Park, G., Johnson, H., et al. (2013). Comparing the impact of online and face-to-face professional development in the context of curriculum implementation. *Journal of Teacher Education*, *64*, 426–438.

Forbes, C. T., & Davis, E. A. (2007, April). *Beginning elementary teachers' learning through the use of science curriculum materials: A longitudinal study*. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, New Orleans, LA.

Frumin, K., Dede, C., Fischer, C., Foster, B., Lawrenz, F., Eisenkraft, A., et al. (2018). Adapting to large-scale changes in Advanced Placement Biology, Chemistry, and Physics: The impact of online teacher communities. *International Journal of Science Education*, *40*, 397–420.

Greeno, J. G. (1997). On claims that answer the wrong questions. *Educational Researcher*, *26*, 5–17.

Greeno, J. G., Collins, A. M., & Resnick, L. B. (1996). Cognition and learning. *Handbook of Educational Psychology*, *77*, 15–46.

Hoadley, C. (2012). What is a community of practice and how can we support it? In D. Jonassen & S. Land (Eds.), *Theoretical foundations of learning environments* (2nd ed., pp. 286–299). New York, NY: Routledge.

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education*, *25*, 157–175.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage Publications.

Loper, S., McNeill, K. L., & González-Howard, M. (2017). Multimedia Educative Curriculum Materials (MECMs): Teachers' choices in using MECMs designed to support scientific argumentation. *Journal of Science Teacher Education*, *28*, 36–56.

Macià, M., & García, I. (2016). Informal online communities and networks as a source of teacher professional development: A review. *Teaching and Teacher Education*, *55*, 291–307.

Marco-Bujosa, L. M., McNeill, K. L., González-Howard, M., & Loper, S. (2017). An exploration of teacher learning from an educative reform-oriented science curriculum: Case studies of teacher curriculum use. *Journal of Research in Science Teaching*, *54*, 141–168.

McNeill, K. L. (2009). Teachers' use of curriculum to support students in writing scientific arguments to explain phenomena. *Science Education*, *93*, 233–268.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Thousand Oaks, CA: SAGE Publications.

Moon, J., Passmore, C., Reiser, B. J., & Michaels, S. (2014). Beyond comparisons of online versus face-to-face PD: Commentary in response to Fishman et al., "Comparing the impact of online and face-to-face professional development in the context of curriculum implementation". *Journal of Teacher Education*, *65*, 172–176.

National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers learning: Enhancing opportunities, creating supportive contexts*. Committee on Strengthening Science Education through a Teacher Learning Continuum. Board on Science Education and Teacher Advisory Council, Division of Behavioral and Social Science and Education. Washington, DC: The National Academies Press.

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Pawan, F., Paulus, T. M., Yalcin, S., & Chang, C. F. (2003). Online learning: Patterns of engagement and interaction among in-service teachers. *Language Learning & Technology*, *7*(3), 119–140.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher*, *29*, 4–15.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*, 211–246.

Remillard, J. T., & Bryans, M. B. (2004). Teachers' orientations toward mathematics curriculum materials: Implications for teacher learning. *Journal for Research in Mathematics Education*, *35*, 352–388.

Schneider, R. M., Krajcik, J., & Blumenfeld, P. (2005). Enacting reform-based science materials: The range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching*, *42*, 283–312.

Schuchardt, A., & Schunn, C. D. (2016). Modeling scientific processes with mathematics equations enhances student qualitative conceptual understanding and quantitative problem solving. *Science Education*, *100*, 290–320.

Schuchardt, A. M., Tekkumru-Kisa, M., Schunn, C. D., Stein, M. K., & Reynolds, B. (2017). How much professional development is needed with educative curriculum materials? It depends upon the intended student learning outcomes. *Science Education*, *101*, 1015–1033.

Song, L., & Hill, J. R. (2007). A conceptual model for understanding self-directed learning in online environments. *Journal of Interactive Online Learning*, *6*, 27–42.

Tekkumru-Kisa, M., Schunn, C., Stein, M. K., & Reynolds, B. (2017). Change in thinking demands for students across the phases of a science task: An exploratory study. *Research in Science Education*, 1–25.

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*, 5–8.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge: Cambridge University Press.

Wenger, E., McDermott, R. A., & Snyder, W. (2002). *Cultivating communities of practice: A guide to managing knowledge*. Boston, MA: Harvard Business School Press.

Zygouris-Coe, V. I., & Swan, B. (2010). Challenges of online teacher professional development communities. In J. O. Lindberg & A. D. Olofsson (Eds.), *Online learning communities and teacher professional development: Methods for improved education delivery* (pp. 114–133). New York, NY: Information Science Reference.