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Abstract: The exploratory study reported here is part of a larger-scale research project aimed at building theoretical and practical knowledge of complex systems in students and teachers with the goal of improving high school biology learning. In this paper we propose a model of adaptive expertise to better understand teachers' classroom practices. Through three case studies, we further illustrate the characteristics of adaptive expertise of more or less successful teaching and learning. By doing this research, it is our ultimate goal to contribute to scholarship on practices and training in which teachers must participate to support complex systems teaching and learning in classrooms.

Introduction and Framing the Issue

The study of complex systems in the sciences and social sciences has become increasingly essential to understanding disciplinary and interdisciplinary content and practices (The National Academies, 2009). Likewise, in education, research on teaching and learning about complex systems has achieved solid grounding as an important field within learning sciences research (Hmelo-Silver & Kafai, 2011). In terms of educational policy and classroom enactment, the study of systems is also featured prominently in the *Next Generation Science Standards* (NGSS). Complex systems are generally defined as existing when any given numbers of interconnected and interdependent parts interact. The patterns of interactions form a network of relationships that exhibit emergent properties that cannot be observed or decomposed at subsystem levels.

Over the last couple of decades, learning sciences researchers have developed valuable resources and computational models for learning about complex systems such as StarLogo and NetLogo (e.g., Colella et al., 2001; Wilensky & Reisman, 2006). However, few studies have focused on how best to scaffold the learning experiences for students in classrooms when the complex systems resources are expected to be integrated into standard science courses. Many studies instead have investigated the efficacy of those resources on learning (e.g., Yoon, 2008; 2011) without fully considering the contextual factors, including teacher differences in things like pedagogical beliefs that may be in play when implementing new resources. Because of the situated nature of teachers, classrooms, and schools, teachers' implementation of projects may diverge from developers' intentions in order to fit the learning needs of their contexts (Penuel et al., 2011). Hmelo-Silver & Azevedo (2006) have also pointed out that more research is needed on how to train teachers in complex systems resources and approaches to better support curricular and instructional experiences.

Given the importance of systems in the NGSS, the time is ripe to address these needs for developing teachers' knowledge and skills. A preliminary question to ask in terms of research design is what theoretical lens might be appropriate for understanding how to in-service teachers, and furthermore, for assessing the efficacy of teacher development. In one prominent line of research focused on understanding technology integration, researchers have identified barriers such as teacher beliefs, readiness, and a steep learning curve (e.g., Aldunate & Nussbaum, 2013; Ertmer et al., 2012). Others have discussed the importance of more exposure to computers (Mueller et al., 2008) or extensive computer training (Pierson et al., 2001). However, none of these studies offer information about or images of teachers who are in the process of becoming experts in computer-supported curricular integration. Thus, capturing how teachers enact reforms and evaluating their ability to adapt in order to identify levels of expertise can be instructive for teacher training purposes. We argue in this paper, that an adaptive expertise lens can offer support for understanding how teachers are able to navigate contextual factors (Penuel et al., 2011) while at the same time providing a framework to understand the quality of classroom implementation of computer-supported complex systems reform curricula in high school science. The exploratory study reported here is part of a larger-scale research project aimed at building theoretical and practical knowledge of complex systems in students and teachers with the goal of improving high school biology learning. In this paper we propose a model of adaptive expertise. Through three case studies, we illustrate the characteristics of adaptive expertise of more or less successful teaching and learning.

By doing this research, it is our ultimate goal to contribute to scholarship on practices and training that teachers participate in to support complex systems teaching in classrooms.

Adaptive Expertise

Improving high school science teaching in the US has increasingly become a policy and practical imperative. High on the list of reasons are to meet the needs of a STEM-literate workforce (NRC, 2011; NSB, 2010); to produce better problem-solvers (OECD, 2011); and to support better decision-making about issues that can impact students' daily lives (Yoon, 2011). The number of reform-oriented STEM projects are far too numerous and varied to discuss here. However, the millions of dollars that the National Science Foundation alone pours into research and development every year for teaching and learning in science; such as *Discovery Research K–12*, *Cyberlearning*, and *Innovative Technology Experiences for Students and Teachers;* attests to the importance of reforming practice to improve student learning and participation. What many of these programs attempt to do is to build teaching expertise using new resources, new knowledge, and new skills. At the same time, it is widely known that situational issues like socioeconomic stress, lack of adequate resources, and few professional development opportunities (e.g., Ingersoll & May, 2012) make the work of teaching, especially in science, challenging to do. How can teachers successfully balance the calls for reform and the needs to consider their teaching contexts? A look into the adaptive expertise literature may provide insights into how to do this.

There is a robust tradition on the study of expertise in the learning sciences (e.g., Bereiter & Scardamalia, 1993) and teaching (e.g., Berliner, 2001). In our research, we are interested in understanding what expertise might look like and how it can be developed with new or reform-oriented curricula and instruction. How to enhance performance on novel problems has been characterized as adaptive expertise (Barnett & Koslowski, 2002; Hatano, 1982; Scardamalia & Bereiter, 1993). Adaptive expertise goes beyond simply having more years of experience or possessing more knowledge in a content domain or pedagogy. The complex nature of teaching requires teachers to be able to orchestrate a myriad of often unobservable variables, see multiple perspectives, recognize problems, and identify possibilities in existing and emergent situations (Bransford et al., 2005; Fairbanks et al., 2010). In other words, teachers need to constantly be adaptive with new or non-routine events. Adaptive experts actively seek to extend their capabilities and are always working at the edge of their competence. In this way, as Bereiter and Scardamalia (1993) suggest, expertise should be understood as a *process* rather than a *state*. From this perspective, searching for qualities that represent what adaptive experts look like necessarily requires us to identify actions.

With respect to actions, a review of the literature reveals three important characteristics: flexibility, ability to demonstrate deeper level understanding, and deliberate practice. Berliner (2001) writes that compared to non-experts, experts are more flexible, opportunistic in their planning, and can change enactments faster when it is appropriate. Adaptive experts flexibly and critically apply their knowledge (Ferrari, 2002) in new situations (Bransford, 1999) and are constantly learning while doing it (Chi, 2011). Flexibility is also manifested in teachers' abilities to integrate aspects of teacher knowledge in relation to the teaching act while responding to their specific contexts (Tsui, 2009). In terms of the characteristic of deeper level understanding, experts represent problems in qualitatively different ways than novices and can recognize meaningful patterns faster (Berliner, 2001; Levy & Murnane, 2004). Routines are automatized, which frees up cognitive load to attend to deeper level problem solving or other tasks (de Groot, 1978; Bransford, 1999; Hammerness et al., 2005) and allows experts to perform at a higher level (Ferrari, 2002; Ericsson et al., 2006). Experts are also recognized by their ability to engage in reflection and conscious deliberation (Tsui, 2009). They are highly motivated, self-regulated, and constantly seek to improve performance by identifying problems, addressing them, and finding new problems to work on (Bereiter & Scardamalia 1993; Berliner, 2001; Tsui, 2009).

In the next section, we operationalize these descriptions of adaptive expertise by applying them to three cases of teachers we worked with on a project aimed at implementing computer supported complex systems reform curricula in high school science.

Methodology

Context

Our NSF-funded project engages teachers and students in learning experiences that build knowledge of scientific practices using computational models and knowledge in complex systems and biology. The project entails building a curricular and instructional sequence in five high school biology units – Genetics, Evolution, Ecology, The Human Body, and Animal Systems. Participants use biology simulations that are built on an agent-based modeling platform that combines graphical blocks-based programming with a 3-D game-like interface. We have developed classroom curricular materials that lay out the scope and sequence of two to three day units in each of the biology topics and constructed professional development experiences during the summer and school year to support teachers' implementation of the project. All project activities are underpinned by a complex systems curriculum and instruction framework that includes: i) curricular relevance in 21st century needs, standards alignment, and collaboration between researchers and teachers; ii) cognitively-rich pedagogies instantiated in social constructivist strategies such as argumentation and constructionist learning for building computational models; iii) tools for teaching and learning including agent-based computer models and student and teacher curricular guides; and iv) content expertise in complex systems, biology, and computational thinking (see Yoon et al., 2013 for more details). Teachers are expected to integrate project units into their regular Biology curricula throughout the year. During the implementation, teachers have access to project facilitators who assist them in their classrooms; they also have access to other teachers in the project community through a shared online resource tool and periodic face-to-face Saturday professional development meetings. The data reported here are from the first pilot year of the project's implementation from 2011–2012.

Case Study Methodology, Participants, and Data Sources

Since the goal of this exploratory research is to provide a model that defines and illustrates characteristics of adaptive expertise, we have chosen a case study methodology to provide rich descriptions of enactments in classrooms. Case studies enable investigators to explore multiple bounded systems over time through in-depth and multiple data collection and analyses (Creswell, 2007). Furthermore, they afford researchers perspectives on the impact of project activities in naturalistic settings (Creswell, 2007) whereby evidence can be collected and interpretations can be made based on how events unfold in real-world scenarios.

The three cases in the study have been constructed around three participants with fairly differing teacher level and school level demographics. The first participant was Imelda, who had taught for 16 years. In terms of school demographics, her school had the highest achievement of the three with 47% of students scoring in the advanced range in science and just 6% registering on free and reduced priced lunch. The second participant was Jenny, who had 9 years of high school teaching experience and advanced levels of content knowledge (the year after she participated in the project, she was accepted into the Ph.D. program at Harvard to study biology). Of the three schools, her school had the lowest achievement levels with just 14% of students in the advanced range in science on the state test and a high proportion (58%) of students on free and reduced priced lunch. The third participant was Matt, who at the time of the project had 6 years of high school teaching experience. In his school, 20% of students scored in the advanced range in science with 30% of students on free and reduced priced lunch. Across the three cases, the classes were taught at the freshman and sophomore levels.

We collected information from five data sources: i) classroom observations that averaged in total 18 hours for each teacher; ii) exit summer professional development and post-implementation interviews which probed teacher opinions, knowledge, and beliefs about the project, their contribution, and perspectives on success of the implementation; iii) teacher surveys; iv) a focus group interview with project facilitators that captured informal insights into how the implementation in each class occurred; and v) student learning outcomes as measured by growth in student understanding of complex systems in an open-ended question on ecological systems.

Data Analysis

Transcriptions of the data sources were analyzed qualitatively for instances which demonstrated adaptive expertise in the three categories of *flexibility*, ability to demonstrate *deeper level understanding*, and *deliberate practice*. The definitions of the categories were derived from the literature review of adaptive expertise. Levels of expertise were identified through an iterative mining of participant observation and interview data of the larger cohort of project participants. Examples that appeared to be upper and lower anchors of each category were discussed and agreed upon by the research team and used to construct the coding manual found in Table 1. Moderate or medium levels of each category were assigned if they fit in the category between the low and high anchors. The medium codes will eventually be added to the coding scheme with further iterations of analyses. While external validation of the coding manual is forthcoming, we attempted to achieve internal validity by assigning the analysis of each case to two members of the research team who did the coding independently and then compared results. Any discrepancies in the codes were negotiated until consensus was reached.

Table 1: Categorization Manual for Adaptive Expertise.

Category and Definition	Examples
Flexibility The category of flexibility is defined by actions of the teacher that demonstrate the ability to incorporate project activities into their daily practice. Demonstrating flexibility includes an awareness of their student population and their needs, an awareness of the school context, and an ability to respond to unexpected issues that arise through the course of implementation. They are	**High**: Teacher instructs the students that when they get to [argumentation], they need to stop and talk with another group and they should turn off their monitors when they are ready to discuss. (*Here the inference is that he understands that students will continue to play with the simulation without taking the argumentation seriously and then puts instructions into place that will force productive behaviors*). **Low**: Teacher informed us that 17 of the 30 students in this class were failing. He had also NOT prepped the students at all in terms of

able to adapt their practice by being able to incorporate project expectations in their situated context. (Simply eliminating parts of the curriculum is NOT flexible because there is no consideration of how to adapt within the constraints).	introducing them to the simulation environment beforehand. I don't think he reviewed the evolution concepts beforehand either. (*Despite the fact that students are failing in this class, the teacher makes no attempt to scaffold project activities for them*).
Deeper level of understanding This category is defined by actions of the teacher that demonstrate their ability to go beyond what they are required to do with the project. They have assimilated the information and are able to implement extensions or make connections that build or address deeper level of knowledge construction or problem solving. They are able to bring in variation from outside the present system of activity (inclusive of the classroom and school context and the project).	**High**: Teacher told the students who finished early to "mess with what you've done." The students were able to create their own mini experiments by changing one of the variables in the model. This kept the group engaged while waiting for slower students. This also allowed the students space to explore and ask new questions. (*The project at this point did not require students to go under the hood and program. He recognized that for advanced students this might be an interesting thing to do*). **Low**: From here on, the teacher is completely hands-off. It is clear some students are very confused and don't know where to start. (*He is unable to go deeper with his students*).
Deliberate practice This category is defined by actions of the teacher that demonstrate their ability to show motivation, focus, and repeated effort to monitor their practice, and to devise and subsequently attempt new approaches to improve implementation. Teachers exhibit explicit evidence of reflecting on a problem and how to improve.	**High**: Teacher was surprised in the first class that the students didn't "fly though it" and make it through the whole activity. He said that he could have prepared a bit better (*making it his responsibility to organize class better*). "You lose some of your game if you don't practice." (*Here he is metacognitive about what needs to be improved in his practice*). **Low**: In debrief with the teacher: He did not prepare his students at all before implementing the evolution activity. He seemed to think it 'went OK' and again reiterated that this group of students was a tough group. (*Here he is not metacognitive about what needs to be improved in his practice and instead blames students for being "tough"*).

Case Study Results

In this section, we present instances that emerged from the study data sources that illustrate the case teacher's levels of adaptive expertise in each of the three categories. The cases are presented in a semi-hierarchical order of low adaptive expertise to medium/high. The instances selected are representative of the average level of the teacher over time although there may be other instances that diverged from those levels not reported here. In the pilot year, we did not see any teachers with solidly high levels of adaptive expertise, which we expect would improve as teachers continue to implement project activities in following years.

Imelda

Over all, Imelda demonstrated lower adaptive expertise characteristics than the other teachers. In terms of *flexibility*, she had some challenges in effectively adapting her practice and responding to students' confusion about particular aspects of the simulations. During one classroom observation, it was noted that there was "confusion regarding what the curds [were]. It was written on the board, but the students jumped in without reading it" (10/4/2011). Here, it seemed that Imelda had anticipated students' difficulties in identifying parts of the simulation by writing a key on the board beforehand to help students organize these pieces. However, the effectiveness of this scaffold was limited as she failed to direct students' attention to the key. Observations of the same unit revealed that she attempted later to alert students to the key, but that this too resulted in limited impact as "some eyes [were] still on the computer/worksheets [and therefore] not sure how many people followed" (10/5/2011). This example demonstrates Imelda's low flexibility because it illustrates her inability to adapt her instructional practices to set students up to work with and navigate through the simulation. Even when she tried to respond to students' needs, her redirection lacked the facility to effectively support students.

Imelda also demonstrated a low level of *deeper understanding* of the project's tasks and goals. This was most evident in her inability to teach parts of the project's curriculum related to her understanding of how complex systems were instantiated in the computer simulations. In classroom observations, Imelda appeared to ask a lot of simple to answer questions with no active student discussion and no student questions probing more deeply into the material. Her lack of understanding of the content prohibited her from delving into conversations with students that would help them acquire a deeper understanding of the information. For example, when students asked her about how to answer the complex systems questions in the student activity packet, observation notes state that she "deferred to [the facilitator]" (10/6/2011) to answer the questions. Despite the fact that the summer professional development focused a good deal of time on definitions of complex systems, how characteristics were built into the simulations, and examining resources meant to improve teacher knowledge, evidently Imelda's inability to assimilate the information herself prevented her from extending it to her students.

In the third category of expertise, Imelda showed a moderate level of *deliberate practice*. In her post-implementation interview reflecting on how different students progressed through the activities, she explained,

> What I saw was…how different stages are for each topic we cover. There were some students who finished the whole thing and there were some who just got to the 2nd section…Given each class there were students at all different levels, putting them in smaller individual groups helped me understand where they were. But I found a lot of students moving ahead just to finish the page and move onto the next, I'm not sure if they understood what they were doing. I didn't have time to go over all the answers in class. (04/2012)

Observation notes showed that Imelda tried different configurations of student activity groups through different grouping arrangements and organization of desks. In response to seeing the disparate paces at which students completed their work, she purposefully placed her students in smaller groups to better monitor their progress. This reflects a concerted effort on her part to understand students' levels of progress, which locates her at a moderate level of deliberate practice. However, she stopped short of improving her practice, in this example, by not following up on whether the smaller groups made a difference in her ability to monitor student learning.

Jenny

In contrast to Imelda, Jenny demonstrated higher levels of expertise in her classroom implementation. With respect to the category of *flexibility*, it was evident from observations that she needed to be flexible in being able to navigate how she would use the computers available to her in the school. One observation showed that she made room switches with her colleagues in order to use the school computer lab rather than the laptop cart, which held computers that were not compatible with the project's software. In this example, she showed even further flexibility in terms of dealing with the limitations of the computer room set up. In a study survey Jenny commented, "The challenge with the computer lab is that it is nearly impossible to hold class discussions in that room due to the layout. I overcame this by doing discussions before and after the activities, in our regular classroom, and only very infrequently pausing the students while they were working in the lab" (7/12/2012). She identified that, for her students to be able to learn from a group discussion, the layout of the room needed to be different, thus she was able to shift when and where she conducted discussion. However, while Jenny showed flexibility around adapting her practice for optimal computer use, she was only moderately flexible with the content of the curriculum. Observation notes showed that the level at which she pitched her instruction was somewhat higher than her students could comprehend. Her deep content knowledge and ability to connect content to complex systems was the highest of the three teachers and yet, often, she dwelled on aspects of the science that were not necessary for students to understand the simulation.

With respect to demonstrating *deeper level understanding*, Jenny exhibited challenges in helping her students understand how simulations and computational thinking were related to complex systems or biology. The following excerpt from observation notes on an introduction to complex systems illustrates this point.

> [Jenny] ran the simulation a few times and made various changes, explaining some parts of the code and engaging the students to consider "what if" questions. A few students actively responded but a few others started commenting out loud "what does this have to do with biology?" "What does this have to with science?" "Isn't this computer science?" (11/15/2011)

In this episode, Jenny did not appear to be able to answer student questions even though she intentionally tried to bring in computational thinking by posing "what if" questions. The fact that she did however, try to bring computational thinking into the science curriculum shows that she exhibited a moderate deeper level of understanding.

Finally, Jenny showed a high level of *deliberate practice*. In her exit interview after the summer professional development, Jenny expressed concern that she would not be allowed to mold the units to fit her students' needs. She asked, "So one of my questions is to what extent, if any, am I allowed to tweak in this year? Like we have these lesson handouts that are on the flash drive that presumably are already used. I mean I always want to modify things just because of my own particular students or whatever, and I don't feel like I have a good sense at this point about that" (08/2011). In thinking about the upcoming school year, Jenny was concerned that she would not be allowed to tailor the reform activities to her students needs. It is evident that during the summer professional development, Jenny was already thinking about her classroom practice, which continued into the school year. For example, after one of the classroom implementations of the enzyme activity in the Human Body unit, Jenny reflected,

> [The] Potato + hydrogen peroxide lab (which they did before this) is LESS abstract than this. But maybe this was just boring because they already knew so much (or at least had so much exposure) from that experience. For sugar transport, let's try the [project simulation] activity earlier in the sequence to see if that makes it more engaging. (11/18/2011)

In this comment, Jenny reflected on the students' experience and began already planning how to create a better learning environment for her students with the next unit. Here she was motivated and focused on improving the learning experience for her students and demonstrated a high level of deliberate practice.

Matt

Similar to Jenny, Matt exhibited moderate to high levels of expertise. In the category of *flexibility*, he showed moderate ability to adapt project materials into his daily practice. This was most prominent in his attempts at working with the students to complete the required activities in each unit despite other issues getting in the way. For example, when time constraints were an obstacle, rather than simply not completing the activity or eliminating certain portions of the lesson, Matt was open to rearranging the class schedule. One observer noted, "The lab took longer than Matt had wanted, so he changed the plan and said they should complete part 2 for today. He said he would probably need to book the lab for another period to let them complete the whole thing" (11/15/11). Matt was not only flexible in the amount of time required for the activities he also worked to ensure every student participated. He stated in a post-implementation survey,

> This [computational thinking] is not a way in which students are used to thinking. Some students can become frustrated and confused when asked to think in a new way. As a consequence there is a balance that needs to be found to help enhance some students with computational thinking, while not losing the other students. (6/20/2012)

However, occasionally Matt did not seem to be successful at this. For example, an observer reported, "many [student] pairs having only one student working and the other not paying attention. There were also numerous distractions, with students walking through the computer lab and stopping to talk" (11/16/2011) These examples of Matt's inconsistent successes to adapt to external obstacles such as student behavior and time constraints are evidence of Matt's moderate flexibility.

In terms of the category of *deeper level understanding,* Matt showed moderate ability. Several observations noted that he contextualized the project lessons by embellishing the content with demonstrations, "Matt did two demonstrations about diffusion: match (odor) and dye-in-water (liquids)," and questioning, "Matt pointing graphically to the different simulation shapes and asking questions about what components are" (11/10/2011). He also led the class in discussions before and after the lesson each day. For example in one lesson, "Matt did a wrap-up as a class: He summarized: 'the first run was random, was any one color always dominant?" This session continued with a class discussion. Matt occasionally circulated the room, answering students' questions, probing student understanding, and further explaining concepts (4/11/2011), but as one facilitator noted in the focus group interview, "Just comparing him [Matt] to the other teachers, he was much more hands off. He'd hand out the worksheets. He'd actually contextualize the activity, which is nice because not all the teachers did that but then he just kind of let the students go" (5/18/13). Matt's incorporation of simple demonstrations, asking and responding to questions, and leading discussions that supported lesson content are evidence of deeper understanding of the goals of the reform, but because these efforts lacked more robust biology and complex systems content and his hands-off approach during the activities indicate that he did not necessarily facilitate student learning on a deeper level beyond basic conceptual understanding.

Regarding *deliberate practice*, facilitators viewed Matt as one of the most reflective teachers in this cohort. As one facilitator reported in the focus group interview, "He was the most open to feedback of any of the teachers and spent the most time with us debriefing during and after implementations on how he could improve and how he could change things and how we could change things to make them better for him" (5/18/13). His intention to continue honing his approach to incorporating the reform curriculum was clear. On the post-implementation survey at the end of the year he wrote,

> In the future I plan on being more conscious of complex systems in biology and expressing and exploring these ideas more explicitly in my teaching…I hoped that themes of randomness, complex systems, and emergence would carry over into other parts of the curriculum that did not happen to the degree that I hoped, but still intend to pursue this further, next year. (6/20/2012)

While there is no evidence of the frequency and consistency with which Matt practiced deliberately, such statements indicate his interest and intent to improve his practice, which were higher than the other two case teachers.

In the next section, we provide a summary of our efforts in this research. We discuss implications for using an adaptive expertise model as a lens to understand classroom enactments of computer supported complex systems reform curricula with the goal of improving teachers' instructional practices.

Discussion

We were motivated to do this research for several reasons. The study of complex systems has become a prominent research focus in the science and social sciences (The National Academies, 2009) with equally increasing emphasis on learning and instruction particularly in the recently constructed *Next Generation Science Standards*. Although curricular and computational resources to support the learning of complex systems with students has been a focus in the learning sciences, relatively little attention has been paid to understanding how teachers can best support classroom learning experiences, how they can become experts in this support, and what this expertise might look like. Acknowledging the importance of addressing the situated nature of teachers, classrooms, and schools (Penuel et al., 2011), in this paper, we have proposed an adaptive expertise model for evaluating implementation experiences that aims to illustrate the differential qualities of teachers' abilities to adapt complex systems curricula and tools in their biology courses. The model outlines three important characteristics of adaptive expertise: *flexibility* in accommodating project activities into daily classroom and course requirements, ability to demonstrate *deeper level understanding*, and intending or showing efforts toward *deliberate practice* to improve instruction.

The examples illustrated above do not provide evidence of every level of expertise within each of the three categories defined by the model, but there was sufficient data to rank the teachers' levels of adaptive expertise relative to one another. Ultimately this overarching assessment was determined not only by quality of expertise exhibited by each teacher, but by the frequency and consistency of such observations. For example, Imelda showed little to no effort to flexibly incorporate project activities into her classroom. Jenny exhibited high levels of flexibility at times, but only with respect to technology use, and this flexibility was not consistent. Although there are several instances in which Matt's flexibility was high in his response to student engagement or time constraints, he demonstrated some hands-off behaviors at times when students may have needed some further scaffolding. Regarding exhibiting deeper levels of understanding, Imelda's implementation of the lessons was limited and rarely deviated from the teacher's guide other than to ask simple questions. Although Jenny's biology content knowledge was extensive, she often over-reached in terms of students' abilities to comprehend the science. Matt most frequently contextualized the lessons to make the science accessible to students though his efforts were somewhat superficial. All three participants shared reflections regarding their teaching practice, but Matt also initiated dialogue with and sought feedback from project facilitators in order to further reflect upon and improve his practice.

We believe that using an adaptive expertise model helps professional developers and researchers interested in learning how to train teachers to teach with complex systems resources and approaches (Hmelo-Silver & Azevedo, 2006) by illustrating the range of contextualized classroom enactments. As Fairbanks et al. (2010) and others suggest, the complex nature of teaching requires the orchestration of many variables and responses to emergent situations that often cannot be predicted a priori. Particularly with computer-supported learning, where teachers' knowledge of and exposure to technology can impact integration success, (Aldunate & Nussbaum, 2013; Ertmer et al., 2012; Mueller et al., 2008), understanding why or how integration is challenging can be instructive in professional development activities. Furthermore, by investigating and identifying instances in practice that illustrate the characteristics of an adaptive expertise continuum, we aim to articulate a *process* rather than a *state* (Bereiter & Scardamalia, 1993) that can actively extend teachers' capabilities beyond their current competencies. From our small sample of cases, we have already begun to construct tools for developing teachers' adaptive expertise. For example, we have matched teachers who have the same school demographics and provided release or substitute teacher funds for teachers to conduct peer observations. We have selected teachers who have exhibited higher levels of expertise and arranged videotaping of a project unit in action for other teachers to view and discuss. During our most recent summer professional development workshop, we invited teachers to lead discussions about challenges in implementation, and we structured multiple peer sharing sessions for teachers to be able to listen and learn about alternative instructional approaches. These sessions were even extended to peer construction of differentiated lessons for English Language Learners and students with special learning needs. This example specifically encourages deeper level problem solving (de Groot, 1978; Bransford, 1999; Hammerness et al., 2005) that ideally will enable our teachers to perform at a higher level (Ferrari, 2002; Ericsson et al., 2006).

Another area of interest for this research involves providing authentic examples of teachers in action who are working with these reform oriented complex systems curricula. Although we aim to articulate a model of adaptive expertise, we also aim to use the model to map teacher practices to provide other researchers with modular images and descriptions that may be expected of their participants in such projects. Knowing the range can help researchers intentionally plan professional development activities that will best support all teacher learners from the start. We are also ultimately interested in seeing whether our categorization of adaptive expertise correlates with, or even better, predicts student-learning outcomes. In this area, we have already begun to compare the three cases of teacher expertise to the amount of student gain of complex systems understanding which was measured through open ended short answer responses to questions on ecological systems. We hypothesized that findings would reveal a link between higher levels of adaptive expertise as defined by this framework and higher student learning outcomes. Interestingly, across the three teachers, Imelda's students showed negative significant growth in complex systems understanding ($F(1,16) = 6.572$, $p = .012$). Jenny's students showed no growth ($F(1, 6) = 3.769$, $p = .110$) and Matt's students showed marginal significant growth ($F(1, 53) = 3.656$, $p = .061$). We are aware of the unevenness of sample sizes of students in each of the classrooms, which is why we have not offered these results as official evidence at this point. But the student learning outcomes analyses serve as some encouragement that our adaptive expertise model may be able to help in assessing the success of teachers' contextualized implementation of complex systems resources and approaches. Currently, we are analyzing more data with a larger number of teachers and students to see whether this hypothesis is true.

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