Validating a Model for Assessing Teacher's Adaptive Expertise With Computer Supported Complex Systems Curricula and Its Relationship to Student Learning Outcomes

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Abstract: The success of the *Next Generation Science Standards* (NGSS) and similar reforms is contingent upon the quality of teaching, yet the shifts in teaching practice required are substantial. In this study, we propose and validate a model of adaptive expertise needed for teachers to successfully deliver NGSS-informed computer supported complex systems curricula in high school science classrooms. The model is comprised of three research-based qualities that we hypothesize teachers need to demonstrate: *flexibility*, *deeper level understanding*, and *deliberate practice*, in adapting interventions to their particular teaching contexts. We apply the model to understand whether it can, a) show variation between teachers, and b) predict student-learning outcomes. Results show that teacher enactments and interview responses assessed on the model reveal sufficient variation, and are also predictive of students' growth in complex systems understanding. The model has important implications for how to support teachers in adopting new science education reforms.

Keywords: teacher's adaptive expertise, computer supported curricula, complex systems, NGSS

Introduction

The recently released *Next Generation Sciences Standards* (NGSS) in the US provides a vision for science education reform that includes greater emphasis on constructing scientific models, using computational learning supports, and understanding systems and system interactions. The success of the NGSS and similar reforms is contingent upon the quality of teaching, yet the shifts in teaching practice required are substantial (Reiser, 2013; Wilson, 2013). It is also widely known that situational issues like lack of adequate resources, and few high quality professional development (PD) opportunities make adopting reforms challenging (Blandford, 2012; Calabrese Barton, 2007). Furthermore, given the complex nature of science teaching (Wilson, 2013), the extent to which teachers are able to adapt their practice and demonstrate expertise is likely to influence the success of curricular reform adoption and implementation.

With respect to teacher expertise, recent literature has broadened the stance on high quality teaching to include the effect of context on teaching and learning where previous conceptions of expertise, particularly in science, focused mainly on improving teacher's content and pedagogical content knowledge (Kennedy, 2010; National Research Council, 2011; National Science Board, 2010). This supports an expanded notion of expert teaching that includes not only teachers' human capital, but also how teachers navigate the complex and situated nature of teaching (Lin, Schwartz, & Hatano, 2005; Rozenszajn & Yarden, 2013) also known as adaptive expertise (Crawford et al., 2005; De Arment, Reed, & Wetzel, 2013; Hammerness et al., 2007).

While there is substantial theoretical literature on teachers' adaptive expertise, there is a need for empirical evidence illustrating specifically what adaptive expert teaching looks like and whether it promotes improved student-learning outcomes (Janssen et al., 2015; Soslau, 2012). In previous research, we conducted case studies of what adaptive expert teaching looks like when working with computer-supported complex systems curricula defining three essential characteristics: flexibility, deeper level understanding, and deliberate practice (Yoon et al., 2015b). The goal of this current study is to validate the proposed model of teacher adaptive expertise with a larger sample of 10 high school science teachers and to test whether the model is predictive of student learning of complex systems content with 351 students. If the model is robust, we should be able to see significant variation in teacher's adaptive expertise enactments. Thus, the first question guiding our research is, "Does the model differentiate between teachers' levels of adaptive expertise?" Likewise, if the hypothesis that teachers, who have higher levels of adaptive expertise, are better able to adopt and implement reforms, is correct, we should be able to see improved student learning in the classrooms of those teachers. Thus, the second question guiding our research is, "Do levels of teachers' adaptive expertise predict levels of student learning in the target area of reform?" In the following section we briefly review literature on teachers' adaptive expertise and outline the conceptual framework we used to measure it.

Teachers' adaptive expertise for complex systems teaching and learning

High school science teachers are expected to have extensive knowledge of their subject matter, but research has explored how the complex context in which teaching occurs influences student learning in addition to subject matter knowledge (Penuel et al., 2011). From this perspective, pedagogical content knowledge is considered to extend far beyond a teacher's grasp of the subject or training in pedagogy and classroom management. Recent literature defines teachers' pedagogical content knowledge as "teachers' understanding of how to help a group of students understand specific subject matter while using multiple instructional strategies, representations and assessments…working within the contextual, cultural and social limitations in the learning environment" (Nilsson, 2014; p. 1795). Some researchers assert that there is not a single definition of expert teaching, and that the value of teachers' knowledge is context dependent (e.g., Van Driel & Berry, 2012). However, in order to operationalize teaching expertise, we need a way to evaluate expert practice when we see it.

To investigate this, we turn to the study of expertise in the learning sciences (e.g., Bereiter & Scardamalia, 1993) and teaching (e.g., Berliner, 2001). In our previous research, we outlined what expertise might look like and how it can be developed with new or reform-oriented curricula and instruction (Yoon et al., 2015b) carefully examining the practice of three teachers. We constructed a model of important characteristics of teacher adaptive expertise based on literature briefly reviewed below.

How performance on novel problems can be enhanced has been characterized as adaptive expertise (Barnett & Koslowski, 2002; Hatano, 1982; Scardamalia & Bereiter, 1993). The complex nature of teaching requires teachers to be able to orchestrate myriad variables, see multiple perspectives, and identify problems and possibilities in existing and emergent situations (Bransford et al., 2005; Fairbanks et al., 2010). As adaptive experts, teachers deal with non-routine events, and seek to extend their capabilities 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*, which is by nature action oriented and therefore can be observed as it is enacted.

A review of the literature reveals three important characteristics with respect to actions associated with expertise, i.e., flexibility, ability to demonstrate deeper level understanding, and deliberate practice. Flexibility is characterized by the ability to opportunistically plan, change enactments faster than non-experts, and flexibly and critically apply their knowledge to new situations while constantly learning (Berliner, 2001; Bransford et al., 1999; Chi, 2011; Ferrari, 2002). 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). Deeper level understanding is associated with one's ability to recognize meaningful patterns quickly, allowing one to attend to deeper level problem solving and in turn perform at a higher level (Berliner, 2001; Bransford, 1999; Ericsson et al., 2006; Ferrari, 2002; Hammerness et al., 2005; Levy & Murnane, 2004). Deliberate practice is manifested in one's ability to engage in reflection and conscious deliberation. Experts who demonstrate deliberate practice 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 Yoon et al. (2015b), we found that the three teachers varied in these characteristics and that the variations appeared to influence the success of the implementation of project activities based in teaching and learning of complex systems. In this study, we aim to validate the model with a larger sample of teachers. We see this as an efficacy study testing the model with a different population, where the previous pilot work would be categorized as design and development research using the *Common Guidelines for Education Research and Development* (IES/NSF, 2013). Such progressions of research are necessary to ensure high quality evidence, meaningful findings, and actionable results through the systematic development of knowledge (IES/NSF, 2013). Before moving onto the study, we briefly describe complex systems and instruction that is best supported through computer simulations (Yoon et al., 2015a).

Complex systems are found in myriad natural and social phenomena. While definitions of complex systems vary based on discipline, central features include multiple interacting variables that form patterns discernable over time fueled by dynamic processes (Yoon, 2011). For example, ecological systems are made up of different trophic levels (e.g., producers and consumers) whereby through predator-prey interactions, energy flows through the system optimally existing in states of equilibrium (e.g., stable producer and consumer populations). System states fluctuate often by hidden variables (e.g., random mutations) at micro levels that are only observable over time at larger scales (a process known as emergence). Therefore, complex systems researchers use computer simulations to assist in modeling system evolution to investigate as well as to make predictions of future states (e.g., how drought patterns affect food webs).

Methods

Context

This study is part of a larger project aimed at building students' and teachers' understanding of biology content and instructional practices through exploring computational models of complex systems. For training on the intervention, teachers participated in a weeklong 30–hour summer PD workshop and follow-up Saturday workshops during the school year (approximately two workshops per semester totaling 10 hours) between 2012 and 2013. PD activities included hands-on training in five biology units on the topics of Genetics, Evolution, Ecology, the Human Body, and Animal Systems. The units entail working with the agent-based simulations that combine graphical blocks-based programming with a 3-D game-like interface. The units also include working through experiments that provide experiences in core scientific practices as outlined in the NGSS, such as analyzing and interpreting data, engaging in argument from evidence, and obtaining, evaluating and communicating information There is no set sequence for the units; instead, teachers can implement the units in the order that suits their school curriculum. The curricular materials for each unit take 2 to 3 days to complete and include popular and academic literature about complex systems as well as short movies, PowerPoint presentations, and teacher and student activity guides.

PD activities also included training in complex systems structures and processes, such as feedback, interdependence, self-organization, and emergence, as well as activities that specified where the units fit into the high school biology curriculum. During the school year, teachers implemented the units in their biology classes.

Participants

We recruited 10 teachers—seven women and three men—from eight Boston-area public schools. The teachers came from a diverse set of schools. One school was as high as 75% ethnic/racial minorities, while another school was almost entirely White (3% minority). School-level percentages of low-income students ranged from approximately 14% to 80%. The percentage of students considered proficient or advanced on the state standardized science test ranged from 45 to 93. Teachers, on average, had 8.5 years of teaching experience, with a range of 3.5 to 19 years.

We collected student data in 10 classrooms drawn from 8 schools and a total of 351 students. The schools did not release individual student demographic and achievement data to us, so we cannot report accurate sample data in these areas. However, due to the range of classrooms, we believe that the students we worked with are a relatively representative sample of the population-level statistics that are reported. Table 1 provides further demographic details of the student population.

Table 1: School Level Demographic Data

School ID	School-Level Characteristics		
	% Low Income	**% Above Proficient on State Assessment**	**% Minority***
1	36.0	71	NA
2	79.6	45	75.3
3	59.0	63	70.5
4	27.7	65	40.2
5	18.0	93	36.2
6	14.8	89	30.5
7	14.2	82	3.6
8	NA	78	25.5
Totals	35.6	73.3%	40.3

*Minority defined as non-white

Data sources

To see how teachers varied in their enactments of teachers' adaptive expertise, we analyzed classroom observations, year-end teacher interviews, teacher reflections of each unit implementation, and researcher focus group interviews. For the classroom observations, teachers and students were observed at least twice during the school year by research staff. The observation protocol required attention to details about how teachers and students worked with the simulations, how teachers facilitated learning with the curricular materials, and how teachers scaffolded student understanding of complex systems. Teacher interviews and reflections probed teacher's ideas about challenges in implementation and how they overcame them with particular focus on context variables such as student abilities, and resource availability. At the end of the year, a focus group interview was also held with the research staff who observed in teacher's classrooms to capture more formal and anecdotal information about the content of their communication with teachers between observations, and general impressions of teacher's relative abilities to teach using intervention activities.

To determine student understanding of complex systems, two open-ended questions were administered before and after the intervention that provided scenarios on the topics of ecology and evolution. The scenarios are presented below.

> Ecology Scenario
> Imagine a flock of geese arriving in a park in Boston, where geese haven't lived before. Describe how the addition of these geese to the park affects the ecosystem over time. Consider both the living and non-living parts of the ecosystem.
>
> Evolution Scenario
> Some mosquitoes no longer die when DDT (a powerful chemical used to kill insects) is sprayed on them, while others do. Many years ago, DDT worked to kill almost all mosquitoes. How would biologists explain why some mosquitoes do not die anymore when DDT is sprayed on them?

Analysis

To analyze teacher's adaptive expertise enactments, the interview transcripts and recorded reflections and classroom observations were mined and coded for levels of enactments based on the categorization manual found in Table 2. The manual was first constructed and validated for the previous study (Yoon et al., 2015b) by researchers on the project team (authors 1–3) with only low and high enactments specified. For this study, we modified the manual to include enactments that were determined to fall in the middle range to provide a greater range. Two researchers external to the project were trained on the manual with 20% of the data yielding an interrater reliability alpha score of .75. The full data set was then scored by the authors. Discrepant or uncertain enactments were negotiated and given a single code. The highest score a teacher could receive in each category was 3 with a total combined adaptive expertise score of up to 9. We ran an analysis of variance (ANOVA) with the complete data set to see whether there was sufficient variation between teachers.

Table 2: Categorization Manual for Teachers' Adaptive Expertise

Category and Definition	Examples
Flexibility • Ability to incorporate project activities into their daily practice. • Awareness of their student population and their needs • Awareness of the school context • Ability to respond to unexpected issues that arise • Able to adapt their practice by being able to incorporate project expectations in their situated context.	**High**: Teacher ran the simulation on the smartboard from his computer as students worked on their own so he could point things out and they could follow along. **Medium**: 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. **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 introducing them to the simulation environment beforehand. I don't think he reviewed the evolution concepts beforehand either.
Deeper level of understanding • Actions of the teacher that demonstrate their ability to go beyond what they are required to do with the project. • Are able to implement extensions or make connections that build or address deeper level of knowledge construction or problem solving. • Bring in variation from outside the present system of activity	**High**: Teacher introduces complex systems. Talks about agents that follow certain rules. Talks about intestines and about phospholipid bilayer. **Medium**: 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. **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.

Deliberate practice	High: After some readjustment from Day 1 between teacher A & teacher B, teacher B determined they could split the laptop cart and she could use laptops in the room – this was a big advantage.
• Actions of the teacher that demonstrate their ability to show motivation, focus, and repeated effort to monitor their practice, • Devise and subsequently attempt new approaches to improve implementation • Teachers exhibit explicit evidence of reflecting on a problem and how to improve.	**Medium**: 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 **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

Student responses to the open-ended question were scored on a three-point scale from (1) clockwork thinking (non-complex) to (3) complex thinking in four categories: predictability, processes, order, and emergence and scale. Table 3 shows a shortened version of the categorization manual which has been validated in previous studies, e.g., Yoon et al., 2015a; Yoon et al., forthcoming). We ran a regression analysis to see whether teachers' adaptive expertise scores were predictive of students' complex systems scores.

Table 3: Categorization Manual for Student's Complex Systems Understanding

Complex Systems Components	Descriptions
Predictability	The emphasis is on the predictability of the effects caused by the agent in question. According to the clockwork framework, the way in which a part or agent operates or affects other components of the system is predictable. In a complex framework, it is impossible to anticipate precisely the behavior of the system. This is because the actions of agents cannot be predicted (as random forces or chance factors can affect an agent's actions) even if we know the rules or characteristics of the agent.
Processes	Processes refer to the dynamism of the mechanisms that underlie the phenomena (i.e., how the system works or is thought to work_. In a clockwork framework, there is a beginning, middle, and end in the system. The system is composed of static events. While perturbations (actions by/on parts) in the system may cause change to occur, the change terminates once an outcome is achieved. In a complex systems framework, there is no definite beginning and end to the activity. System processes are ongoing and dynamic.
Order	The focus is the organization of the system or phenomenon as centralized or decentralized. A clockwork framework assumes that all systems are controlled by a central agent (e.g., all action is dictated by a leader). Order is established top-down or determined with a specific purpose in mind. In a complex systems framework, control is decentralized and distributed to multiple parts or agents. Order in the system is self-organized or 'bottom-up' and emerges spontaneously.
Emergence and Scale	Emergence refers to the phenomenon where the complex entity manifests properties that exceed the summed traits and capacities of individual components (Davis & Sumara, 2006). In other words, these complex patterns simply emerge from the simpler, interdependent interactions among the components (Capra, 1996). In a clockwork framework, parts of the system are perceived to be isolated with little interdependency among them. This is because of the linear nature that characterizes these relationships. Thus, there are no large, global patterns that emerge from actions imposed on the system. Rather, these actions cause only localized changes (e.g., geese eat plants causes a decrease in grass). In a complex system, because parts or agents are interdependent in multiple ways, an action (small or large) that is imposed on the system may have large and far-reaching consequences on the numerous parts and agents of the system. This may in turn result in large-scale change and evolution.

Findings

Teacher adaptive expertise combined scores ranged from 3.67 to 7.65 out of a possible score of 9 (see Table 4). The mean adaptive expertise was 6.18 with a standard deviation of 1.01. To determine whether there were meaningful differences in adaptive expertise between teachers, we conducted an ANOVA of the teachers' adaptive expertise item scorings (See Table 5). From these results (F (9, 362) = 15.07, p <0.001), we conclude that the teachers in our sample differed significantly in their adaptive expertise.

Table 4: Adaptive Expertise Scores by Category for Each Teacher

Teacher	Flexibility	Deeper Understanding	Deliberate Practice	Overall Expertise
1	2.25	2.17	2.00	6.42
2	1.15	1.18	1.33	3.67
3	2.65	2.59	2.42	7.65
4	2.06	1.79	2.20	6.04
5	1.67	1.43	2.43	5.53
6	2.06	1.79	2.36	6.21
7	2.50	2.13	2.00	6.63
8	2.21	2.18	2.62	7.02
9	1.92	1.10	2.67	5.69
10	2.22	2.04	2.67	6.93

Table 5: Analysis of Variance of Teacher Adaptive Expertise Item Scorings

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Teacher	9	60.53	6.73	15.07	<0.001
Residuals	362	143.30	0.40		

To test whether teachers' adaptive expertise scores were predictive of student understanding of complex systems, regressions were run holding student pre-scores constant. The first regression examined student complex system understanding in ecology and the second regression examined student complex system understanding in evolution. Table 6 shows results for ecology (F (2, 350)= 22.13, p<0.001). For each one-unit increase in teacher combined AE rating, there was an increase of 0.94 points in student performance on the ecology question. Table 7 shows the results for evolution (F (2, 295) = 28.64, p<0.001). Here, student scores were 1.24 points higher for each one-unit increase in their teacher's combined AE rating. Both of these analyses led us to the same conclusion: adaptive expertise is significantly related to student achievement in complex systems.

Table 6: Regression Assessing the Relationship Between Student Complex Systems Understanding of Ecology and Teacher Adaptive Expertise

	Estimate	Std. Error	t-value	p-value
(Intercept)	3.09	0.57	5.39	<0.001
Overall Combined AE Rating	0.94	0.27	3.46	<0.001
Pre-test	0.25	0.05	4.78	<0.001

F-statistic: 22.13 on 2 and 350 degrees of freedom (p-value <0.001)

Table 7: Regression Assessing the Relationship Between Student Complex Systems Understanding of Evolution and Teacher Adaptive Expertise

	Estimate	Std. Error	t-value	p-value
(Intercept)	1.55	0.75	2.07	0.039
Overall Combined AE Rating	1.24	0.36	3.44	<0.001
Pre-test	0.39	0.07	5.89	<0.001

F-statistic: 28.64 on 2 and 295 degrees of freedom (p-value <0.001)

Conclusions and implications

Our findings provide a model of the qualities important in defining teachers' adaptive expertise and what it looks like in the classroom with computer supported complex systems curricula. Furthermore, as we have found the model to demonstrate sufficient variation among teachers and to be predictive of student learning, this study provides important empirical evidence to the research on teachers' adaptive expertise (Janssen et al., 2015; Soslau, 2012). 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 by illustrating the range of contextualized classroom enactments. As Fairbanks et al. (2010) and other researchers suggest, the complex nature of teaching requires the orchestration of many variables and responses to emergent situations that often cannot be predicted a priori.

We are aware of the limitations of the study in that the sample was small and self-selected therefore we can make no generalizability of claims. We do believe, however, that this efficacy research provides evidence of the support of such an adaptive expertise model for teachers in line with developing systematic knowledge that can eventually be scaled (IES/NSF, 2013). Furthermore, as Wilson (2013) notes, it is rare to be able to link learning directly to teacher practices. These findings provide promising evidence in support of a larger scale effort to develop teachers' adaptive expertise to ensure adoption and high quality implementation of curriculum and instruction based in the NGSS.

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