Feedback and Adaptation Within a Complex Systems Approach to Designing for Scalable and Sustainable Professional Development

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Abstract: This paper reports on the efficacy of a professional development framework premised on four complex systems design principles of which two are detailed here—feedback and adaptation. The framework is applied to the design and delivery of the first two years of a three-year study aimed at improving teacher and student understanding of computational modeling tools. We demonstrate that structuring a professional development program around these principles facilitates the development of important strategies such as the identification of salient system variables, effectively distributing expertise, and constructing curricular adaptations. We discuss two meta-level themes that may account for the success of the principles: attending to structure vs. agency and setting short-term vs. long-term goals. Each illustrates the tension existing between competing variables that need to be considered to effectively program for professional development around educational technology with the goal of sustaining and scaling innovations in real world complex educational systems.

Purpose

The complexity of implementing educational change has been a recent focus of many educational leaders interested in understanding how curricular and pedagogical reform efforts can have a scalable, enduring impact in educational systems. In his *Change Forces* series, Fullan (cf. 2003) uses complex systems theory as an organizing framework to reveal core concepts such as non-linearity, unpredictability and multi-level agency that are important issues to contend with in real-world educational systems. In reference to scale, Elmore (1996) writes about the difficulties experienced by nested clusters of innovation when trying to move from local to global contexts. Coburn (2003) reinforces the notion of complexity stating that problems of scale stem from the inability of research to address the inherent multidimensionality between and within classrooms, schools and districts. Cuban et al., (2002) likewise remark that changes of deeply entrenched systemic organizational and operational factors must take place in order to move beyond simple fleeting modifications to practice. Collectively, there is ample evidence to suggest that a complex systems approach for the design and implementation of an educational improvement program is a prudent undertaking. This paper reports on the results of a research study in which complex systems processes are used to organize, harness and evaluate professional development activities around educational technology. Described in greater detail below, the proposed complex systems approach is applied to a comprehensive large-scale NSF-funded project under the program title *Information Technology Experiences for Students and Teachers* (ITEST). The specific purpose of this paper is to reveal outcomes of two design principles in the complex systems approach—*feedback* and *adaptation*—in the first two years of a three-year project implementation.

Theoretical Framework

Examples of complex systems run from relatively micro levels of cellular organization to more macro levels of companies, cities and ecosystems. Despite variation in physical components or agents, complex systems can be generally defined as existing when any given number of interconnected elements, parts or individuals, communicate in non-linear ways. The patterns of interactions form a collective network of relationships that exhibit emergent properties that are not observable at subsystem levels. When perturbations occur, the network self-organizes in, often unpredictable ways where new properties can emerge. The manner in which complex systems communicate, respond to perturbations and self-organize is understood by studying the dynamical processes through which they evolve over time. Acquiring information from their environment, complex systems identify regularities in that information and use this to modify behavior in the real world (Gell-Mann, 1994). In this way, they are said to be *adaptive*. To understand how a system's adaptive attributes emerge, a necessary process to consider is *feedback*, i.e., how systems handle information acquired from the environment. Such complex system processes have already been used to inform research with the goal of *designing* structures and strategies to improve the success of organizations outside of education (cf. Senge, 2000).

Methods

The Program

The ITEST project entitled *New Mexico Adventures in Modeling (AIM)*, consisted of activities structured around two modeling tools called *StarLogo* (Colella & Klopfer, 2000)—a desktop computer application that allows users to interact with agent-based complex systems simulations and Participatory Simulations (Klopfer et al., 2005)—handheld computer simulations. Previous research efforts were channeled into creating stable modeling tools and developing accompanying curriculum materials (Colella et al., 2001). The focus of the present study was to understand how the modeling tools and curriculum materials could be applied in formal school settings.

Professional Development Framework

Using four design principles (of which the first two are reported here), feedback, adaptation, network capital and self-organization, a professional development framework was constructed to inform the scope and sequence of professional development activities that included: 1) A 10-day 60 hour intensive summer teacher workshop; 2) Bi-monthly whole group face-to-face meetings; 3) Access to local expert facilitators; and 4) Communication of a shared on-line bulletin board. How the concepts of feedback and adaptation were applied is described below.

Feedback

The design principle of feedback was used to gather important information about how the professional development community was operating at every stage of the project. Continuous and multiple data collection techniques such as pre/during/post-workshop surveys, video and audio-taped workshop discussions, assessment of online community, participant interviews, focus group discussions, timelines, curriculum plans and researcher field notes, were used to evaluate the success of the program at specific instances in time. This information was used as starting points for the redesign of program activities to influence the alignment of system variables with program learning goals so that outcomes were mutually beneficial to participants and the program.

Adaptation

The second design principle in the complex systems framework was adaptation. In attending to environmental and individual conditions garnered from feedback activities, the program sought to respond to context-dependent factors that influenced individual teaching experiences, and curricular and system-wide purposes. Through continuous modifications to program structures and goals, professional development strategies evolved toward meeting the needs of multiple constituencies.

Participants

47 middle and high school teacher participants were recruited from school districts in a mixed urban-rural area in the southwestern part of the U.S. Teachers were recruited to participate in either the 2003-2004 (Cohort 1) or 2004-2005 (Cohort 2) academic school years. Teaching subjects included Mathematics, Earth Science, Biology, General Science Social Science, Computers and English. Computer programming skills and complex systems understanding ranged from expert to novice. Of the 47 teachers recruited, 43% were female and 57% were male, half had a masters degree or higher, 45% taught less than 6 years, 19% taught between 6-10 years and 36% taught more than 10 years. The instructional team consisted of three local facilitators and three research investigators.

Data Sources and Data Analyses

The extensive list of data sources used in the study is outlined in the section on *Feedback*. The intent of the multiple data source collection was to capture as many of the implementation details as possible. The methodology was qualitative in nature (Lincoln & Guba, 2000) with the assumption that categories and themes would emerge from the data. Codes, categories and themes for the data set were, for the most part, negotiated amongst the investigator team (Strauss & Corbin, 1998). An external rater was used to obtain inter-rater reliability (90%) for the topology of affordances and barriers to implementation presented in Table 1. A categorization manual for the topology was constructed using the categories of structure, function and behavior described in Hmelo (2000). The variables were further divided into micro, meso, and macro level variables that reflect the organization of

Table 1. Topology of Affordances and Barriers to Implementation

Levels	Structure	Function	Behavior
Micro	• individual teaching time constraints	• a teacher's ability to integrate AIM activities with the standard curriculum • number of years of experience a teacher has • a teacher's experience in previous careers e.g., being a computer programmer • a teacher having ready-made curriculum materials to implement AIM activities • a teacher's skill in using information technology • the subject domain of a teacher and grade level applicability • a teacher's classroom management skills • a teacher's programming knowledge/skills	• a teacher's self-efficacy beliefs • a teacher's preferred teaching style, e.g., student-centered vs. teacher-centered • a teacher's level of innovativeness • a teacher's complex systems understanding • a teacher's epistemological beliefs about teaching • a teacher's risk-taking threshold • a teacher's comfort level using technology
Meso	• lack of classroom space to house computers within the school • organization of the school day within the school • centralized control of computer lab, i.e., one person with the key • location of computers in the school, e.g., computer in a lab vs. computers in each classroom • AIM facilitator accessibility, e.g., how facilitator's have been organized or allocated • one vs. several teachers implementing AIM activities in a school • inadequate computer hardware in a school • disorganization at the school level	• a school's demographics, e.g., economically challenged, high ESL • administrator's support within a school • quality of AIM instructor facilitation, e.g., behavior, energy level, enthusiasm • face-to-face AIM community support and collaboration • on-line AIM community support and collaboration • intensive summer workshop to learn how to implement AIM activities • on-going post-summer workshop support • one or no technology support staff available	• teacher envy in a school, e.g., innovators vs. status quo • a school's or departments commitment to or disposition toward other curricular/instructional programs • school culture, e.g., beliefs or philosophies that encourage innovation
Macro	• other district-wide edicts or agendas • insufficient technology funding at the district level • district level disorganization • standardized testing • No Child Left Behind legislation	• AIM program connections to outside educational programs such as the New Mexico Adventures in Super Computing Challenge and Los Alamos National Labs	• motivation to choose high paying PD workshops because of low teacher's salaries in the state • a districts commitment to or disposition toward other curricular/instructional programs

educational systems. The micro, meso and macro level categorization has been used in a range of different domains to characterize complex system organization (cf. Liljenstrom & Svedin, 2005). In this study, micro level variables encompassed individual teachers and their classrooms; meso level variables encompassed multiple teachers within the school or within the *New Mexico Adventures in Modeling* project; and macro level variables encompassed multiple schools, district-wide activities and beyond.

Results

This section is organized by evidence and/or outcomes under each of the design principles that illustrate or reveal the evolving nature and success of the professional development activities undertaken in the project.

Feedback

Table 1 shows a topology of affordances and barriers to implementation constructed from the structure, function, behavior—micro, meso, macro taxonomy. The topology was used to support several program activities.

Identifying a Propensity Toward Change Hierarchy

Surveying the topology of variables allowed the project team to identify which variables were the most difficult, comparatively, within which to facilitate change. Structural variables presented the greatest challenge. For example, the location of computers within a school appeared to be a ubiquitous concern for our participants, many of whom complained about having to waste valuable teaching time tracking down the computer lab manager, reorganizing schedules to accommodate available space, and moving classes between rooms that were often located in different halls or even different buildings. These structural variables were ones that the project team had little control over. The pattern of difficulty also appeared to increase, not surprisingly, moving from micro to macro levels, e.g., from the individual to the school-wide district. Behavioral variables were the next most difficult to work with, however, many of these variables showed small increments of growth as participation in program activities increased over time. For example, teacher's risk-taking thresholds and comfort levels in working with both the desktop and handheld computer simulations improved with successive iterations of classroom implementations. Frequent availability of facilitators and willingness to provide technical, pedagogical and moral support was found to be a key change mechanism. Thus, in terms of behavioral variables, the role of some members of the project team was one of edification, a kind of support or resource that was continuously available as changes in self-efficacy beliefs, for example, emerged. However, similar to structural variables, the locus of control generally existed just outside the purview of the project team. Likewise, the level of difficulty in effecting change generally increased as the size of the system increased. Functional variables were by far the easiest ones to facilitate in terms of working toward improving implementation conditions. Apart from two variables, i.e., number of years of experience a teacher has and a teacher's experience in previous careers, the project team had some level of control over all other variables that enabled relatively immediate action. For example, teacher's indicated that they would be more inclined to use StarLogo activities in the classroom if they had ready-made curriculum materials available to them. Therefore, compiling and constructing subject-specific models and curricula became a focal aspect of our professional development workshops where previously, skill in programming and the development of complex systems theoretical understanding took the greatest priorities.

Distributing Expertise

Understanding specific implementation needs enabled us to select from the available bank of expertise and assign activities to the most appropriate project members. For example, due to his previous career experience as a manager for various web-based games and simulations projects one of our lead facilitators assumed the responsibility for the design and construction of the web-based models library. Another facilitator, with 40 years of teaching experience, had worked in various leadership capacities including district-wide technology coordinator, and had an implicit understanding of teacher self-efficacy issues in science and technology classes. She had also developed a vast and intricate educational network in which she could draw on the expertise of former colleagues and make valuable connections between people. She visited several of our struggling teachers to lend moral support and in two cases, through her network of connections, secured extra computers in classrooms that had insufficient hardware to run StarLogo models. Through her work with after school programs in the local school district, another of our lead facilitators became well connected with the various middle and high school administrators in the district. Furthermore, because her own children were attending district area schools, she knew exactly when special events were being held, when schools were closed and when teachers would be tied up with other professional commitments. All of this information was very useful in planning, for example, when our key informational open houses would be held to showcase the program to schools and administrators.

Adaptation

Adaptations made to key professional development components in the project included the categories of recruitment, partnerships & networks, administration, workshops, facilitation structure, curriculum development and communication tools. Three components are discussed in detail below that show the evolution of adaptive professional development strategies.

Workshops

Three major goals underpin the program framework: working with teachers to develop and integrate Adventures in Modeling curriculum in their specific content areas; facilitating a shift toward understanding phenomena from a complex systems perspective; and teaching computational skills to construct, manage and interpret models or simulations. Although all three serve important roles, arguably the most critical of these is the ability to use AIM curricula in the classroom. However, what we found from participant feedback was that learning the StarLogo programming language was the first barrier to entry in terms of teacher self-efficacy beliefs, comfort levels and risk-taking thresholds. For a majority of our participants who were novice programmers, this perception became a deterrent for using AIM activities with their students. Consequently, a good portion of workshop instructional time during the first year focused on helping teachers improve programming skills. Yet despite this effort, teachers continued to struggle with this dimension. Obviously some changes needed to be made. According to discussions with facilitators and long-time StarLogo users, there was underrepresented potential and value in exploring uses of existing models. It was revealed that more experienced StarLogo teachers often began with working code and simply made minor modifications to suit the purpose of the particular concept being illustrated. In order to follow this curricular route, however, teachers needed to have a solid understanding of the complex system they wanted to model. The focus of the second summer and follow-up workshops thus shifted to address the latter two of the three major goals. Not coincidentally, the percentage of teachers who incorporated StarLogo activities within the first term of the school year increased from 41% with Cohort 1 to 65% with Cohort 2.

Facilitation Structure

Initially the program began with three instructional facilitators (tier 1) who had differing levels of responsibilities, time commitments and flexibility in their workday that constrained or enabled participation in the project. The inner-city science teacher for example, could not leave his school during the day to facilitate in another teacher's classroom. After school time was also tied up with detentions and/or staff meetings focused on school improvement. The facilitator with the greatest flexibility in her schedule was the after school program coordinator. She indeed had an enormous impact helping teachers work with their students on AIM activities, however, she was only one person and there were many more teachers who could have benefited from the assistance. To address this issue, the program moved toward a more decentralized facilitation model during the second year of the project in which four Cohort 1 participants became mentors in their own schools as tier 2 facilitators. The hope was that this would alleviate some of the time constraints previously experienced by tier 1 facilitators and that small communities would emerge around a nucleus of like-minded teachers. After some time, we found that, although there was a strong desire to create local community structures, the notion of decentralized facilitation still could not overcome the day-to-day teaching issues such as difficulties in finding common times to meet across different subjects and grade teams. In the Winter '04 and Spring '05 terms, the facilitation structure became a combination model of within school decentralized facilitation accompanied by two centralized non-teaching facilitators who shared classroom visitation and facilitation duties across program schools. This structure appeared to suit the greatest number of participant needs allowing for more informal collaboration between tier 2 facilitators and the teachers in their schools and more formal classroom assistance conducted by tier 1 facilitators.

Curriculum Development

Changes made in the curriculum development component are perhaps the most illustrative of how the program continuously adapted to emergent professional development foci. Four curriculum tools were developed over the course of the two-year implementation, each reflecting participant needs at the time of development. As previously discussed, it was determined after the first summer workshop that a major barrier to program efficacy was teachers' understanding of StarLogo programming and model construction. In order to assist teachers, one tier 1 facilitator created a comprehensive modeling tutorial and provided pedagogical strategies that would help teachers use the tutorial with their own students. A models library (http://education.mit.edu/starlogo/library) became the next curriculum piece to be developed as participant needs and program foci shifted to curriculum integration. A multi-media case of exemplary StarLogo use in the classroom (http://education.mit.edu/aim-cases/index.php) was also constructed as teachers voiced their concerns about not being able to observe how AIM activities would work in real classroom settings. And finally, the curriculum binder was constructed with ready-to-use sample units parsed into subject content areas and grade levels. It was expected that participants would continue to add lessons to the binder and maintain it for their own purposes. Although the curriculum binder may seem to be a trivial addition, it represented movement toward a more autonomous, self-organized point within the professional development continuum where teachers were poised to take more ownership of their own learning. After each curriculum tool was introduced, participants showed overwhelming interest and used them to more or less degrees in their curricula.

Discussion and Educational Implications

Reiser et al. (2000) have written about the importance of attending to mutual adaptation of research goals and local contexts in order to support educational reform efforts. Fishman et al. (2004) present a list of key issues to explore when dealing with technology innovations and the capacities of the educational contexts the technologies are intended for. By highlighting the mechanisms of feedback and adaptation we have offered practical insights for professional development efforts in a number of different ways. When looking across the evidence, two meta-level themes can also be hypothesized to account for the success of the framework. Also rooted in a complex systems explanation, these themes: structure vs. agency and short-term vs. long-term goals, have promising implications for professional development and educational reform. The tension between structure and agency is an essential characteristic of real world complex systems. As Watts (2003) notes, “It is through our surrounding structure that we order and make sense of the world. Yet too much structure, too strong a hold of the past on the future, can…be a bad thing, leading to stagnation and isolation” (p. 100). Ensuring a balance between structure and agency appeared to be a critical enabling component of our professional development framework. Structure can be interpreted in at least two ways, i.e., the structure of professional development activities and the educational structure as outlined in the topology of implementation variables (Table 1). Similarly, multiple levels of agency existed in the program, i.e., individual participant personal and professional agency, facilitator/researcher agency, a collective group agency as educators in our distinct community or educators within the more global educational system. Understanding the context within which we operated through feedback—the physical barriers such as centralized computers, broader educationally imposed barriers such as NCLB and the like, then applying this information to promote adaptation, facilitated a constant development and exchange between structural (e.g., construction of curricular tools) and agency-related (self-efficacy beliefs) variables.

Lemke (2001) presents a model for understanding multi-scale complex systems that is premised on interpreting processes and activities that occur within and between different levels of organization. He suggests that how we come to understand the meaning of something is often contingent on the accumulation and transfer of information, acquired through short-term events, that may be distant from each other in space and time. Thus, we must be cognizant of the notion that change can happen over shorter and longer periods of time. He also states, “To analyze human social activity, development and learning across multiple time scales, we must be as willing to look at biography and history as at situations and moments, as methodologically and theoretically prepared to study institutions and communities as to study students and classrooms” (p. 25). In Table 1, we presented a topology of implementation variables that include biographical and historical information (e.g., previous career experiences) as well as contextual or environmental information that potentially impacts the success of the program. These implementation variables have also been analyzed to take account of the multiple levels of systems we work with. But perhaps the greatest use of the topology that we have found has been as a tool for setting short-term and long-term program goals as well as for understanding short-term and long-term participant goals. Identifying hierarchies of change and determining which variables were the most feasible to address at different times, provided the project team with a manageable structure from which to proceed toward positive project development.

Conclusions

The purpose of this paper was to demonstrate the efficacy of a professional development framework informed by two complex systems design principles of feedback and adaptation. We have shown that structuring a professional development program around these principles facilitates the development of important strategies and processes for program organizers such as the identification of salient system variables, effectively distributing expertise, and adaptation of essential professional development resources and activities. We hypothesize two meta-level themes that may account for success. Each illustrates the tension that exists between competing variables that need to be considered in order to work effectively in real world complex educational systems. We believe that knowledge gleaned from this study contributes to our understanding of how the complex systems mechanisms of feedback and adaptation can have potentially powerful impacts on scalable and sustainable professional development and educational reform.

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Acknowledgements

We would like to gratefully acknowledge Judy Perry for her assistance on the data analysis portion of this paper. This research was supported by a National Science Foundation ITEST Grant (Award # 0322573).