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Making a Mesh of It: A STELLAR Approach to Teacher Professional Development

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Abstract. We propose a model for Internet learning grounded in a theoretical analysis of transfer and embodied within a general tool called STELLAR (Socio-Technical Environment for Learning and Learning-Activity Research). STELLAR supports creation and management of online courses that systematically integrate collaborative design with study of text and video. The objective of STELLAR is to help learners develop "meshed" cognitive representations that support transfer of course knowledge to professional practice. Using STELLAR, we created experimental online courses in the learning sciences[1] for pre-service teachers. Our research produced substantial evidence supporting our approach and a body of empirically tested online materials and collaborative activities for teacher education.

Keywords: Teacher education, transfer, online learning, instructional design, problem-based learning, design-based learning, video cases

INTRODUCTION

There is substantial evidence, summarized in publications sponsored by the US National Academy of Education (Bransford, Derry, & Berliner, in press) and US National Academy of Science (Bransford, Brown, & Cocking, 2000), that when educators base instructional decision making in discipline-appropriate learning sciences, students of all ages and abilities are more likely to acquire deeper, more meaningful, more useful understandings. However, although virtually every program of teacher education "covers" learning-sciences subject matter in one or more courses, research shows that knowledge acquired during teacher preparation is used by teachers in limited and naïve ways (Darling-Hammond & Sykes, 1999; Weiss, Pasley, Smith, Banilower, & Heck, 2003). Moreover, evidence from multiple disciplines shows that transfer of training from classroom to practice is very difficult to achieve (Gick & Holyoak, 1980; Lave & Wenger, 1991; Salomon & Perkins, 1989). Thus, an important question motivating our work is how to design learning environments that can feasibly be implemented on a large scale and that will help teachers acquire *useful* learning-sciences knowledge from their teacher education programs.

We are especially interested in learning how to exploit the power of Internet technology for "scaling up" good professional development. Instructional approaches with new media can enhance transfer, accelerate learning (Spiro, Collins, Thota, & Feltovich, 2003; Spiro, Feltovich, & Coulson, 1992), and create more seamless connections between formal learning environments and professional practice (Fischer, 1998). Although online graduate programs for educators are proliferating, we believe most current models fail to address the changing demands of professional practice. Like Fischer (2003), we argue for educational programs that encourage students to be life-long, reflective learners who employ new media to conduct research and collaborate with others to solve problems. Unfortunately, most Internet educational programs too closely mimic traditional instructional forms; that is, they are technologically "gift wrapped" (Fischer, 1998) versions of traditional knowledge-delivery systems, too removed from professional practice.

[1] *Learning sciences* refers to current scientific and theoretical knowledge about students' learning and development in formal and informal learning settings.

Our alternative to technology "gift wrapping" is a method embodied in a system we have built to support online course design, development and management. Called STELLAR (Socio-Technical Environment for Learning and Learning-Activity Research), this system contains tools to build and manage courses that systematically integrate study of text with study of digital video cases of student work and teacher professional practice, and with activities in which teacher-learners collaborate in creating and critiquing designs for their own practice. The types of assessments that STELLAR courses are intended to impact are evaluations of authentic teacher work, such as justified lesson designs.

In the next section we will elaborate further on the theoretical basis for our instructional design approach, including its connection to and difference from other instructional design theories. Next, we will describe a course that was built and managed in STELLAR and offered over several years in two different university settings. We will show empirical evidence regarding course effectiveness. Finally we will discuss the new directions in collaborative learning research that our future work will address, including some reflections on the future of CSCL as a field of study.

THEORETICAL RATIONALE

The STELLAR approach can be framed in terms of what Salomon and Perkins (1989) and other cognitively-oriented researchers (e.g., Schwartz & Bransford, 1998) call *the transfer problem*. STELLAR courses attempt to scaffold students in developing *transferable* representations of course ideas -- learning-sciences concepts and skills in this example. An important stage of transfer occurs when, during professional practice, there is spontaneous and situation-appropriate activation and use of complex knowledge systems that incorporate course ideas. We call those knowledge systems *schemas,* in the tradition of (Bartlett, 1932). The goals of STELLAR courses include helping students develop schemas that will promote spontaneous transfer of course ideas and that will serve as a basis for "professional vision" (Goodwin, 1994), future professional discourse, and continued learning.

We believe that the schemas that STELLAR online learning environments help students acquire are characterized by a high degree of *mesh* (Glenberg, 1997) among the *concepts* and *skills* taught by a course, *perceptual visions associated with cases of practice,* and *plans for* acting in the professional setting. Although the concept *mesh* is very important to our theory, there is not space in this presentation and it is not the purpose of this paper to develop a model of the specific cognitive processes underlying *mesh*. We will state only that we use the term in two ways: 1. we see mesh during the learning process if there is evidence in work or discourse that students make connections between two or more ideas or perceptual experiences; and 2. we assume that repeated meshing of ideas and perceptions during learning promotes cognitive representations that reflect that mesh. So, we speak of seeing mesh in classrooms and on line (Hmelo-Silver, Derry, Woods, DelMarcelle, & Chernobilsky, this volume), and of learning outcomes as cognitive representations (e.g., schemas) that mesh perceptions and ideas.

STELLAR courses are "high-mesh" courses. They attempt to engineer mesh among forms of knowledge (concepts, skills, perceptual encodings of cases, and plans for doing). This is accomplished through carefully designed learning activities that scaffold students as they systematically and repeatedly bring together course ideas garnered through text study, visions of practice gained from video case study, and planning knowledge gained from facilitated collaborative lesson design. The point is to create meshed memories that automatically and flexibly activate one another, in professional settings that are similar to (but not exactly alike) those that are encountered through problem solving and case study in college courses.

However, transfer to future practice is not just *spontaneous* and *automatic* activation, for practitioners must also *adapt* to situations and continue to learn from resources available in their professional environment. Thus teachers must not only spontaneously activate previously learned course ideas and plans in response to events in their practice, but they also must respond by using course knowledge to help them take an evaluative and reflective stance on their work. Thus STELLAR courses also aim to help future teachers develop skills and tendencies needed to consider different situational interpretations, and to recognize when situations are in some sense new and thus require additional knowledge and alternative plans of action.

Relationship to other instructional design theories

Our view of transfer is related to Cognitive Flexibility Theory (CFT) (Feltovich, Spiro, Coulson, & Feltovich, 1996; Spiro et al., 2003; Spiro et al., 1992; Spiro, Feltovich, Coulson, & Anderson, 1989; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). A CFT analysis suggests that teaching is an ill-structured domain in which practitioners must learn to flexibly assemble a multiplicity of concepts, including pedagogical concepts (how to teach), disciplinary concepts (e.g., biological concepts such as *adaptation*), and learning-sciences concepts (e.g., how students learn through collaboration) as appropriate in different situations.

Our approach also shares connections with case-based reasoning (Kolodner & Guzdial, 2000). We build on the notion that, in many ill-structured domains without a strong causal, mechanistic underpinning, knowledge is organized around cases. A case representation includes a problem, the solution, and the evaluation of that solution. One can reason about cases that represent both successful and unsuccessful solutions. Case-based reasoning suggests that when we have a problem, we use our knowledge of previous cases to help point us toward helpful solutions and to help avoid ineffective solutions. Similarly, we suggest that for transfer to occur from the college classroom to the teacher's own classroom, the teacher needs a foundation of conceptual knowledge that is meshed to a base of case knowledge.

Our view of transfer is also consistent with Schwartz and Bransford's (1998) notion of preparation for future learning, the idea that transfer includes the capability to adapt and learn from new situations. When actions produce outcomes, teachers must determine if outcomes were the desired ones and what actions to take next. If outcomes are unexpected or problematic, a "breakdown" has occurred that requires creative problem framing and a search for relevant knowledge (Fischer, 1994). Thus teachers must be reflective practitioners and a course should help them become that. That reflection is an important stage in professional learning is the basis for the well-regarded reflective practitioner model (Schön, 1983) and all major cognitive models of self-regulated learning (Azevedo, Guthrie, & Seibert, 2004; Pintrich, 2000; Winne, 2001).

Differences from other theories

Our thinking has evolved beyond CFT in several respects. For one, we have been explicit regarding some specific forms of knowledge that should be meshed together into schemas during instruction. For teacher preparation in the learning sciences, these include: 1) both declarative (e.g., what is scaffolding?) and procedural (e.g., how do you scaffold instruction?) knowledge of the learning sciences; 2) perceptual visions of classroom practice that represent general cases that are likely to be seen in future; and 3) planning knowledge, both component instructional activities and general planning skills. The planning approach we have taught in our STELLAR courses are strategies for goal setting, assessment, and instructional activities (Wiggins & McTighe, 1998).

Our theoretical position also differs from case-based reasoning in important ways. Regarding knowledge representation, we do not believe cases are maintained intact in memory; rather, we believe that memories of particular cases fade with use and over time and that case memories become meshed together with other similar cases. We believe that experience with many cases over time can build on the schemas developed in courses, shaping and updating and abstracting them in important ways (Derry, 1996). A purpose of professional courses is to develop foundational schemas that will evolve during future learning.

Finally, as we plan our future work, our theoretical position is evolving away from reflective practitioner models that focus primarily on developing the individual, self-regulated learner. Learners in STELLAR courses not only work and learn as individuals, but also are scaffolded to engage in and acquire reflective collaborative practices within socio-technical environments that distribute knowledge over people and technology-based tools. We have more to say on this topic in the last section of our paper.

AN EXAMPLE COURSE ACTIVITY

The STELLAR system provides tools for helping course developers and researchers create and manage online student-centered collaborative learning activities that intertwine text and video case study with design activities. Although many different course and activity designs are possible, one example of a course activity built with STELLAR is provided. This activity was part of the eSTEP (Elementary and Secondary Teacher Education Project) course, a teacher preparation course in learning sciences that has been offered at both UW-Madison and RU since spring, 2001. The eSTEP course materials are housed in a website (created with STELLAR) that integrates three components: a Knowledge Web (an online learning-sciences hypertext book); a video case library that is thematically intertwined with the Knowledge Web; and PBL online, a collection of facilitated small-group lesson design activities that follow a PBL format (Barrows, 1988; Hmelo-Silver, 2002). A typical eSTEP course consists of several 2-3 week segments in which participants intensively study video cases and text to acquire "perceptualized" conceptual knowledge about learning sciences. They also engage in instructional design activities that integrate this knowledge with planning for future practice.

For instance, in Fall Semester 2002 at UW-Madison, pre-service teachers were guided through an eSTEP instructional activity by the toolbar presented in Figure 1.

Figure 1. eSTEP task bar

In Step 1, participants signed on and read their PBL problem, a group assignment to design a "bridging instruction" lesson for a mathematics concept of their group's choice. "Bridging instruction" is a complex pedagogical idea taught in the eSTEP course. To prepare, the pre-service teachers first read about bridging instruction in the Knowledge Web and studied an online video case depicting a bridging instruction lesson taught by an experienced teacher. As students studied the case, they followed links into the Knowledge Web that provided guidance in case analysis. In Step 2, participants used online personal notebooks to develop a case analysis and an initial lesson idea. This work was shared and discussed with group members in Step 3. In Steps 4–6, groups used a backwards-design strategy (Wiggins & McTighe, 1998) to complete a lesson design, an activity supported online by a STELLAR tool, the *group whiteboard* (Hmelo-Silver et al., this volume), which facilitates group design and decision-making (Figure 2). In Step 7 and 8, students submitted individual critiques of their group design and reflected on their learning, collaboration, the design of the lesson itself, and the usefulness of their designs for their own practice. As instructional designs evolved over the course of the PBL activity, they were reviewed by online facilitators, who offered ongoing formative help to individuals and groups. An analysis of the online PBL process is found in Chernobilsky, Nagarajan & Hmelo-Silver (this volume).

FROM ESTEP TO STELLAR.

Although the UW and Rutgers implementations of eSTEP share many similarities, each course serves different populations of preservice teachers and must be adapted to work in their respective contexts. These differences provided a reason and opportunity to build STELLAR, a general system that embodies our theoretical principles and can be adapted to different contexts and teaching subjects. STELLAR provides tools to support instructional designers, facilitators and researchers. For instance, course designers can use STELLAR to select and adapt tools and interfaces (e.g., the group whiteboard, Figure 2), and combine them into new activity structures, such as the PBL activity for math education students. STELLAR facilitates uploading of and presentation of videocases in multiple instructional formats, such as contrasting cases formats (e.g., Schwartz & Bransford, 1998). Hypertext environments can be developed within STELLAR and can be integrated with the video case library. This flexibility allows researchers to create and manipulate instructional designs and test theories about cognition and instruction. Likewise, STELLAR has an interface for online facilitators, which they use to access all participating learners' work, and to interact with individual learners or entire groups. This provides opportunities for powerful and frequent formative assessment. Once a course is complete, researchers can use STELLAR interfaces to access summaries of student work and to retrieve a variety of log files, including statistical summaries of Likert-scale feedback on the tools and activities used in a course. STELLAR products are extensible as well, so eSTEP materials can be added to and used in other professional development contexts.

RESEARCH STUDIES

Data sources and scoring

In addition to students' ratings of tools and activity steps, our experimental eSTEP course offerings have typically produced the following categories of data: 1) Group instructional plans developed online during PBL activities; 2) Online group discourse during each PBL activity; 3) Individual reflections, adaptations, and analyses from PBL activities; 4) Pre- and post-course analyses of teaching/learning video cases; 5) Pre- and post-course self-reports of beliefs and attitudes related to teaching and learning; and 6) Log data that can be analyzed to determine individual patterns of use of Web-site tools and learning resources.

To evaluate the work in Items 1–4 above, we developed *concepts-in-use* rubrics for judging and scoring pre- and post-video analyses and other student products in order to measure the level of sophistication manifest in students' spontaneous (students were unaware of rubrics) embedded uses of target learning sciences concepts, such as *understanding*, *metacognition*, and *transfer*. All rubrics in our research are being designed for use across multiple types of learner products, documents, and classroom performances. All include features to help coders determine what to focus on when judging learners' work, and all are calibrated to a single scoring scale. The psychometric properties of the rubrics are being assessed and improved through validity and reliability studies.

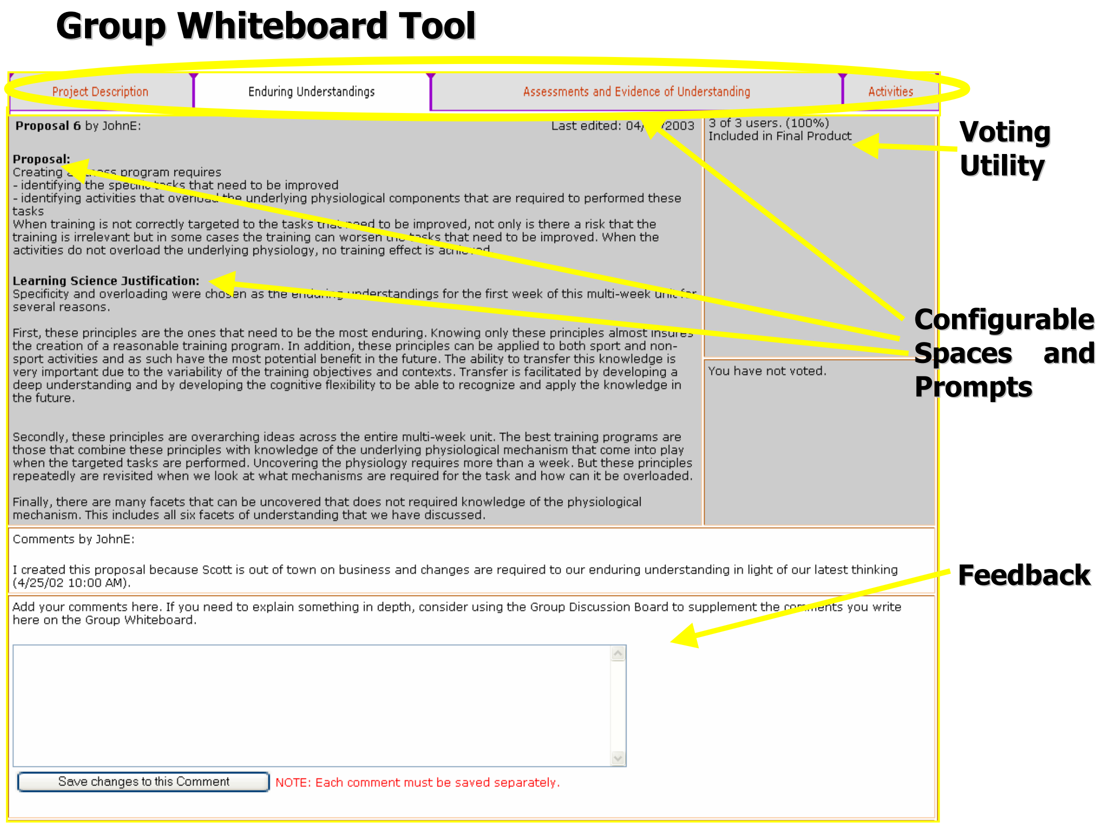

Figure 2. STELLAR whiteboard

As an example, the features of our rubric for the concept *understanding* and the scoring scale to which it is calibrated are shown in Tables 1 and 2. Inter-rater reliabilities for this rubric in repeated uses have consistently exceeded .90.

Table 1
Features considered in judging ability to use the concept understanding in planning and analyzing instruction

Points are not awarded for use of the term *understanding*. Judge whether products or explanations explicitly or implicitly represent knowledge that:
1. Understanding is actively constructed knowledge. 2. Understanding builds on prior knowledge. 3. Understanding in context is an active process of comprehension that involves constructing a situation model. 4. Understanding supports the making of inferences and/or application in new contexts. 5. There are different depths or forms of understanding. 6. Understanding involves grasping the underlying principle, theme or big idea. 7. Understanding is socially negotiated and distributed in *communities of practice* (broadly defined to include classrooms and groups).

Table 2
Scoring scale

0 "Knows nothing." Observations or products contain no evidence that any aspect of the concept is understood or attended to, or there is evidence that the concept is rejected or not understood. The concept is very unlikely to be used correctly in planning or implementation unless the student teacher receives and is open to *intensive assistance.*

1 "**Needs substantial scaffolding**." Observations or products indicate that there is some limited understanding and acceptance of the idea and that a limited range of acceptable implementation of the idea is occurring. However, there are major omissions, weaknesses, or misunderstandings in relation to the idea and the student teacher will probably need *substantial assistance* to help him or her use the idea successfully.

2 "**Demonstrates early expertise**." Observations or products indicate the idea is likely understood with some range and depth and is being implemented with at least moderate success as conceptualized. However, there are some weaknesses or omissions that should be addressed, and this part of the student teacher's work could be improved in important ways with *some assistance.*

3 "**Expert**." Observations or products provide evidence that the idea is well conceptualized in depth and detail and over a range of uses and is being implemented successfully and reflectively with sophisticated understanding, even though improvements might still be possible. Encouragement and positive feedback but *little assistance* would be appropriate.

Study 1: Evaluation of 2002 course offerings at two campuses

Student evaluations

Students' evaluative ratings of the online activities overall, specific steps in the activities, and the system tools used in implementing the activities online, were generally positive, ranging from 3.78 to 4.52 on a five-point scale. The data indicated that students favored collaborative over individual steps in the learning activity.

Although a few students' comments reflected a struggle with technology (this type of comment is becoming less common with increasing availability of high-speed Internet connections), characteristic quotes from students, taken from their reflections about the experience (steps 7 and 8), were positive.

- *. . . this lesson that we have designed as a group is definitely something I could see myself using down the road when I have my own classroom. I feel it is a well thought out lesson that can be easily modified to meet the needs of whatever type of class "make-up" that I may have.*
- *The plan that we made up as a group will be something that will be extremely useful for me as a teacher. I also learned the value of input from others' viewpoints on the same unit because you are able to see different perspectives that can give you some new and different ideas.*

Learning outcomes and correlates.

Table 3 shows mean scores from students' pre- and post-course video analyses, based on the *'understanding of understanding'* rubric previously described. Essentially, these means reflect gains in the college students' abilities to apply their psychological knowledge about the cognition of understanding to carry out a critical analysis of videotape of classroom teaching and resulting student performance. This is an important outcome variable, and the gains made in the eSTEP courses were substantial and meaningful in two contexts.

Table 3
Pre- and post-course "understanding in use" means and standard deviations (in parentheses) for UW & Rutgers

	UW	**Rutgers**
N	N = 60	N = 33
Course Level	Learning Sci taken in last year of Teacher Ed	Ed Psy prerequisite for entering Teacher Ed
Pre-course score	Mean = 0.65 (.46)	Mean = 0.42 (.55)
Post-course score	Mean = 2.09 (.63)	Mean = 1.56 (.63)

We conducted exploratory stepwise regression analyses with these same data to help generate hypotheses about possible relationships between college students' experience in the online environment and their actual learning outcomes (based on the understanding score), as well as their *perceptions* about how much they learned (based on an overall self-report rating). In the first analysis, the "understanding of understanding" score was the dependent variable. Predictor variables allowed to enter into the regression equation were various "successful tool use" indices, which included students' ratings of system tools and other data on system use, such as number of times a student logged on. The set of independent variables that best predicted successful performance on the video analysis, scored with the understanding rubric, were: a) entering pretest performance; b) site (Rutgers versus UW); c) positive ratings of the group whiteboard for collaborative online design; d) positive ratings of links between video cases and the KWeb, which scaffolded video viewing; and e) overall number of Web hits (R^2 = .38). However, when self-reported *perceptions* of learning (e.g., students' ratings of how much they believed they learned) was the dependent variable, the best predictors were success scores with tools and resources that were designed for individual study (R^2 = .42). A strong predictor was successful experience with the KWeb, which was designed in accordance with cognitive flexibility theory (Spiro et al., 1992) and was often used by individual students to explore personal interests.

We also conducted a factor analytic study in which items from a pre-course questionnaire were factored with the understanding score. At both sites, "understanding of understanding" loaded negatively with items comprising a factor that seemingly measured a belief that the cause of learning is primarily external context. A person holding this 'contextualist' point of view would tend to respond "strongly agree" to an item such as "teachers (or the home environment) are the main determinants of student learning." From this finding, which was consistent in separate analyses across two sites, we hypothesized that helping college students develop an appreciation of the role of cognitive processes in teaching and learning may require challenging strong incoming beliefs that only contexts external to the child are responsible for success in school. We hope that teacher-learners leave our course with an alternative view, that learning environments are complex systems involving coordination of both internal and external factors.

Study 2

A study conducted at Rutgers in 2004 compared performance and gains in the eSTEP course to performance and gains of students drawn from multiple traditionally-taught lecture courses of approximately the same size and student population. (Because the eSTEP course at UW-Madison is taught as an advanced course to the entire secondary education cohort, no similar comparison course for the same student population exists at UW-Madison.) Since the instructors differed for these two courses, results must be interpreted with caution. Nevertheless, based on scores derived from a video analysis task and the understanding rubric previously described, there was a statistically significant difference in final performance and performance gains, favoring the eSTEP course (ANCOVA F (1, 67) = 69.62, $p<.001$). Results are displayed in Table 4.

Table 4
Comparison of eSTEP with traditional course

		N	Mean	Std. Dev
Pre	**eSTEP**	32	.97	.55
	Comparison	37	.93	.50
Post	**eSTEP**	33	1.92	.77
	Comparison	37	.78	.48

CONCLUSIONS

In summary, we have accomplished the following:

- Developed a theory-based model that is feasible for online instruction on a large scale and that addresses a continuing major problem: the failure of most college classrooms to teach conceptual content in ways that insure its use in students' future professional lives. Our approach integrates text-based instruction with video study and authentic problem-based learning (PBL).
- Developed extensive online video, text materials, instructional activities, and online tools for supporting this instructional model to teach learning sciences to future teachers. The materials and tools are available through eSTEPWeb.org (a password protected site because of human subjects regulations regarding online uses of classroom video). They include the eSTEP Knowledge Web, an online multimedia textbook on learning science, an integrated (with hypertext) video case

library, and a system for setting up and managing collaborative problem-based learning activities on line.
- Using the resources above, we designed, offered, and tested innovative, experimental online learning science courses for pre-service teachers, demonstrating the effectiveness of our approach in variations adapted to two contexts. This entailed developing theoretically valid and psychometrically sound rubrics for scoring student work collected from eSTEP courses, which can be generalized to evaluation of teaching beyond the current project.

In addition, we believe the following:

- STELLAR designs produce significant increases in teacher-learners' abilities to think deeply about student understanding in analyses of realistic video cases of teaching and learning.
- A STELLAR "high-mesh" course was more effective at producing transfer than a traditional lecture-based approach covering the same material, although the non-experimental nature of this research requires a conservative interpretation.
- The STELLAR suite of online instructional tools can be combined in designs to produce effective instruction. The group whiteboard, which was configured to scaffold collaborative online lesson design, was an effective tool.
- In STELLAR courses, performance on a targeted instructional goal was moderately correlated with variations in site context and with successful use of tools that scaffold collaboration. However, students' *perceptions* of how much they learned were more dependent on successful use of tools that aided individual exploration.

We acknowledge that there are some limitations in the work we have reported here. There are many improvements to interface design that might be accomplished given adequate time and funding. We recognize that we have not conducted experimental studies to prove the effectiveness of our approach. And although we have developed some authentic assessments, we have not studied the impact of our course design on actual teaching practice, much less on how that practice affects K-12 student learning.

And yet our work so far represents a pioneering step in an emerging science of web-based course design that is informed by cognitive theory and that blends online video case study with collaborative problem solving. We continue to improve our general tool (STELLAR) that will allow researchers and developers from any discipline to design, offer, and monitor "high-mesh" courses and activities representing variations on our model.

FUTURE DIRECTIONS AND REFLECTIONS ON THE FUTURE OF CSCL

We envision a socio-technical future for teachers, one that helps empower them as professionals and as agents for social change (Gutiérrez, 2002). Developing teachers who can move into that future is part of our agenda now. Developing new theories of learning, new models for teacher professional development (TPD), and new socio-technical environments that support teachers as lifelong learners within communities will be major themes in our future work.

In the US, teaching is one profession where there is little opportunity for collegial interaction during the typical workday (Ball & Cohen, 1999; Lieberman, 1996). Yet situative theorists conceptualize individuals' use of knowledge as an aspect of their participation in social practices (Greeno, 1998; Lave & Wenger, 1991). Putnam and Borko (2000) argue that professional development must attend to both individual teachers as learners and as participants in professional communities. It is not surprising that collaborative Web-based technologies and professional Web sites are increasingly embraced by teachers as important forms of support for building professional community.

Online community approaches to continuing TPD, including graduate education, are often founded by non-profit groups with particular agendas. An example in the US is Wisconsin's Mathline (now Teacherline). Mathline was initially funded in 1995 through a Department of Education grant to the Public Broadcasting System and in Wisconsin grew over the intervening 10 years into a PK-16 statewide teacher professional development network. Mathline followed what Smith (2001) and others call a practice-based model of TPD (Ball & Cohen, 1999; West & Staub, 2003). In this model, online dialog among participating teachers is grounded in concerns of professional practice, and discussion of the organizing group's objectives occurs after teachers are comfortable discussing their own work (Grossman, Wineburg, & Woolworth, 2001). Trust is a crucial ingredient, and creating such trust is not easy. Mathline's strategy was to find facilitators who were recognized by their peers as master teachers, and to support these master teachers with extensive training in online facilitation (Collison, Elbaum, Haavind, & Tinker, 2000; Fullan, 1999; Lieberman, 1996). An initial study of Mathline dialogue suggested that fully half of the community's discourse was unplanned by facilitators and driven directly by the immediate needs of practicing teachers. Professional learning communities integrate the day-to-day concerns of teachers with the course's main themes.

Given existing models to build on, it does not require a giant leap of faith to envision a future in which TPD communities might operate as self-sustaining socio-technical systems that integrate formal, informal and work-related concerns and that engage in meaningful collaboration, social creativity, and problem framing around socially important issues (Fischer, 2002). Achieving this vision and developing theory to support this achievement are goals we embrace for our future work. Our approach will involve building on existing success models in an attempt to design new STELLAR graduate courses that will seed facilitated online professional communities for teachers and that will continue to attract them as participants beyond the life of the course. In the socio-technical communities we envision, teachers will continue to work and study together to further their knowledge and involvement in the very themes (for example, teaching mathematics for social justice) that attracted them to enroll. However, it is not only our vision that counts, for what we hope will emerge from this effort is a co-evolving system: a reflective community that is capable of deciding for itself what it is, including the ability to adapt its socio-technical environment to meet its changing needs. The socio-technical environment and organization must itself support this, incorporating strategies to encourage continuous reflection and problem solving. This is one version of what Fischer and others have called the science of *meta-design* (Fischer & Giaccardi, 2004), a process that involves "seeding" communities using basic "reusable" socio-technical designs that are adapted to each community's needs. We think this is an important concept for our future work with teachers and an interesting topic for the CSCL research community to address.

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REFERENCES

Azevedo, R., Guthrie, J. T., & Seibert, D. (2004). The role of self-regulated learning in fostering students' conceptual understanding of complex systems with hypermedia. *Journal of Educatonal Computing Research, 30*(1), 85-109.

Ball, D. L., & Cohen, D. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. In L. Darling-Hammond (Ed.), *Teaching as the Learning Profession: Handbook of Policy and Practice* (pp. 3-32). San Francisco, CA: Jossey-Bass.

Barrows, H. (1988). *The tutorial process*. Springfield, IL: Southern University Press.

Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge: The University Press.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience and school*. Washington DC: National Academy Press.

Bransford, J. D., Derry, S. J., & Berliner, D. C. (in press). Theories of learning and their roles in teaching. In L. Darling-Hammond & J. Bransford (Eds.), *Preparing teachers for a changing world*.

Collison, G., Elbaum, B., Haavind, S., & Tinker, R. (2000). *Facilitating online learning: Effective strategies for moderators*. Madison, WI: Atwood Publishing.

Darling-Hammond, L., & Sykes, G. (1999). *Teaching as the learning profession : handbook of policy and practice* (1st ed.). San Francisco: Jossey-Bass Publishers.

Derry, S. J. (1996). Cognitive schema theory in the constructivist debate. *Educational Psychologist, 31*, 163-217.

Feltovich, P. J., Spiro, R. J., Coulson, R. L., & Feltovich, J. (1996). Collaboration within and among minds: Mastering complexity, individually and in groups. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 25-44). Hillsdale, NJ: Erlbaum.

Fischer, G. (1994). Turning breakdowns into opportunities for creativity. *Knowledge-Based Systems, 7*(4), 221-232.

Fischer, G. (1998). Making learning a part of life--beyond the 'gift wrapping' approach of technology. In E. Kammler (Ed.), *Lifelong learning and its impact on social and regional development* (pp. 435-462). Bremen Germany: Donat Verlag.

Fischer, G. (2002). Beyond "couch potatoes": From consumers to designers and active contributors. *First Monday, 7*(12).

Fischer, G., & Giaccardi, E. (2004). Meta-Design: A Framework for the Future of End User Development. In V. Wulf (Ed.), *End User Development — Empowering people to flexibly employ advanced information and communication technology* (pp. (in press)). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Fullan, M. (1999). *Change forces: The sequel*. Philadelphia: Falmer Press.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*, 306-355.

Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences, 20*, 1-55.

Goodwin, C. (1994). Professional Vision. *American Anthropologist, 96*(3), 606-633.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53*(1), 5-26.

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community, *Teachers College Record* (Vol. 103, pp. 942-1012).

Gutiérrez, R. (2002). Enabling the practice of mathematics teachers in context: Toward a new equity research agenda. *Mathematical Thinking and Learning, 4*(2&3), 145-187.

Hmelo-Silver, C. E. (2002). *Collaborative ways of knowing issues in facilitation.* Paper presented at the Proceedings of CSCL 2002.

Kolodner, J. L., & Guzdial, M. (2000). Theory and practice of case-based learning aids. In S. M. Land (Ed.), *Theoretical Foundations of Learning Environments* (pp. 215-242). Mahwah NJ: Lawrence Erlbaum Associates.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate perpheral participation*. Cambridge: Cambridge University Press.

Lieberman, A. (1996). Creating intentional learning communities. *Educational Leadership, 54*(3), 51-55.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451-502). San Diego, CA: Academic Press.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4-15.

Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer: Rethinking mechanisms of a neglected phenomenon. *Educational Psychologist, 24*, 113-142.

Schön, D. A. (1983). *The reflective practioner: How professionals think in action*. London: Temple Smith.

Schwartz, D. L., & Bransford, J. D. (1998). A time for telling. *Cognition and Instruction, 16*, 475-522.

Smith, M. S. (2001). *Practice Based Professional Development for Teachers of Mathematics*. Reston, VA: National Council of Teahers of Mathematics, Inc.

Spiro, R. J., Collins, B. P., Thota, J. J., & Feltovich, P. J. (2003). Cognitive flexibility theory: Hypermedia for complex learning, adaptive knowledge application, and experience acceleration. *Educational Technology, 43*, 5-10.

Spiro, R. J., Feltovich, P. J., & Coulson, R. L. (1992). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. In T. M. D. D. H. Jonassen (Ed.), *Constructivism and the technology of instruction: A conversation* (pp. 57-75).

Spiro, R. J., Feltovich, P. J., Coulson, R. L., & Anderson, D. K. (1989). Multiple analogies for complex concepts: Antidotes for analogy-induced misconception in advanced knowledge acquisition. In A. Ortony (Ed.), *Similarity and Analogical Reasoning* (pp. 498-531). New York: Cambridge University Press.

Spiro, R. J., Vispoel, W. P., Schmitz, J. G., Samarapungavan, A., & Boerger, A. E. (1987). Knowledge acquisition for application: Cognitive flexibility and transfer in complex content domains. In S. M. Glynn (Ed.), *Executive Control Processes in Reading* (pp. 177-199). Hillsdale NJ: Lawrence Erlbaum Associates.

Weiss, I. R., Pasley, J. D., Smith, P. S., Banilower, E. R., & Heck, D. J. (2003). *Looking inside the classroom: A study of K-12 mathematics and science education in the United States*. Chapel Hill, NC: Horizon Research, Inc.

West, L., & Staub, F. C. (2003). *Content-focused coaching: Transforming mathematics lessons*. Portsmouth, NH: Heinemann.

Wiggins, G., & McTighe, J. (1998). *Understanding by design*. Alexandria, VA: Association for Supervision and Curriculum Development.

Winne, P. H. (2001). Self-regulated learning viewed from models of information processing. In B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 183-189). Mahwah, NJ: Erlbaum.