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ABSTRACT

This paper examines the implementation of the CoVis Project in three schools. CoVis is a national Secondary School Science Education Testbed designed to promote project-based pedagogy supported by facilitative technology through reflective learning. The reflective learning that these three schools engaged in while enacting CoVis is examined in order to determine how that reflection lead to successful implementation. Emphasis is placed on past reform efforts at the schools as well as on the fit between the visions of those schools and the goals of the CoVis Project. Findings from these three case studies are used to suggest design approaches intended to foster such reflection at other schools implementing CoVis. The idea presented here is to design curricular innovations that help educators learn about teaching and learning practices through enactment of the innovation. Findings suggest a learning curriculum where not only students but teachers and administrators learn from curricular materials. Curricula should be designed to support reflection in action. When viewed from a Learning Sciences perspective, the project suggests the design of a new technological architecture for the development of learning curricula. Contains 20 references. (PVD)

Inventing Interventions: Three Successful CoVis Cases

by
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1. Introduction

This paper examines the implementation of the CoVis Project in three school cases. CoVis is a national Secondary School Science Education Testbed designed to promote project-based pedagogy supported by facilitative technology (Pea, 1993a). Currently CoVis has been implemented in 54 schools across the country. Some of those implementations are more successful than others. Further, the successful schools seem to share some characteristics. Specifically these schools had participated in previous reform efforts through which they had begun the process of reflecting on and changing their teaching and learning practices. This reflection on practice was a critical tool that helped them to approach the implementation of CoVis as an organizational learning problem. We examine the reflective learning that these three schools engaged in around the enactment of CoVis in order to understanding how that reflection lead to successful implementation. We then draw on what we learn from these three cases to suggest design approaches intended to foster such reflection at other schools implementing CoVis. The idea here is to design curricular innovations that help educators learn about teaching and learning practice through enactment of the innovation (Ball & Cohen, 1996).

We begin by describing the CoVis project at the conceptual level as well as at the level of student experiences and teaching practice. We go on to describe the three school cases presented here. Here we put particular emphasis on past reform efforts at the schools as well as on the fit between the vision of those schools and the goals of the CoVis Project. We then characterize the reflective practice at the schools and analyze it in terms of the Spillane and Thompson (1997) model of implementation.

The paper begins with a description of the CoVis project. The CoVis design is described in terms of both the types of student experiences and the teaching practices it intends to foster. The paper then turns to an examination of CoVis implementation at Jarvis, Sloan and Petersville.

1.1 Inventing Interventions

Our focus on reflective learning is related to the CoVis implementation philosophy. The CoVis project assumes a flexible implementation model. When school communities implement CoVis in their classrooms they are co-constructors of the CoVis design. School communities take the products of our design work at CoVis and tailor them to meet local needs and context. In this sense the end-product — classroom practice — is co-designed by researchers and school communities.

We say school communities rather than teachers because we believe that local practice is affected not only by teachers, but by administrators, students, parents and other community members.

CoVis views school communities as "inventing interventions." As researchers what we design is not classroom instruction, rather it is the curriculum and tools (i.e., resources) that support the design of classroom instruction. Teachers design instruction by taking the resources we provide them and inventing local practice. To enable this process those resources must be flexible enough to enable school communities to adapt them to their particular classrooms. In this sense enactment of curriculum is an adaptive process of fitting resources to different contexts.

We adopt this flexible model in response to the implementation failures of previous educational innovations. For example, despite the many successes of Reciprocal Teaching and its wide-scale appeal, Brown & Campione (1996) describe the phenomenon of lethal mutation wherein individual teachers implement projects in terms *inconsistent* with the design intentions. One way to look at the lethal mutations problem is to think of it as the result of a faulty implementation model which expects teachers to adopt innovations whole-cloth. Our flexible intervention model recognizes that school communities will *always* need to modify innovations to meet local needs. The question then is how to support that process so that the co-constructed end product is consistent both with the goals of the innovation and of the school community? In the three cases presented here that co-construction was supported by reflective learning. We wish to understand how to foster that process at other CoVis schools.

1.2 Capacity Building Through Reflection

Among our 54 schools there are many contexts in which implementation of CoVis has been successful, and many others where it has not (for an examination of implementation in five high schools see Shrader, Gomez, Lento, & Pea, 1997). To address the questions above, this paper examines the successful implementation of the CoVis project in three schools; the Jarvis Community School — a public K-8 school in Chicago, The Sloan Middle School in northwestern Indiana, and the Petersville High School in central Indiana.

We believe that the success of Jarvis, Sloan, and Petersville is related to the organizational context that existed at the schools prior to their participation in CoVis. Each of the schools was engaged in some school or district-wide improvement plan prior to their participation in CoVis. Around those improvement plans a spirit of reflective learning thrived in the schools. As organizations they *reflected* on their teaching and learning practice, thus *learning* about and improving those practices. The improvement plans provided a context within which, and a structure around which, the schools could reflect. CoVis simply became the thing around which they reflected and learned.

The realization that these successful schools were all reflective learning organizations is the focus of this paper. The analysis presented here borrows from Spillane & Thompson (1997) viewing reflective learning as a capacity building mechanism. In their implementation study, Spillane and Thompson found that three of nine districts were successful enacting Standards based math and science reform in Michigan because they had local cultures supportive of reflection and learning. The learning culture in turn was both a product of and a resource for the building of local capacity to enact reform. Local Capacity was operationalized in terms of financial (i.e., staffing, time and materials), human (i.e., knowledge, skills, and dispositions of leaders within the district), and social (i.e., social networks, trust and collegiality) capitals that operated at the schools. In their view the districts were successful because they had high human capital in the form of knowledgeable administrators and teachers who were committed to enacting the reforms as well as high social capital in the form of a spirit of trust and collaboration among the school staff. In these systems human and social capital interacted around reflective learning to expand local capacity to enact the reforms. In their words:

> To understand the LEA's capacity for ambitious reform, then, we must explore the complex interaction of its human capital and social capital. Social capital can be instrumental in the LEA's capacity to forge ambitious reform. But whether it becomes so will depend in part on the LEA's human capital, especially the knowledge, commitment, and disposition of the district leadership. .... When it

> comes to the LEA's capacity for ambitious reform, human and social are interdependent: they develop in tandem (p. 23)

In a like fashion we believe that the three CoVis schools reported here are reflective learning organizations that draw on their human and social capitals as capacity building resources which they draw on to enact reform. Further, we believe that this explains their success with our project. Below we examine how three schools successfully built capacity to enact CoVis through reflective learning around enactment. But, first we describe the CoVis project in greater detail.

2. The CoVis Project

The goal of CoVis is to promote project-enhanced science pedagogy supported by high performance computing and communications technologies (Pea, 1993a). CoVis focuses on three areas – project-enhanced science teaching and learning, developing communities of practice, and providing a facilitative technological infrastructure – as a means for transforming science education. In previous work we have described these three areas in terms of a three part program model (Shrader, et al., 1997).

Part one of that model is project-enhanced pedagogy. To foster project-enhanced instruction CoVis has designed a suite of curricula that address topics from global warming to water purification. These curricula are meant as seeds that provide concrete opportunities which engage teachers in project-enhanced instruction (Lento, 1996).

Part two of the program model is technological support for project work. CoVis teachers have access to a suite of educational technologies intended to support student work on projects. The suite includes: (1) networked communications (i.e., email, Netscape, etc.) which supports communication between students, their teachers, and mentors in the scientific community; (2) The Collaboratory Notebook – a electronic medium that supports student discourse on group projects (O'Neill & Gomez, 1994); and (3) Scientific Visualization Technology which makes primary scientific data sets accessible to students by providing graphical displays of the data (Gordin & Pea, 1995). Together the technologies provide CoVis students with access to data and a medium through which to discuss their work with students at other schools, teachers, and scientists.

Part three of the model provides a different kind of community; a community of teaching practice. CoVis pedagogy represents a fundamental change in teaching practice. Making such a change requires a considerable effort and is bound to fail if not supported. The community of teaching practice puts CoVis teachers in touch with one another and with CoVis researchers in forums (e.g., Summer Conferences and On-line user support groups) where they can discuss the challenges that they face and share ideas.

The three elements of the CoVis program model are interdependent. The overarching goal is to engage students in project-based science (Ruopp, Gal, Drayton, & Pfister, 1993). This goal is achieved by provided supportive technologies and by developing a community of practice for teachers. The model is intended to promote the flexible model of implementation described above. CoVis hopes to create a resource rich testbed (Hunter, 1992) within which teachers form communities of practice working to *invent interventions* appropriate to local culture, pedagogical values, and needs. That is, given the curricular and technological resources described above, members of school communities invent their own versions of project enhanced science adapted to meet their local needs.

2.1 Student Work in CoVis

Traditional science instruction views students as consumers of scientific content knowledge and its texts, testing, and instruction all value the transmission of factual knowledge. Standards based reforms are critical of such instruction (NRC, 1996) because it creates among students a misconception about science. Students taught in this traditional transmission mode come to view science as a collection of objective facts that can be argued from with authority. In contrast, the Standards encourage an active view of science in which "... students describe objects and events, ask questions, acquire knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas (p. 20)." The Standards go on to argue that "Implementing the *National Science Education Standards* implies the acquisition of scientific knowledge and the development of understanding (NRC, 1996)." Thus science is not simply knowledge of facts, but it is knowledge with understanding. This understanding implies a whole new epistemology; one in which we come to view science not simply as a body of knowledge to be mastered, but a process to be undertaken. Power comes not only from knowing but from the capacity to discover.

Active learning implies that students must be engaged in activity. Thus projects are a focal aspect of the CoVis classroom. Students are engaged not in memorizing facts that teachers and texts value, but in pursuing scientific questions by engagement in authentic problems. Not only does authenticity have the potential to increase student motivation, but it situates learning in the context of use (Brown, Collins, & Duguid, 1989). Students are learning science through the process of engaging in scientific processes. Thus they come to appreciate what scientists actually do by participating the work of science. In this sense they are participating in a community of scientific practice (Ruopp, et al., 1993).

We do not mean to suggest by this that students are mini-scientists or, for example, that the work of science in a middle school is akin to the work of real scientists. Rather, the work that students engage in is like the work of scientists in its form: students take on a part of the work of science that matches their ability or expertise. In this sense students are engaged in a form of cognitive apprenticeship (Collins, Brown, & Newman, 1989). In other words student work in project based science classrooms is a form of legitimate peripheral participation (Lave & Wenger, 1991).

Project based science also creates a forum in which students can engage in the community of scientific discourse. Students work and talk not only with one another and their teacher, but with knowledgeable others beyond the school walls. They might work with students from another school, with mentors at universities or in industry, or communicate directly with scientists working on similar problems. This aspect of student work draws on two theoretical disciplines. First, in a Bakhtinian (1981) sense it situates students work on scientific problems within the larger discourse of science. Student work is not distinct from scientific discourse, rather it is a part of that discourse; albeit a peripheral part. Students participate in a conversation that extends beyond both physical and temporal boundaries. They draw not only on the work of others in the past via reading about scientific theory, but upon the work of others in the present by communicating with scientists and mentors. Thus project based science in CoVis classroom values distributed intelligence (Pea, 1993b). Knowledge and expertise are not only possessed by individuals, rather they are distributed in the scientific community. Scientific work involves drawing on one's own knowledge *as well as* the knowledge distributed in the scientific community, by working with others in that community.

So student work in CoVis classrooms differs considerably from the work of students in traditional classrooms. They engage in active problem solving by working on authentic scientific problems. Through engagement in those problems they become legitimate peripheral participants in the discourse and practice of science. Here they work collaboratively with other students, mentors, and scientist. This allows students to situate their work in the discipline of science, to appreciate the larger discourse community of which they are a part, to value the distributed nature of knowledge, and to come to an understanding not just of scientific phenomenon, but of the nature of science and scientific work.

2.2 CoVis Pedagogy

Of course such fundamental changes in students' experiences in science classrooms implies dramatic shifts in teaching practice as well. One consequence of such a shift is that teachers need to give up control over the classroom. As previous implementation research reports, the ceding of control can be a problematic issue for teachers (Olson, 1981). Shifting control results when teachers give up their role as disseminators or transmitter of knowledge, and assume a role as classroom coaches, guides or facilitators (Brown, et al., 1989). That is not to say that teachers abdicate responsibility for structuring the intellectual content of the classroom activity. Rather, it is the way that they engage students in that content that changes. In CoVis classrooms teachers are encouraged to let student discourse guide classroom discussion. The idea is that work on projects will lead students to face problems and raise questions. Those problems and questions present teachable moments. The teaching goal is to recognize teachable moments and foster discussion around those. We don't want teachers to provide solutions for students, rather we want them to help students to identify problems when they occur and work toward their own solutions. In this sense project based teaching is more responsive than traditional classroom instruction.

All this implies a whole new classroom management repertoire. Once students begin work on projects, that work is often times carried out in groups. Thus teachers need effective group management strategies. In turn group work on projects implies that not all student or all groups will be involved in the same activities on any given day. So, teachers need to develop strategies to monitor and manage the work of students and groups engaged in multiple task. Further, project work is resource intensive. Given that resources are in short supply, this means that resources need to be shared and that teachers need strategies that help students to share resources. For instance, in a classroom with three computer and six groups working on projects, not all students can use the computer at a given time.

Project based learning also implies new forms of assessment. If knowledge is distributed and if students work collaboratively toward the solution of problems, then existing assessments that value only individual knowledge are inadequate. Teachers need assessment strategies that allow them to value the collective work that students produce as they solve problems and conduct projects. Portfolios and rubrics are two potential models. But both strategies require significant learning and practice to execute effectively.

So teachers in CoVis classrooms face a whole set of new instructional challenges. Not only must they cede control of classroom discourse to students, but they must come up with new strategies for classroom management and student assessment.

3. The Cases

Let us now return to the thesis of this paper: the Jarvis, Sloan and Petersville schools have successfully enacted CoVis in their classrooms because these schools are reflective learning

organizations. The schools each engaged in school or district-wide improvement programs around which they were engaged in the process of reflecting upon and changing teaching and learning practices. When they became CoVis schools they turned their reflective learning toward the task of enacting CoVis. We now examine the work of these three schools beginning with their school improvement projects.

3.1 A History of Reflection in Action

The Jarvis Community School was built in 1992 with educational reform in mind and subsequently became a Comer School (Comer, 1988). Under the Comer model a schools forms a Governance and Management team consisting of parents, teachers, administrators and mental health workers. Using a child development perspective the school provides parental resources, employs parents as teacher-aides, provides counseling services for students, responds to disciplinary problems by changing school practices to meet students needs, provides social activities in addition to educational ones, and supplements classroom learning with special projects. The goal is to design the school from the students perspective providing the social, counseling and educational resources that match students' developmental needs.

The Sloan Middle School has a long history of project-based instruction. Beginning with a 1982 grant the school began work on interdisciplinary projects. Then, in 1994 the school became a Co-NECT school. The Co-NECT framework recommends new organizational structures for schools (e.g., multiage classrooms), advocates the use of interdisciplinary projects, and leans on telecommunications technology to facilitate better schooling. Local school design teams at Co-NECT schools work to adapt the framework creating a school design that reflects their local conditions, cultures, and needs. The focus is on increased parent and community involvement, improved test scores, the development of competitive job skills, and high quality work for all students (Olds & Pearlman, 1992).

Finally, the Petersville schools have been engaged in a multimillion dollar district-wide technology planning process around which they have reconceptualized teaching and learning. Under the technology plan the new high school was built with an Intranet connecting all classrooms, offices, and libraries. All classrooms have at least one computer and eight network connections. To accommodate classroom computing, each department has 50 computers on carts which can be rolled into any classroom for a particular project. In addition to networking the new high school, the old high school was similarly equipped and opened as the middle school. Motivated by their investment, the district has undertaken a commitment to utilize their new infrastructure to reconceive teaching and learning. In our interview the Assistant Superintendent described the districts two-pronged strategy to meet this goal. First, all administrative tasks (i.e., attendance, grades, etc.) are done on the computer as a means of helping teachers learn to use the infrastructure. Second, teachers are supported in the exploration of "best practices" (i.e., innovative teaching that utilizes the technological infrastructure). Tom described CoVis as "helping us to identify best practices."

We contend that these school or district-wide improvement plans are important to understanding how the three schools implemented CoVis. The schools came to CoVis having already engaged in reflection around their school improvement efforts. This meant that CoVis researchers did not have to foster a spirit of reflection in these schools, we only needed to provide good ideas around which the schools focused their reflection. CoVis did not build reflection into these school communities, it became the thing around which these school communities reflected. In fact, in all three cases the people that we interviewed described CoVis as fitting into their school vision. They chose to participate in CoVis

because it helped them to achieve a goal that they had set for themselves. The marriage between these school visions and participation in CoVis will be examined in the next section.

3.2 School Vision

One important aspect of the reflection around CoVis that occurred at the three school's is that they all described CoVis as fitting or matching their school vision which in turn was a product of their school improvement efforts. CoVis was described as an instance of the kind of teaching and learning practice that the school's valued. For instance, Rosa, the Jarvis Curriculum Supervisor, refers to the school's CoVis partnership as a "marriage." Describing Jarvis' mission as providing quality Math and Science education utilizing technology, Rosa reported that:

> CoVis helps us actualize the vision that was really Jarvis School. It is right on target and in keeping with the vision that Jarvis is, and where we are trying to go. We're not changing anything that we were to get CoVis, there was a natural marriage between where CoVis was [in terms of integrating curriculum and technology] and where Jarvis is going.

Likewise Georgia Madsen, a Petersville High School Chemistry teacher described her participation In CoVis as a good match. She explained that she's worked over that past few years to integrate projects into her teaching. Relating that to her CoVis experience she said, "It was like this CoVis thing was from heaven. Lots of project ideas." She described CoVis as providing her with project ideas that helped her to change her teaching. In the following exchange between Georgia and I she describes how CoVis also matches the district's commitment to integrating technology into the curriculum:

GREG:	So you're describing project based learning across the school curriculum. Even beyond the Sciences?
GEORGIA:	Oh yeah they have really really pushed it at Petersville in the past few years.
GREG:	Project based learning in general?
GEORGIA:	No the technology stuff.
GREG:	Which ends up getting translated into project based?
GEORGIA:	Yeah. Because you can do such cool stuff with it.

So, at Petersville there is an explicit connection between the new technological infrastructure and the use of project-based instruction. What is valued in their connection to CoVis is precisely that link. CoVis helps them to use technology in project-based instruction. This is what Assistant Superintendent Tom Campbell meant when he described CoVis as helping Petersville to explore "best practices." He describes his initial interest in CoVis in terms of meeting an existing need at Petersville:

> Well I had heard Roy Pea's [CoVis Co-Principal Investigator] presentation at meeting in Chicago. There was an Educational advisory board that I was on. He explained the project to us. To us it made a lot of sense. *It looked like a way that we wanted to use technology as an integrated part of the curriculum* versus being a

> stand alone grill and kill approach that some people use technology for. So it sounded like an excellent approach. It did have some things as far as the advantages that we were trying to work toward. How do we use the Internet? How do we expand the opportunities for our kids? How do monitor and control that? So we were very impressed with the presentation and the fact that it was the kind of thing that we wanted which was how do we supplement what's taking place in our classroom versus replacing with a program that we've never tried before. *So it really came right into the scheme of how we were planning on using technology and expanding some things we already started.*

Similarly, when we asked Sloan Principal Frank Macowski how CoVis fits into his school's curriculum he responded by describing how CoVis has helped his teachers move project-based instruction into their academic instruction:

> CoVis fits in beautifully. It has picked up not only on [Co-NECT] project time , but now we're doing projects in the regular class too. Katie Greene and Pamela Maddox are really involved with this. They have picked up on CoVis in their regular classroom sessions. *So this really meshes up really well with what we were trying to do as far as project based curriculum.*

Reflecting on her teaching practice, Pamela adds that in addition to providing her with an opportunity to move projects into her regular science instruction, CoVis projects have helped her to meet the new Indiana State Standards:

> [In the Standards] the key elements of Science instruction are divided into curricular one's, and then cognitive one's. That's not the right word but I'll say cognitive based on process. There's process and curriculum Standards. I think that CoVis really helped me to meet more of the process ones. I was really excited because I was playing this game where I was planning my own year. I wrote a curriculum and I'm going through and checking off. About a third of the curriculum, then maybe more than a third of the process. Then after a few months of CoVis I went back through it and I went through all of the process Standards at some level.

So Pamela used CoVis to incorporate the project-based instruction that she had viewed as a supplementary approach with Co-NECT into her day to day science teaching. In addition to responding to the school's vision of providing students with project-based learning opportunities, she was able to address the State's new process standards.

In all three cases presented here, not only had the schools already been engaged in school or district-wide improvement efforts, but they identified CoVis as a project that conformed with their vision of where their schools were headed. CoVis helped them to meet their school improvement goals by providing them with a way to integrate technology into instruction and improve teaching and learning locally. In all three cases they reflected on CoVis as a means toward an end that existed prior to their participation in the project. To reiterate, in these reflective learning organizations, CoVis became the thing that they reflected around. Our goal in this analysis is to uncover how these schools reflected around, and therefore effectively enacted, CoVis.

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To summarize, Jarvis, Sloan and Petersville were all participating in school or district-wide improvement efforts that engaged them in reflecting on teaching and learning practice prior to their participation in CoVis. Their ability to articulate a school vision regarding teaching

and learning is evidence of the reflection that they engaged in on those projects. That they recognized in CoVis the potential to reach those visions is further evidence of that prior reflection.

Returning to the Spillane and Thompson (1997) model we argue that the school visions presented above are elements of human capital. The visions and the arguments that individuals formed around them demonstrate the knowledge about reforms that exists in these school communities. But to build capacity requires not only human capital, but social capital. Below we describe how the social capital in these three schools enabled them to turn their reflective energy on the enactment of CoVis.

3.3 Building Capacity

In this section, we examine social capital in these three school communities in terms of trust and cooperation as well as collegiality.

3.3.1 Trust and Cooperation

One of the key commonalties between the schools is that in all three cases some administrator has taken interest in and become an advocate for the CoVis project in their school. In the Petersville schools the Assistant Superintendent for Instruction assumed that role. As described above, he met a CoVis PI at a school networking advisory meeting. He became interested in the project and advocated Petersville participation. In a like manner, the Sloan Middle School Principal and the Curriculum Supervisor at Jarvis got their schools involved. The later describes her interest in CoVis as follows:

> I'm the reason that CoVis is in the building. We went to a technology conference in which they spoke about CoVis. I just got overjoyed, talked to people about it, and by the time Juile [the science teacher] got to them they said, "well we've already talked to your curriculum supervisor, she said she'd like to have it." ...because of the requirements of CoVis that we be networked, that we have computers in a certain space, Juile an Margaret [the technology coordinator] said, "you know we can't do that." I said, "well we need this." I said, "it would be perfect for us because our children are right here and Northwestern is right there." I kept pushing and they said, "...but we're not networked." I said, "I know, but we're going to get a network." So I kept pushing, kept pushing until Margaret and Juile said, "Rosa, if it hadn't been for you, we would never have had this." Because I just wouldn't give up on it. I just thought it was a fantastic opportunity for the kids.

Keen administrative interest like this led to cooperative trusting relationships between administrators and teachers working to enact CoVis at the three schools. This level of cooperation and trust was evident when we asked the teachers in these schools whether they felt supported in their work on CoVis. We asked the question because we recognized that changing to a project-based approach represents a significant risk. For example, in a number of our other schools teachers fear that project-based instruction may put their students at risk of performing poorly on standardized tests which are highly valued by parents, politicians, and college admission boards. Especially where schools are traditionally successful on such tests, changing instructional practice is sometimes viewed as something of an act of faith. Teachers must believe that students will continue to perform well under the new pedagogy. Further, in order to feel comfortable in their attempts enact project-based instruction, they must believe that administrators are prepared to support them regardless of the end result. Understanding this tension, we asked all the teachers that we interviewed about their administration's tolerance for experimentation. In all three of the

schools presented here, the teachers interviewed felt very supported. For example, one Petersville teacher said, "They're [the administration] terrific!" She later elaborated saying "Every time I've wanted to do something new, they have never said no. Its always 'do you think this will work?' then 'Go for it. Try it.'" Another Petersville teachers indicated that both the Assistant Superintendent and the School Board were supportive of CoVis:

> They're very supportive of it. Dr. Campbell [the assistant superintendent] has encouraged it. When we were looking into CoVis we also had a school board member come up to Chicago. He was just really excited about it. From K through 12 all the way through they're very supportive of doing things to find better ways of helping students learn.

So the administrators advocated participation in CoVis and also helped teachers to feel supported in their work on the project. The teachers were then free to work hard enacting CoVis without feeling threatened by their efforts.

Of course, fundamental shifts in teaching practice do not come without a great deal of discussion, work and learning (the focus of this paper). The Jarvis School provides us with some insight into the negotiations between school actors involved in the implementation of CoVis. The Curriculum Supervisor was enthusiastic about CoVis as indicated by her enthusiasm for initiating the project (see quote on page 9), and was enthusiastic about the results that she observed in Julie's classroom:

> I have come in [to Julie's classroom] and looked at the things that the kids were doing. I found them able to work together around computers, in groups, which was fabulous that they were really interacting and exchanging ideas. I asked them to pull up some things [on their computers]. I found that these children were advanced because of CoVis, because of the opportunity that they had to be on-line, and to work with the computer much more readily. They were much more knowledgeable.

However, the teacher characterized the Principal as a more reserved supporter. She described him as a discipline focused man who had some trouble adjusting to work in a CoVis classroom where students move freely about the room working on a variety of different activities.

> You need to have a Principal who's going to be okay walking into a room where the kids aren't all on the same task, because when you're doing projects like this, they're all over the place. Some kids are up getting books up there, some kids are on the computer, some are doing labs, it's noisier than a regular classroom. You have to have an administrator who says, "OK, I trust her as a professional to know what's going on in there." I'm not talking about chaos that's going to disrupt other classrooms. My Principal says that that's what he's for, but he has a hard time accepting it.

So, while the Principal is supportive of her work, it took him time to adjust to the new pattern of school work evident in her classroom. The point for this analysis is that even though the Principal was reluctant to accept the new teaching practice, he was able to put his doubts aside, put trust in his teacher, and allow the process to move forward. Trust in the building was such that the Principal could accept the judgment of his Curriculum Supervisor and his teacher thereby allowing the program to move forward. As a result CoVis was successful at Jarvis, the CoVis teacher won teaching awards, and — most importantly — the Principal learned from the success of his teacher.

While space prevents us from examining all three school cases in detail here, we find similar levels of trust existing in Petersville and Sloan. There too change is feared at times, but the organizations are able to move forward on the strength of trusting relationships. At Sloan for example, when some teachers objected initially to Co-NECT and then to CoVis, the principal created a "traditional" team where teachers follow a typical middle school model. This compromise not only allowed the projects to move forward, but it enabled the school to service students whose parents objected to the new model. The Principal trusted the judgment of the dissenting teachers, allowed them to work within their bounds of comfort, and created a solution that meets a number of needs in the school community.

3.3.2 Collegiality

Relating to trust, there was also a spirit of collegiality existing at all three of the schools. School personnel have good working relations that support their work enacting CoVis in their classrooms. At Jarvis Juile described how the other teachers on her team (not CoVis teachers) worked with her to accommodate the demands of project-based learning:

> There has to be collaborative support with your peers - we're a departmental program. Sometimes I run over time. I have to know that it's not going to cause a mini-revolution with my peers. My team said, "Well some day I wouldn't mind if you need to take a double period..., I wouldn't mind reworking the schedule for that." That's really important.

Juile also explained how her work with Margaret, the Jarvis Technology Coordinator, around learning technology skills was instrumental to her success. The pair were both new computer users when Jarvis joined CoVis. Joking about how they learned together Juile quipped, "Well Margaret and I are sort of equally incompetent." The pair spent hours working together before and after school to set up student email accounts, learn new software packages (e.g., Climate Watcher), and solve systems problems so that the computers would be ready for student use.

The CoVis teachers at Sloan also shared a good relationship. They were the science teachers for two different Co-NECT/CoVis teams. The focus of their collaboration centered on the adaptation of the CoVis CIA materials to meet the needs of their students. They felt that the CIAs were written for high school students and needed to be re-written for middle school. Of their collaboration Pamela said:

> We don't teach the same kids as each other, but we teach the same exact subjects. We usually plan with each other, and steal from each other regularly. Anything, pencils on down.

But, its not just "stealing" from one another. Katie described how she and Pamela rewrote a CIA together:

> I rewrote them for my middle school kids. There was just a lot of that. When I first looked at it sounded good. Then when I started reading through stuff I was like "kids are never going to get this." So Maddox and me spent a lot of time figuring out how we could bring it down to their level.

In part that rewriting derived from a process of trial and error. Pamela describes the benefit of being two days ahead of Katie:

> That's why I like the teacher collaboration because of being able to go "well I'm 2 days ahead of her." If someone is behind you then you can say "the kids really didn't get this. I tried it four times."

So the two worked together, rewriting projects for their students and field testing their work. Again, we find the spirit of collegiality in many instances across our experience with all three schools.

We have thus far examined both human and social capital in the three schools. But, the central argument here is that human and social capitals are both preconditions for reflective learning in organizations. We now examine reflective learning at Jarvis, Sloan, and Petersville.

3.3.3 Reflective Learning

Finally, we examine evidence of reflective learning that happened in the enactment of CoVis. That reflective learning was enabled by high degrees of social capitals and in turn builds human capital. Reflective learning builds the schools capacity to engage in reform projects like CoVis.

Collegial relationships were often formed around the learning required to enact CoVis. The relationship between Juile and Margaret focused on learning the technological skills needed to maintain computers, facilitate networking, and use software in the classroom. The relationship between Katie and Pamela focused on learning how to adapt CoVis CIAs to their middle school classrooms. The two conversed daily around the re-construction of project lessons. They took CoVis project materials, tested them in their classrooms, rewrote portions to meet the needs of their students, and, as described below, learned to write rubrics for the assessment of project work.

3.3.3.1 Reflection in Action

Teachers also described learning experiences that Schön (1983) call reflection in action. When they encountered problematic situations in their classrooms, they reflected on those problems and invented solutions. To illustrate, one place that reflective problem solving is evident in the invention of new classroom management strategies that the teachers designed to meet the demands of project based classrooms. While all of the teacher invented a number of management strategies, here we present one strategy used at each school.

Peer Teaching: Katie used a number of software applications through the course of the year. Rather than stop and teach students how to use each application, she employed peer teaching. In Katie's words, "I just found out who knew how to use it. Then I found out how well they knew. If they knew it really well I said "Good then you'll be teaching it.'" Those students helped other students to learn how to use the software. At Petersville Georgia used a similar approach using students with good Internet searching skills to help other students: "I could pick a few kids with good searching skills and I'd put one in each group."

Structure: Georgia noted that many of her students had difficulty with extended project deadlines. They would fail to pace themselves and then end up doing poor quality projects in the last few days of a project cycle. To solve this problem, she provided structure for her students in the form of project milestone deadlines. "I gave them all deadlines. You have to have this done by this date. When you get that done, you've got to do this."

Groups and Multitasking: Juile described using student groups that worked together on projects as a means of sharing resources. She formed six groups because she had six classroom computers. "I set up six groups because each group could have a computer." But since not all students could work at the computer at one time, she encouraged them to work on different parts of the project. This way while one or two students used the computer, the others could work on something else. "That was beautiful. It just created a flow that worked very nicely."

In each of these instances the teachers designed a classroom management solution to a problem that arose in the project-based teaching situation. In other words, they reflected on their teaching situation and invented a solution.

3.3.3.2 Reconceptualizing Practice

We also see evidence that the teachers reconceptualized their pedagogical practices. They all moved from previous practices that were by and large determined by traditional curriculum guides and textbook, to incorporate project-based learning into their classrooms. As described previously some of the teachers had used project before — notably Georgia, Pamela and Katie — but none had used them to the extent that they did this year. All the teachers did at least 10 weeks of project work, and one teachers did a full 30 weeks worth of projects. At Jarvis, Juile was especially articulate about learning new teaching practices. She explained that she began CoVis thinking of herself as a good inquiry science teacher, and believing that project-based science would be much the same. Instead she found herself needing to learn a whole new set of teaching skills:

> In inquiry science teachers don't give answers, students find out. I've done this almost since I started out in science. What I find when I'm using technology is that you're not doing inquiry science. You're doing problem-based learning. In *inquiry* I can do in a lab in 40 minutes. I walk it and I say to the kids, "You know I stopped at McDonalds and got some coffee. When I dropped a sugar cube in I started wondering does it dissolve faster if it's hot, or does it dissolve faster if it's cold? What do you think?" I ask them, "How can you find that out." Then, I can do a nice little lab. But, *problem-based* is loosely structured kinds of problems. It requires a lot more research integration. You can do inquiry science that's all hands on. You don't have to do research. Inquiry tasks are like the typical science labs: 40 minute periods of time where you investigate something. You approach it from finding out, you don't give answers, you don't throw a ton of information at students and then do a demonstration to support what you've said - you find out. Problem based learning is a bigger issue. It's more what they need to do to get involved in science - to get prepared to be involved in a good way in science. It requires research. It requires defining the problem. Even though I do inquiry, in my mind *I have the problem that we're going to be investigating set in my mind.* In this problem-based learning, *the problem kind of evolves from the situation* that you look at. I found out that just for kids to make a problem statement was really difficult for them. I think that all of that came on me when I said OK, "now here's global warming, because global warming was the first CIA that I did. That's problem based. Here's this data. Here's this stuff. Now look at it. Now let's investigate. Let's decide where we fall on this issue, this debate, this controversy. I don't think that I was cognizant of how different that was.

Later in the interview she returned to the issue of problem definition explaining that she now recognizes that students need scaffolding for this process. So, when she begins a new project, she finds ways to help students define a problem:

> So, I know that there are some preliminary things that I can do. Like I have to really work on [helping students] make problem statements. Whether I construct a little scenario or give them some information that they have to have. Its just really tricky.

So Juile shifted from an inquiry perspective to a project-based perspective meeting a range of new instructional challenges along the way. She found that teaching in this way was more complicated than she had anticipated and more difficult than her previous inquiry teaching style. But, she faced those challenges, learning from them, and was pleased with the result. Reflective learning is apparent in her comparison between her new and old teaching practices. She had given enough thought to how these practices differed that she could quickly summarize them in our interview. Further, she reflected on the difficulties associated with project-based learning. She identified areas of difficult for students (e.g., defining problems) and generated solutions (e.g., provide exercises that help students to write good problem definitions). In a similar way all the teachers that we interviewed at Jarvis, Sloan and Petersville described themselves as learners through the enactment of CoVis.

3.3.3.3 Learning in the CoVis Community

Another measure of learning is participation in professional development opportunities provided by the CoVis project. All of the teachers at the three schools participated in both the 1995 and the 1996 the CoVis Summer Conferences. The Conferences are designed as opportunities for CoVis teachers to get together and share their experiences. Teachers both attend and present sessions on topics ranging from assessment to technological trouble shooting. These teachers' participation represents a commitment on the part of both the teachers and their districts to learning about CoVis technology and pedagogy and to improving local teaching and learning practice. At the 1996 CoVis Summer Conference Juile, Katie and Pamela were presenters; further evidence of their reflection about teaching and learning practice. They reflected about assessment practices in their classrooms and presented a workshop about the use of rubrics in the assessment of student projects. Juile also presented at the Conference sharing her reflections about the use of telementors — scientists serving as mentors via email based discussions with students around projects — and described her experience to her peers suggesting a number of issues to consider around telementoring.

So learning became a daily part of the teachers enactment patterns. This was evidenced by their learning from one another in collegial working relations, by reflection in action, by their reconceptualization of teaching practice, and by their active participation in the Conference.

4. Analysis

We have not addressed financial capital in this paper, but have addressed it elsewhere (Shrader, et al., 1997). All three of the schools described here had sufficient financial resources at their disposal. This does not mean that the schools are wealthy. In fact Sloan is in a working class community in industrialized northwestern Indiana and Jarvis is a Chicago City School located in a relatively impoverished neighborhood. These schools got their financial resources by being resourceful. Jarvis for example benefited initially as the recipient of a CoVis gift which paid their networking fees for one year and purchased six classroom computers. Since then they have written, and been awarded, two State grants which provided funding for the continuation of network service and for the purchase of additional equipment. So, financial resources are essential for successful work on CoVis; or for any significant change effort, but — as Spillane & Thompson (1997) have also

observed — financial resources depend not on absolute wealth, but on the resourcefulness with which schools use and raise money.

Here we take finances as a necessary, but not sufficient resource for enactment. Money is key, but money alone will not guarantee success. This leaves us to consider human and social capital. We take these to be the crux of the implementation problem. How does a school build capacity for enactment? They do it by building their human and social capital. And how do schools build human and social capital? They do it by reflective learning. Let us return to the three cases to illustrate.

In all three schools there existed a culture of reflection around school-wide improvement efforts. At Jarvis the school reflected around their participation as a Comer School. In Sloan the school reflected around its participation as a Co-NECT School. And, at Petersville they reflected around the writing and implementation of a district wide technology plan. They had an institutional mission to re-invent teaching practice around their new technology infrastructure. Thus the Assistant Superintendent at Petersville characterized the school as examining and disseminating "best practices."

So the personnel at these three schools were already accustomed to reflecting about teaching and learning issues. Thus, in all three cases interviewees characterized CoVis not as something altogether new, but as an instance of the kind of teaching and learning practices that their school communities valued. At Sloan both the Principal and the teachers indicated that CoVis represented an opportunity to move the project-based instruction that they engaged in as a Co-NECT out of a supplementary role and into academic instruction. Project-based pedagogy was not new to Sloan. They already used and valued it. What was new was the use of projects as the core focus of science instruction.

So we had in the three schools knowledgeable educators. The teachers and administrators alike had already committed to reform teaching and learning in their schools and had given that effort a great deal of thought and reflection. In fact at Sloan the Principal traced the roots of reform all the way back to 1982. They knew about educational reform and they were prepared to receive a program that thought differently about teaching and learning. They had, in other words, *human capital*; knowledgeable committed persons willing to invent CoVis.

But this is not to say that they knew how to "do CoVis." In fact all those interviewed described themselves as learners through the process of enactment. Juile & Margaret learned computer skills. Harry, the Jarvis Principal, learned that urban students could learn in project-based classrooms. Pamela & Katie learned how to adapt CoVis to their multi-grade middle school classrooms. And, Georgia learned new classroom management strategies. This learning was enabled by the spirit of trust and collegiality that existed at the three schools. The administrators valued CoVis and trusted their teachers to enact it. They provide support in the form of money to attend CoVis Summer Conferences and in the form of latitude to enact CoVis without fear of reprisal if the project should fail. The teachers in turn felt comfortable taking the risks associated with such a fundamental change in their practice. They all believed that they had the blessing and support of their administrations as they worked on CoVis. *Social capital* in these schools was high. It resulted in learning, which grew human capital.

As Spillane & Thompson (1997) observed in their study of math reform in Michigan, social and human capital are interconnected. Educators at our three schools work in trusting, collegial, and cooperative environments. These forms of social capital allow them to take risks, to learn through their work co-constructing new practice, and to therefore grow the human capital of the schools. Human capital in turn is vital. These educators were

able to enact CoVis locally precisely because they valued its theoretical foundations. They understood why engaging students in projects has the potential to improve students' learning experiences. Thus, in these environments, with sufficient financial capital, human and social capitals feed on one another expanding the schools' *capacities* to enact CoVis.

What should we make of this? How can our understanding of capacity in these three cases inform our ability to foster successful enactments of CoVis in other school communities? These are essential questions underlying the scalability of educational innovations; technological or otherwise.

5. Design Implications

How can we design to improve the human capital that exists in schools enacting CoVis? We need to find ways for school communities to learn through the enactment of our innovations. We can do this in a number of ways. We can incorporate design rationale into the innovations to make the underlying principles of the design apparent to our school based co-designers. By referring to the design rationale, they can learn about the design of the innovation and about its implications for teaching and learning. We can also build opportunities for reflection into our designs. This might be accomplished by building task-driven interfaces to the curricular materials. Here, we need to anticipate how actors use our materials and present the materials to actors in functional ways. Thus, if we imagine a teacher confounded by a persistent misconception that her students have around a portion of a project, then we can design our materials with a point of entry around repairs for that misconception. We could thus envision that teacher walking out of the classroom shaking her head in frustration and looking to the project curriculum for help. In constructivist terms this is a teachable moment; one around which reflection and learning might occur. The trick is in providing curricular resources that meet that need and that provide users with a good learning experience.

How can we design to improve social capital? Perhaps we can't; at least not directly. Unless we think of school management as integral to enactment of curricula. Perhaps our task-driven functional interface could provide principals with resources which help them to train their teachers to enact a new reform projects. These resources would have to provide the principal with scaffolding for the design of professional development opportunities. That scaffolding might very well include design rationale describing the importance of trust and collegiality in the enactment of innovations. It might also provide the administrator with cases of previous enactments from which she can learn how others have fostered the growth of social capital.

How can we design to improve financial capital? Well if we take Spillane & Thompson (1997) seriously, then it's not the quantity of wealth in a district or school, but the appropriation of the funds that are available. Can we provide schools and districts with insights into the allocation and/or raising of funds in ways that are supportive of reform?

The three previous questions, when thought of from the perspective of the design of curricular innovations, suggest a new paradigm for the design of curricular artifacts. They suggests a learning curriculum where not only students but teachers and administrators learn from the curricular materials (Ball & Cohen, 1996). In other words they suggest that we need to design curricula to support reflection in action Such curricula would be designed with resources that help educators to learn through enactment in context. Finally, when looked at from a Learning Sciences perspective they suggest the design of a new technological architecture for development of learning curricula.

The CoVis project is hard at work conceptualizing such an architecture. That problem has been the subject of our recent grant writing. We look forward to the opportunity to build on the kind of work reported here to provide insight into the design of learning curricula that encourage educators to reflect upon, discuss, and learn from the enactment of innovations. Enactment of innovations could, and should be, viewed as opportunities for schools to expand their local capacity.

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