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ABSTRACT

This paper presents the preliminary results of ongoing case study research in the Learning through Collaborative Visualization Project (CoVis) testbed. The goal of CoVis is to promote project-enhanced science pedagogy. The project focuses on three areas: (1) project-enhanced science teaching and learning; (2) developing communities of practice; and (3) providing a facilitative technological infrastructure as a means for transforming science education. The purpose of the case study research is to understand how local schools invent CoVis. The notion of inventing CoVis arises from the recognition that innovations are never adopted whole-cloth; rather, they are adapted by members of local communities to meet their own needs. Teachers, administrators, and technology coordinators at eight CoVis schools were interviewed about their first year of participation in CoVis. Results show dramatic differences among practices invented between high and low socioeconomic schools. Those differences are examined through three lenses. First, local school capacity is examined vis-a-vis constraints and affordances that bear on local inventions. Second, invention is examined with regard to the three phases of the CoVis program model. Finally, the practices of two teachers (one from a high and one from a low socioeconomic school) are contrasted to shed more light on how study-wide factors from the earlier analyses bear on particular teachers' practice. Contains 15 references. (Author/PVD)

Inventing Interventions: Cases from CoVis--An Analysis by SES

by
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Inventing Interventions: Cases from CoVis - An Analysis by SES

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Abstract

This paper presents preliminary results of ongoing case study research in the Learning Through Collaborative Visualization Project (CoVis) testbed. The goal of CoVis is to promote project-enhanced science pedagogy. The project 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. The purpose of the case study research on the large is to understand how local schools invent CoVis. The notion of inventing CoVis arises from an adoption model which recognizes that innovations are never adopted whole-cloth, rather they are adapted by members of local communities to meet their own needs. Thus, provided with an intervention like CoVis, educators in local school will invent local practice.

In the case study research, a purposeful sample of eight CoVis schools was selected from the 45 participating schools to include: (1) high and low socio-economic status (SES) schools, (2) active and inactive schools, and (3) schools that have relatively little on-site attention from CoVis researchers (here the intent is to examine how the intervention fares in schools where the teachers are not able to work directly with researchers in the classroom). Teachers, administrators and technology coordinators at each of the schools were interviewed about their first year of participation in CoVis. This paper presents an analysis of the interview data from the five high schools in the sample.

The results show dramatic differences in the practice invented at the high and low SES schools. Those differences are examined through three lenses. First, local school capacity is examined at vis-à-vis constraints and affordances that bear on local inventions. As used here, capacity refers to the ability of school communities and their constituents to enact innovations. A school's capacity is constituted by a number of constituent capacities (e.g., district, school, community and individual capacity). The paper examines the constraints and affordances that operate at each of these capacity levels to affect teaching practice. Second, invention is examined with regard to the three phases of the CoVis program model. As noted above CoVis seeks to engage teachers in a new pedagogy (i.e., project-enhanced science), facilitated by technology and by the formation of a community of practice. Data relating to each of these program model areas is analyzed for differences between high and low SES schools. Finally, the practice of two teachers (i.e., their inventions of CoVis), one from a high and one from a low SES school, is contrasted in greater depth to shed more light on how study wide factors from the earlier analyses bear on particular teacher's practice.

A paper presented to the Annual Meeting of the American Educational Researchers Association, March 24-28, 1997, Chicago, Illinois.

1. INTRODUCTION

This paper presents preliminary results of ongoing case study research in the Learning Through Collaborative Visualization Project (CoVis) testbed. The goal of CoVis is to promote project-enhanced science pedagogy supported by high performance computing and communications technologies (Pea, 1993). 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. Teachers participating in the CoVis project have access to: (1) networked communications (i.e., email, Netscape, etc.); (2) The Collaboratory Notebook – a electronic medium for distant group work (O'Neill & Gomez, 1994); (3) Scientific Visualization Technology (Gordin & Pea, 1995); (4) a suite of project-enhanced curricular innovations (delivered in paper and via the Geo-Sciences Web Server – a web-based classroom resource) (Lento, 1996); and, (5) training in each of the preceding areas. The intent is to create a resource rich testbed 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.

The purpose of the case studies is to understand how teachers in different schools invent practice through participation in CoVis and specifically how they make use of the curricular and technological resources provided in the testbed in doing so. The paper examines how members of various school communities invent local practice as members of the CoVis testbed. Specifically, the paper examines the capacity of various schools to use the resources provided by the testbed to invent project enhanced science in their school. By inventing we mean appropriating and adapting CoVis interventions in their school to enact some version of project enhanced science.

This paper presents a subset of the case study results. Teachers, administrators, and technology coordinators at five high schools participating in the CoVis project were interviewed with regard to their first year of experience with the project. The paper examines differences in invention across the five schools along the socio-economic status (SES) dimension. That is, it examines how SES is related to the way that schools and teachers use the resources provided by CoVis to invent local practice. SES is measured in terms of participation in school lunch programs. Schools with over 75% of their students on the lunch program are considered to be high SES, while schools with less that 25% participation are considered to be low SES schools[1].

Three analyses are presented here. First, an analysis of the constraints and affordances at each of the schools suggests that high and low SES schools face a different set of challenges with regard to their invention of project-enhanced science. Second, an analysis of the work in schools according to the CoVis program model suggests that despite those differences both high and low SES schools make progress toward the CoVis vision. We borrow the term program model from the literature on theory driven evaluation (Rossi & Freeman, 1989). The idea is to construct a theory[2] driven model of how a program is

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[1]The actual percentage of students on free lunch in the schools participating in this study are 0.7%, 5.9%, 12%, 80% and 97%.

[2]Here theory is employed in its less formal sense. The notion is to capture the theory underlying the design of CoVis interventions. Such theory need not be explicit. Often it is in the role of the evaluator to make it such. In this case we employ a three part model (described subsequently) which derives from a distillation of

supposed to work which informs the questions and analyses used to evaluate that program. Here, we are engaged in formative evaluation research informed by an articulation of the model underlying the design of CoVis interventions. Finally, the practice of two teachers, one working in a high and the other in a low SES school, are compared in order to illuminate the findings presented in the first two analyses.

1.1. CoVis as Intervention Research

CoVis can be situated as an instance of curricular intervention research. Historically curricular intervention efforts have been plagued by translations (Olson, 1981) or lethal mutations (Lamon, Secules, Petrosino, Hackett, Bransford, & Goldman, 1996) – instances where teachers in local contexts fail to implement an innovation in the manner intended by its designers. Such mutations arise, in part, from the desire of curriculum designers to prescribe a preconceived pattern of use. In contrast, we believe that patterns of use in classrooms always vary from that intended by the designer. With this in mind, the National Science Foundation (NSF) sponsors testbeds designed with the specific intent to promote invention (Hunter, 1993). As a testbed (Gomez, Fishman, & Pea, In press), CoVis encourages active re-creation of interventions. Schools invent a range of use given the constraints and contexts operating within their community.

Yet how flexible is CoVis to invention across diverse contexts? Certainly we do not want to suggest that "lethal mutations" can be eliminated altogether. Particular inventions may very well subvert the spirit of CoVis innovations. Therefore, our goal is to understand the range within which people working in communities of practice reproduce interventions that are true to the spirit of the innovation and to differentiate the factors that contribute to productive and unproductive efforts.

1.2. Capacity and CoVis Invention

Schools are complex systems composed of a number of relatively independent parts interact in a complex fashion (Wick & Gose, 1994) For example, within schools students, teachers, administrators and curriculum materials interact to construct teaching and learning. At a wider level, within school communities parents, school board, and other community entities interact with and bear on the conduct of schooling. Beyond that community factors like socio-economic status, values, and cultural attributes of the community affect schools and schooling. Moving outside the local community state and federal departments of education, legislature, publishers and the like all bear on the conduct of school. Thus factors at multiple levels – some within the school, some in the school community, others in the community surround, and still others in the larger context – affect what happens in schools; that is, they affect school capacity.

To illuminate, CoVis is an innovation developed by researchers at Northwestern University – members of the larger educational context. The project is conceived and designed to afford schools the opportunity to engage students in project-enhanced science. In other words, it is intended to expand school capacity such that project enhanced instruction can be realized[3]. So, CoVis is a project designed to expand capacity. Here it is important to note that a number of other capacities exist in school and that these may bear either positively or negatively on the invention of CoVis locally. For instance, district policy might affect CoVis positively if it values standards based reform (e.g., critical thinking and

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the literature underlying the design of CoVis.

[3]It is important to recognize that there are a number of constituent capacities that are addressed by the CoVis design. Among these are expanding technological, pedagogical, and professional development capacities. Theres will be specified further below.

problem solving) or negatively if it values direct instruction to improve standardized test scores.

It is in this sense that we view schools as complex adapting systems with differing capacities. Here school systems are analogous to family systems . Like schools, families have common elements (e.g., mothers, children, financial worries, and educational decisions); yet, they differ greatly as these elements interact. Similarly, schools have commonalties yet school capacities differ widely across contexts (Wick & Gose, 1994).

In this sense, capacity is a theoretical construct that attempts to account for significant variation within and across schools as a means of better understanding the change process in schools. Through the lens of capacity, one can begin to bring the challenges associated adopting an innovation in a complex adapting system such as a school into focus.

Traditionally, capacity has been thought about in terms of human capital. As used here, capacity refers to the ability of school communities and their constituents to enact innovations. Therefore, in this study the term is utilized in a broader sense that incorporates the social aspects of capacity which are essential to successful curriculum enactment (Spillane & Thompson, 1997). In this sense capacity is a lens that views innovation as a transformative process that occurs with in a social context (Bryk & Hermanson, 1993), taking into account the formal, informal and enduring social relationships on which practice is based and new practice is invented.

In a global sense, the capacity for change in a school classroom encompasses a number of component capacities. This paper addresses four of these: individual capacity, community capacity, school capacity and district capacity. While the four component capacities are differentiated, it would be a mistake to think of them as acting independently. Rather, they collectively constitute capacity in the large. Neither are these four capacities comprehensive. For instance, as argued above state and federal educational policies affect capacity; however, these are not addressed here.

Individual capacities exist in each one of several school community constituent groups. While the example which follows examines the individual capacities of teachers, the point could have been made just as easily with the individual capacities of students, parents or administrators. On the teacher level, differences in domain knowledge, classroom management experience, strategies, or other capabilities can affect teachers' capacities to enact a particular curriculum. For instance, CoVis Inter-school Activities (Lento, 1996) often require students to proceed with projects that go beyond the teachers domain expertise. This requires that teachers acknowledge to their students that they do not know, and place themselves in the position of learning from their students' work as informed by research and/or the advice of mentors. Teachers clearly differ in their capacity to make such acknowledgments. Plainly put, many teachers are uncomfortable and therefore do not implement that part of the curriculum.

Curriculum enactment is also influenced by **community capacity**. For example, community members (e.g., parents) might object to a new teaching practice on the grounds that it does not match their conception of school or school work. They might, as a result, oppose a reform by pressuring the school board. In turn the innovation could very well be dropped.

In a like fashion cultural factors (e.g., values, educational background, primary language, etc.) also bear on community capacity. For instance, in a community with a high population of new immigrants where English is a new language schools will have to focus a great deal of energy on building English competencies. Dedication of resources to meet the English learning needs of the community will influence availability of resources for

other aspects of the school program. In this way, community capacity is a determinant of what schools can accomplish.

The **school capacity** also influences curriculum enactment. For example, innovative curricula often conflict with exiting values in the school community. As a result, the success of the innovation there depends upon the capacity of the community to change its value frame. The capacity of a school community to enact a curricular innovation depends not solely on the teachers in that school, but upon the coordinated action on the part of the school community. Thus, a teacher with the support of her peers and administrators is more likely to make substantial progress than is a teacher operating in a less hospitable atmosphere for change.

School capacity is closely related to **district capacity**. District capacity has to do with the bureaucratic organization and administration of schools. One manifestation of district capacity is illustrated by the difference between a highly centralized administrative structure, and a decentralized one. In the centralized system authority is held by those at the top of the administrative structure and may be shared in some degree through the power of delegation. Here the decisions of Prinicpals are subject to the review and approval of higher level administrators. In decentralized systems more power is held directly by the school and is shared with central administrators at the discretion of the Principal. Another aspect of district capacity is the support of teaching practice. For example, do district level administrators approve of teachers work on innovative curriculum projects. If so do they have the resources and wherewithal to support that work?

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This paper focuses on descriptions of the inventions of CoVis in local context with the goal to understand the salient factors in those contexts that either constrain or afford progress toward those inventions. Capacity, in all its layers, is one lens through which to examine the invention of CoVis innovations in local school communities. We begin by examine the constraints and affordances that exist across a sample of CoVis schools. Here, we examine constraints and affordances through the lens of capacity in order to understand the differential capacities of local schools to invent project enhanced science in their classrooms. The goal is to design a more useable and adaptable intervention.

2. METHODOLOGY

This paper reports findings based on a larger research agenda which employs a *multiple* embedded case study design (Yin, 1995). In this design multiple cases studies are prepared and analysis is conducted across those cases. This affords the development of understandings of variation that occur across contextual boundaries. In this research individual CoVis schools are the primary unit of analysis and; therefore, individual schools are cases in the study. The design also includes *embedded* cases at a secondary unit of analysis. Individual classrooms at each school constitute secondary cases embedded within the school case. Embedded cases inform the understanding of variation within particular cases.

2.1. Context

We choose to conduct case studies for a number of reasons. First, the research context lends itself to case study research. By nature testbed research includes work (1) at multiple sites, (2) in diverse contexts, (3) where constituents sample from a broad menu of project services, (4) and where researchers have little control over implementation. Since we can't know what happens in each of our classrooms, in order to understand practice in the testbed we need to employ a methodology that allows us to construct pictures of

invention in particular places at particular times. Second, the methodology allows us to emphasize comparisons across cases while preserving the organic integrity of individual schools. That is, the methodology does not require us to impose some research construct on the practice of schooling, rather it allows us to examine practice as it actually happens in real classrooms. In this sense case studies are particularly well suited to testbed research as the rigor of the method does not interfere with the progress of the testbed research agenda. This allows us to see how practice unfolds in each case and provides a way to compare and contrast practice at the different schools. Here, diversity (variation) among and between schools becomes a virtue of, rather than a threat to the research design. For instance, it allows us to conduct our analyses along dimensions of difference in our sample. One such dimension is SES, the focus of the analysis in this paper.

2.2. Selection of Cases

To examine invention in CoVis classrooms eight of the 41 CoVis schools were selected for inclusion in this research. The schools were selected using a purposive sampling strategy intended to maximize differences along multiple dimensions. We sampled from:

- both middle schools and high schools;
- both high SES and low SES schools;
- both active and relatively inactive schools[4];
- and, both local and distant schools[5].

The work reported here is based on an analysis of the data collected at five of the eight cases study schools. These five schools are the high schools in the sample.

2.3. Data Collection

The present analysis is based upon data collected during interviews at each of the five high schools. Those interviews focused on six domains of interest:

- Pedagogical beliefs – how do beliefs affect how the interventions afforded by participation in CoVis are interpreted and used in the schools?
- Readiness – What are the perceived preconditions for participation in CoVis?
- Diffusion – how were technological and pedagogical knowledge shared within the school community?
- sustainability – what would it take to sustain project-enhanced pedagogy in the school?;
- Dimensions of difference (i.e., tracking, infrastructure, school culture, etc.) – in what ways do the schools in the CoVis testbed differ? How might those differences affect the schools invention of CoVis?
- Experience – how was CoVis participation experienced in the classroom/school?

Using an interview protocol designed with these six domains in mind, we interviewed each of the teachers (anywhere from one to four teachers per school), the administrator

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[4]A gross measure of activity was derived on the basis of both the school's participation in CoVis sponsored science projects (CIAs) and the relative contact between CoVis researchers and the school. Active schools both participated in CoVis sponsored science projects and maintained ongoing contact with the larger CoVis community.

[5]As measured by the school's proximity to Northwestern University.

principally responsible for CoVis and the district or school technology coordinators at each of the five schools. An analysis of that data along the SES dimension is presented below.

3. ANALYSIS

Clark and Paterson (1986) propose a three part model through which to examine teacher practice. Their model of teacher thought and action includes (1) teachers' thought processes, (2) teachers' actions and their observable effects, and (3) *constraints and opportunities*. The present analysis takes the Clark and Peterson model and expands it to include consideration of others (e.g., administrators and technology coordinators) in the school community. Expansion of the model arises from the view that classroom practice, especially where that practice arise from the adaptation of an innovation, is not solely a function of teacher thought and action, but results from interactions students, teachers, administrators, and others (e.g., parents) in the school community. So, understanding interventions through this wider lens includes an examination of (1) the perspectives of various school community members, (2) classroom practice, and (3) constraints and affordances.

Since we conceive of CoVis as an affordances for changing instructional practice, we begin our analysis by examining the constraints and affordances that exist in five CoVis cases. In this analysis we attempt to accounting for the interactions of various school community members (i.e., teachers, administrators, and technology coordinators) around those affordances. Finally we examine the classroom practice that results. In both cases we consider the perspectives of teachers, administrators, and technology coordinators in each school.

3.1. Constraints and Affordances

The analysis of constraints and affordances in the CoVis testbed rests upon the structured interviews described above. Two types of data were coded into constraint and affordances categories. First, the interviewees were asked directly to report constraints that affected their work inventing CoVis. Second, the interview protocol included a list of six anticipated constraints. Interviewees were asked directly about these categories if they were not spontaneously addressed by the interviewees. Based on their responses, 18 constraints categories were constructed and data from the interview transcripts was coded into those categories. In order to make the meaning of each category clear Appendix A includes a definition for each category.

Closer examination of the constraint data revealed that responses in each category were valenced. That is, the same factor that constrains invention in one school, affords progress in another. For example, one school might have an equipment constraint, while another school has an equipment affordances. Students in the first school might have limited access to computers for project work, while students in the other school have ample access. The data presented here are therefore presented as constraints and affordances that exist in each of the five cases.

Table 3.1.1 presents a gross summary of the constraints and affordances data by school. Each cell in the table represents what interviewees in a particular school had to say about one constraint/affordances category. Entries in those cells are coded in two dimensions; speaker and valance. The speaker may be an administrator (A), teacher (T), or technology coordinator (TC). In the event that more than one teacher or administrator was interviewed at a school, those speakers are differentiated by numbering (e.g.,, the three teachers at Central are coded as T1, T2, and T3). Valance indicates whether the speaker construed the category as a constraint or an affordances. Constraints are coded bold and affordances are coded italics. Uncoded entries are non-valence; that is, the comments were

Table 3.1.1 Constraints by School and Capacity Type

Capacity Type	Constraint	*Rockefeller*	*Meadowland*	*Hoosier*	*Central*	*South*
	Hard Work		A1			
	Inhibits	T	A2			
Individual	Curve L.	T	T2	*A*	*T1*	
	Planning					
	Attitude					**A**
	Creativity					
	School Work					
Community	Attendence				**T1**	
	ESL				**T2**	
	Time		**A2, T2**	*T1,*	**T1, T2, A**	
	Internet Hor		*A2, T1*	T2	T1	
School	Block Sched.	T	A1, A2, **T1**	T1, *T2, A*		**A**
	Planning		**T2**	T2	T1	**A, T**
	Class Size			*T2*	**T1, D**	**D**
	Course Load		*A2, T1*	*T1, T2*		A
	Space	*A*	*A2, T1, T2*	*O*	**A**	
	Equipment	*T, TC*	*A1, A2, T1*	*T1, T2*	**A**, T1, T2	**A, T**
District	Money			*T2, A*	**O**	**A, T**
	Experimentation		*A2, T1,* **T2**	*T1, T2*	**T1**, T2, T3	*A,* **T**

Key: A = Administrator, T = Teacher, TC = Technology Coordinator, O = Observation Notes, D = Documentary Evidence
A1, or T1 = more than one teacher or administrator interviewed
Bold: The issue was decribed by the interviewee as prohibitive
Italics: The issue was described by the interviewee as facilitatative
No Color: The issues was not particularly valenced

neither positive nor negative. For instance, on the issue of teachers' course loads one administrator (South) noted "My teachers have five [classes], but it would be better if they had four." The comment neither suggests that the teachers' workload is over burdensome, nor that the teachers have a great deal of planning time to invent projects.

To make table 3.1.1 more meaningful, constraints and affordances of a like kind were moved together. On the top constraints and affordances under the control of individuals in the school community are noted (Hard work and its sub-categories, attitude, creativity). Then, community issues arising from the characteristics/attitudes of the population outside the school (school work, attendance, ESL) are grouped. The fourth group includes constraints/affordances of the school organization (Home access, Time and its sub-categories, class size course load, and space). Finally district support factors, including financial and moral support, are indicated (Equipment, Money, Experimentation). While there are some patterns apparent in the table as a whole, the more interesting analysis arises from consideration of comparisons across these capacity areas.

Taken on the whole, the trend apparent in table 3.1.1 is that the high and moderately high SES schools (Rockefeller, Meadowland, Hoosier) are coded predominately italics, whereas the low SES schools (Central and South) are coded predominately bold. That suggests that the high and moderately high SES school in the study experience fewer constraints affecting their work inventing CoVis than do the low SES schools. Or looked at from the alternative perspective, high SES schools have affordances that are supporting of their work inventing project-enhanced science. This observation raises a number of questions that drive the remainder of this analysis. What is the exact nature of the differential constraints and affordances in the high and low SES schools? How do those differences affect practice in the two settings? Are these differences the source of insurmountable odds in the low SES schools, or are they simply indicative of differences in starting point? The first step in the examination of these questions is to examine the constraints and affordances more closely.

Dividing the data in table 3.1.1 into capacity areas (e.g., individual, community, school and district capacities as shown in column one of the table) enables a closer examination at how constraints and affordances operate across school cases. As discussed in section 1.2, we conceive of capacity in the whole to be a collection of constituent capacities that each have a bearing on capacity in the large. Table 3.1.1 identifies four constituent capacity areas that collectively constitute school community capacity in each school case: (1) individual, (2) community, (3) school, and (4) district capacity.

3.1.1. District Capacity

Working from the bottom of table 3.1.1 to the top, it is evident by the contrast in italics and bold coding that there are clear differences between the high and low SES schools on the question of district level capacity issues. On the issue of equipment, interviewees in all three high SES schools feel that they have enough access to computers and to networking to support their work on CoVis. In fact, at two out of three of those schools additional computers were purchased at mid-year in order to make the project run more smoothly. In contrast, equipment was a big problem at the two low SES schools. For instance, Central has a network connection in three science classrooms with six each. However, getting the computers and networking is something of a Herculean effort that continues today. In the words of an Central administrator:

> We're still struggling. We have enough computers in this building right now to have at least one computer in every classroom, and in some more, but we can't have them hooked up, we can't get them connected to the network, we have been struggling to them put in for five months now. It [the problem] is with [Central Administration] and the contractors that they farm this stuff out to.

So, the science classrooms are lucky in comparison to others at the school. But, even in the science classrooms, there is a problem supporting the computers. One teacher noted three different instances where lack of software was a problem for her students. In one case, a CoVis Interschool Activity (CIA)[6] called for students to graph a data set downloaded from the CoVis web page, but the computers did not have the needed spreadsheet software. In the teacher's words "...we could not [graph the data] because we didn't have the software." Instead the students did their " ...graphing by hand." Here the difference between the high and low SES schools rests in the ease with which teachers and building administrators at the schools can work with district level administration to provide classrooms with equipment. All the schools had money for equipment, but bureaucracy at the low SES schools ground progress to a halt.

While money for infrastructure investment does not distinguish the high from the low SES schools, money for supplies does. The software problem cited above illustrates this issue. While money for hardware and networking comes out of district and building infrastructure budgets at the two low SES schools, money for software comes from teacher and departmental discretionary monies. Teacher at the high SES schools report that they have adequate budgets with which to order classroom supplies – including software. In one high SES school that money comes from a $4500 departmental budget supplemented by a $10 per student lab fee. In contrast while waiting to interview a teacher at Central, I observed her dolling out halves of paper towels to student lab groups (one half to a group). When asked about this practice, she indicated that she only had $200 for supplies for the year. Likewise money is a problem at South where a teacher explained that students can not afford to pay any lab fees.

Finally, tolerance for experimentation is a problem for the low SES, but not the high SES schools. With one exception, the high SES teachers and administrators felt that CoVis and innovative instruction in general is supported. The one teacher who disagreed, felt that she was supported now, but that if the project failed, the administration would pin the problem on her. She said:

> I think they're in it only for the publicity that they will get from this if its successful. If its not a success, then it will fall on the teachers shoulders.

Such thinking was much more indicative of the low SES teachers. Only one interviewee at the low SES schools, a high school principal, felt that work on CoVis was supported. The teachers had a different view. One teacher refrained from comment and another was fairly benign in his commentary. However, two of the four teachers interviewed directly cited fear that the central administration does not support their work. Here the underlying fear was associated with the recent actions of central administration to placed both schools in this study on academic probation. These teachers felt that innovative teaching practice would be perceived by central administrators to conflict with their new bottom line basic skills focus.

3.1.2. School Capacity

Like district capacity, the high SES schools enjoyed more support at the school level than did the low SES schools. Here the high SES schools are supported with home Internet access (2 of 3 schools), block scheduling (currently in place at one school and

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[6]CIAs are project enhanced curricula written by CoVis researchers in conjuction with CoVis teachers. CIAs are intended to provide teachers with opportunities to engage in project-enhanced science. They are referred to as *Interschoo* activities because they are designed with a bend toward collaboration between students in different school and between students and mentors from science and industry. For a full description of CIAs refer to (Lento, 1996)

beginning in the 1996-97 academic year at another), reasonable class sizes, dedicated classrooms (all three schools – 2 of three explicitly noted in the interviews). In contrast no low SES teacher has home access to the Internet, they all have classes of over thirty students per class, and teachers share crowded classrooms.

To illustrate how schools either constrain or afford inventive practice, let us take a closer look at the issue of block scheduling. Interviewees at four of the five schools raised block scheduling as an issue. With one exception, they all believe that providing larger blocks of time is essential to successful project enhanced science. The one dissenting teacher works in Hoosier where the year of this study was the first year of block scheduling. When asked how important is block scheduling? She responded:

> Not important at all. As a matter of fact, for environmental science I'd rather have a regular schedule because you can't sit in front of a computer for 90 minutes.

In contrast both the other CoVis teacher and the administrator I interviewed at this school advocated block scheduling as an essential support of innovative instructional practice. Likewise, the interviewees at Meadowland articulated a need for block scheduling and related that beginning in the 1997-98 academic year, the school will move to block scheduling. So, shortly two of the three high SES schools will work on a block schedule. Unfortunately block scheduling is not an option at either of the low SES schools. Last year at South the principal brought a block scheduling plan to a faculty vote. The union voted the plan down effectively tabling the motion for five years. At the other low SES school, the administrator explained that overcrowding at the school prohibits block scheduling.

3.1.3. Community Capacity

Community capacity issues were not raised at any of the high SES schools. However, community capacity was an issue at one of our low SES schools where teachers cited poor attendance and a high percentage of English as a second language students (ESL) as challenges for instruction in general and problem enhanced science in particular. Here, one teacher notes that extremely low attendance is a problem. She says that on any given day as many as ten of her students from each class miss school. She explains that project work makes it difficult for her to track which students have made up that work. On the other hand, she argues that if she lectures from a text she can easily identify homework assignments for the students who miss class. She presents her case in a disappointed tone. The teacher clearly enjoys the project work, but has been unable to identify a solution to the attendance problem.

Another teacher in the same school notes that:

> For example. a high percentage of our population is bilingual. In the sense that they've only been in the country for a year our two and their English skills are very poor. And we get them in a science class.

For this teacher, feeling a need to address basic language skills in instruction for his ESL students makes doing projects difficult. Here the extra effort required to address language instruction in the science classroom make the additional effort required to enact project based instruction more burdensome.

The question of community capacity is certainly not settled by this analysis, but it raises questions for future case study work in the schools. This is an area of inquiry that arose from our data analysis and that requires additional investigation. In particular, as the issue was raised in only one school, do community capacity issues affect other schools as well? Does the absence of commentary suggest that community capacity is not an issue at the other schools? Or, did it simply not come up in our interviews? Future interviewing will address these questions by raising the issue at all five schools. It may very well be that

there are curricular and/or technological design solutions appropriate to address these issues if they are found to be problematic in enough contexts. For instance, on-materials could be made available with Spanish translations.

3.1.4. Individual Capacity

Turning to individual capacity, the most noteworthy aspect of table 3.1.1 is the startling lack of commentary on this subject by interviewees at the low SES schools. The data here primarily relate to the hard work the CoVis teachers did over the course of the year to learn technology platforms (e.g., Mac or IBM), networking software (e.g., email or the world wide web), and adapt CIAs to their classrooms. Here the point is that teacher in low SES school, by and large, do not raise such issues. The data here are certainly not conclusive, but, taken with the previous analysis of district, school, and community capacities they suggests the possibility that dealing problems beyond their control occupies the teachers' effort in a prohibitive fashion. That is, perhaps they simply do not have the luxury to expend that additional effort. This question will be pursued in the subsequent analysis

. . . . . .

So, in the large we begin to get a picture suggesting that high SES schools have affordances at the district and school level that make changes in practice possible, whereas low SES schools have constraints at the district, school, and community level that inhibit invention. Such a finding is both uninteresting and dissatisfying. It is uninteresting in that if this is the whole story, then all we've managed to do here is to replicate a long history of inequity findings in such research. It is dissatisfying in that as researchers we think we know that progress is being made in both settings; albeit more slowly and along a different trajectory in the low than in the high SES schools. We therefore turn to a complementary analysis that provides a more hopeful perspective on invention in low SES schools. The next section of this paper examines the interview data with reference to the CoVis program model.

3.2. Examining the Program Model

We now turn to a closer examination of the intervention itself. As described previously we conceive of CoVis as an intervention affording changes in instructional practice. This section examines action in the schools in terms of its relation to the CoVis program model. CoVis uses a three part model which seeks to (1) change pedagogical practice by (2) providing technological supports and (3) creating a community of practice in which educators in multiple schools work together toward that vision. This section considers progress across the cases with regard to the three parts of that model.

There are a number of difference between the high and low SES schools as to their experience in the three dimensions of the CoVis program model. Table 3.2.1 provides an overview of the interview data which illuminates those differences. The table is divided into three sections which present data in categories relating to the three program model dimensions for each of the five school cases.

The first section of the table presents data relating to the use of technology in the five schools. Though they are not apparent in the table, closer examination of the data coded into the technology categories reveals differences in technology along SES. On the other hand differences in pedagogy and community of practice are readily apparent in the table. Specifically, it is apparent that the interviewees in the low SES schools only addressed these two aspects of the project on a minimal level. Given the constraints and affordances analysis presented above, we might very well attribute these differences to the readiness state of the low versus the high SES school. That is, taken on the whole, this analysis

Table 3.2.1: Invention by Intervention Model

Intervention Model	Constraint	*Rockefeller*	*Meadowland*	*Hoosier*	*Central*	*South*
	Technology	A, T	A2	T2, A,T1	T2, A,T1, A2	A, T
Technological	S Use Technology		T1, T2		T2	A, T
	Tech => Inst. Change	A, T	A1, A2	A	T2, A	A
	Change Practice	T	T1, T2, A2	A		
	Styles Learning	A				
	Models	T	A2	A		
Pedagogical	Roles Shifting	A, T	T2	TC	T1, T3	
	Do Projects			T1		
	Data Driven	T	A1	T1		
	Relevance					A
	S. Collaboration			T1, T2, A		
	Generativity		T2	T1, T2		
	Moral Support		T2	T1		
Community	T Collaboration	A, T		T1, T2, A	T2	
	Comm. w/ > Community[1]	A, T, TC	A1, A2, T1, T2	T1, T2, A	A	
	Professional Dev.	A		A		A
	Learner Teacher		T2	A	T1	T

Key: A = Administrator, T = Teacher, TC = Technology Coordinator
A1, or T1 = more than one teacher or administrator interviewed

[1]Communication with the Larger Community

provides evidence suggesting that the people in the low SES schools are working on a different part of the invention process. Further analysis of the of the data represented in table 3.2.1 is discussed below.

Before proceeding, it is important to note that, like table 3.1.1, table 3.2.1 has one column for each of the five school cases. Again each cell in the table reports responses on a particular category by voice and valence. So, for example, An A in a cell indicates that an administrator at a particular school spoke on an issue. The valance is not as important here as it was in the previous table, except in the "Communication with the Wider Community (Comm. W/ > Community)" category where the bold. As indicate that administrators do not take advantage of the inter-school communication aspect of the project. This means that teachers but not administrators take advantage of the opportunity to learn from the experiences of others in the community about the intervention. This is an aspect of the intervention that we may want to address from a design perspective. As argued in section one, one value held by the CoVis Project is that not just teachers, but all members of the school community need to participate in order for invention to be successful.

We now turn to an analysis of invention in the three program areas.

3.2.1. Technology

At first glance the data in table 3.2.1 seem to suggest that all five schools are addressing the technology component of the CoVis program model. And, in fact, they are, but closer examination of the data reveal that the high and low SES schools are addressing the technology problem from different perspectives. In the low SES schools the focus is very much on the acquisition of computers and networking and on the initial training of students and teachers to use that technology. Here, there is a high value placed on students and teachers having the opportunity to learn technological skills. On the other hand, the high SES schools are much more focused on the use of technology *in* instruction. While the teachers in these school do talk about learning to use technology and software, they join their administrators in suggesting ways that technology has and should be used to better instruction. A closer look at the data tells this story.

There are three categories that compose the technology portion of the table: (1) general use of technology, (2) student use of technology, and (3) technology as a vehicle for instructional change. In the general use categories interviewees at the low SES schools report that participation in CoVis has allowed them to bring computers and Internet connections into the school. Here the experience at South is informative. Both teachers there report that if they had not been participating in the CoVis project, they would not have any computers or an Internet connection. One teacher explained,

> We would never be this far, if it hadn't been for CoVis. I can tell you that right now. We wouldn't have any computers.

She went on to document how getting an Internet connection was even more problematic than getting the computers in the first place. Describing her frustration working with the district's central administration she reported:

> I was in wait of this Internet connection. And we waited, and waited, and waited, and waited, and waited. And on the strength of CoVis ... we were able to get a State grant. That was when something started moving.... The state grant people got us connected. The [Central Administration] people were the ones were holding up everything.... We finally got our Internet connection in the second week in June.

So while dealing with district level bureaucracy proved frustrating, the school's association with CoVis lent credibility to its technology plan and helped them to get a state grant for networking.

Meanwhile our high SES schools were engaged almost immediately in the use of technology for instructional improvement. On this theme an administrator at Hoosier reported:

> We had a student [from a CoVis class] present to the board of education what they're doing with the project [CoVis]. ...how that certainly was a supplement to doing scientific experimentation in the classroom. It was really just a heck of an example of why we were investing our money into technology and infrastructure.

Likewise the administrator at Rockefeller reported that participation in CoVis "...gave us the opportunity to use technology in the way it was intended to be used for educational purposes." And following in this theme an administrator at Meadowland talked about the use of technology to promote instructional change:

> Hopefully the technology is just a vehicle to get the students and others to think and also for the staff to extend its repertoire of skills into getting students to problems solve - ways to get the students involved and actively participating in learning. Rather than simply sitting back and being fed this information.

Meanwhile, when they finally got their computers installed, the teachers at South reported that their students learned a great deal about the use of technology:

> I thought my students had learned a lot... Most of them hadn't had any computer experience before. There were a few that were really apprehensive about doing anything. [They'd say,] "I can't do this." You have to help them gain confidence [because] this is something that they are going to have to live with for the rest of their lives, this new technology that is going on. So I felt good that they were learning something they wouldn't have learned otherwise. At least at this point they get it before they leave high school.

So the focus of attention on technology is different across SES lines. In the high SES schools the focus is on the use of technology for better instruction, and in the low SES schools the focus is on the acquisition of technology and on base line training in technological skills for teachers and students. This is not a value judgment about what happened in these two very different school settings. On the contrary, tremendous in-roads were made in the low SES settings. It is hoped that these lead eventually to a focus on the instructional potential of the technology.

3.2.2. Pedagogy

Given the previous analysis of progress with the technology component of CoVis, it is not surprising that we also find differences in pedagogical practice between the high and low SES schools. In the high SES schools we get teachers talking about how participation in CoVis helped them to change their practice in multiple dimensions. Interviewees in the high SES schools discuss how CoVis provided them with instructional models, helped them to change classroom practice (e.g., engage students in multitasking), and do projects. One high SES teacher described her experience learning to conduct projects in her classroom:

> I had a lot of fun. I'm not going to say it was easy. I worked very hard. I was really pleased with the results. I was not so successful in the beginning, but I think ... I truly was successful with the Soil project. I think the kids had a lot of fun doing it. And I really think they learned a lot. And I think they felt successful and that's really been my goal with teaching.

The interviewees at the high SES schools also talk about the shifting role between themselves and their students and place a high value on the ability to engage students in data driven investigations. Here one high SES administrator explained:

> Its a way of getting the students involved in action research. That moves them to utilize computer technology to gather data and to analyze that data. To do some higher level thinking in terms of

> producing meaningful reports to others about what they've learned through the acquisition of that data in relation to a given topic such as weather.

In contrast, there was very little commentary about pedagogy at the two low SES schools. The one notable exception was that the teachers at Central commented on the changing roles between themselves and their students. These teachers did the staging activities of one of the CoVis CIAs and engaged their students in using the Internet to explore research questions. Of this practice one teacher noted,

> We [teachers] no longer have the answer book. So you can't look at page forty-two and know the correct answer. [Now] things are more open-ended and ... I occasionally want to go I-just-want-the-right-answer. That very open-ended way of working and having students at different levels, different locations, different parts of the world--it's a little disconcerting....

When asked to clarify what she meant by disconcerting she indicated that, "...it is worthwhile and I am sure that teaching and learning in this country is changing and I am certain it is very valuable." Another Central teacher also described the shifting roles between herself and her students:

> It was more fun for me than standing there telling them stuff. I do a ... discussion type style. I try not to lecture at them. I hate that. [On CoVis activities], they worked more on their own trying to figure things out and trying to do things. I was afraid at first they weren't going to work on it, but they did. They got into it and enjoyed it. I had my occasional students that didn't, that wanted to sit around and do nothing, but for the most part they took an active part in it. They didn't just sit back and let somebody else do it for the most part.

In sum, this analysis suggests that while the high SES schools are currently out in the lead with regard to the pedagogical mission of the CoVis project, that does not mean that practice in the low SES schools has not changed. After one year we are beginning to see changes in practice in both school environments. At the high SES schools those changes include the incorporation of projects, an emphasis on data driven investigations, and – as we will see in section four – changes in classroom management. In the low SES schools we see similar changes with an emphasis on the different relationships between teachers and their students. While the changes in the low SES schools are not as pervasive as those found in the high SES schools, they are along the same trajectory. We hope and expect to find further change as the schools move forward with the project.

3.2.3. Community

The table also reveals that participants at the high SES schools are more engaged in the community of practice dimension of the CoVis project. Here, the goal was to create a community of practice among CoVis teachers at different schools. The hope was that by providing communication in the form of email discussion groups, the teachers would form a peer group beyond their local school community. In these discussion groups teachers could discuss their project plans, recommend instructional ideas to one another, or seek advice on classroom management. In addition to the listservs, CoVis runs a summer workshop every year where teachers from the CoVis community get together to share their experiences.

Teachers in the high SES schools were more likely to report benefit associated with participation in the community of practice. For example, they reported the that they shared ideas with and got ideas from others (i.e., Generativity), that their students enjoyed the benefits of collaboration and mentoring (i.e., S. Mentoring), and that they got moral support from their peers (i.e., Moral Support). Teachers in the low SES schools were less likely to report these benefits. In large measure this can be attributed to the lag in Internet connectivity at these school. Recall that at South the Internet was not brought into the school until the last few weeks of the school year. At Central, the difference might be

attributable to the location of the Internet ready machines. They are located in the classroom on student lab tables. Since the classrooms at Central are always in use, teachers can not readily log on to check their email during the school day. Instead they must work on the Internet either before school begins or after it ends. Making things more difficult, security regulations in the school discourage teachers from being in the building past 3:30 in the afternoon.

Nonetheless, like the high SES teachers, the teachers at Central and South are likely to refer to themselves as learners. But they focus on learning technological skills where the high SES schools focus on changing practice. Again a reflection of where the schools are in the invention process. When asked what made her feel successful, one South teacher commented:

> Personally, the positive part was that I was forced to learn how to use Macs and I enjoyed that. I was forced to learn--which I like to do anyway--I was forced to learn how to download, upload material. I was forced to learn e-mail. These are skills I wanted to get anyway, but I had an opportunity to get them through CoVis.

So, while they could not participate in the on-line discussions to the extent that the high SES teachers did, the low SES teachers did get benefit out of their participation in the community of practice.

3.2.4. Summary

The results reported in this section point to some fundamental differences in the way that high and low SES school communities experience CoVis. In general the low SES schools are more apt to experience district, school and community constraints than are the high SES schools. As a consequence of the increased level of support in the high SES schools, the teachers there are more apt to perceive that changes in practice are within their control (i.e., individual capacity becomes a factor in practice only when teachers are supported at all the other levels). These differences are in some respects endemic of the conditions under which low SES teachers work. However, they do not seem to be prohibitive of progress, rather they inhibit or slow progress.

We have suggested that some of the problems raised in this analysis might be addressed by making explicit curricular and technological design decisions intended to address the needs of low SES teachers. These will be elaborated in the discussion section below.

The analysis of the CoVis program model provides further evidence supporting the view that, at the point of entry into the innovation process, low SES schools face a different set of challenges than do the high SES schools. Here, the low SES schools are focused on the purchase and installment of computers and networking as well as training on the same. As a consequence, teachers in those settings are less likely to address issues of pedagogical change as squarely as the teachers in high SES schools. However, this does not mean that practice can not improve, it means that changes in practice are subsequent to base line technological improvements. The story repeats itself with regard to communities of practice. High SES teachers participate in the on-line forums and are able to discuss the benefits associated with that experience. Low SES teachers are less likely to participate in on-line forums, and to receive those benefits, but this does not mean that participation in the community of practice is not beneficial to those teachers. They do in fact experience and discuss professional development as a consequence of their participation in the CoVis community.

3.3. Examining Practice: Two Illuminating Cases

We now turns to an in-depth examination of two illuminating cases. Here, we examine the practice of two CoVis teachers, one working in Rockefeller and the other

working in Central, high and low SES schools respectively. These two cases were selected for examination because the two teachers seem similar. Both, according to self report employed a relatively traditional teaching style prior to joining CoVis, and on the surface their practice as CoVis teachers seemed very much alike.

The teachers had different goals motivating their interest in project-enhanced science. The teacher at Rockefeller used CoVis as a model to begin doing project enhanced science. Her interest in the project derived from recent changes in the New York State Earth Science curriculum. The state exam shifted from a purely content based, multiple choice exam, to include a ten point student project. Thus the teacher – we'll call her Marcia – wanted to help her student learn to conduct independent project work. The Central teachers – here Pam – used CoVis as a model to shift from external science fair projects to include projects as a day-to-day part of her instruction. Her previous project experience was entirely related to an Illinois mandate that all science students do an independent research project as part of their coursework. Her students generally did those projects outside of class time with very little support from the teacher. Despite their different motivations for engaging project science, the end result was similar. Students in both classroom pursued independent research projects that utilized CoVis resources and engaged students in data collection, analysis and report writing. This section first examines how teacher describe their inventions of CoVis during the year, and then considers those inventions in light of what was learned in the preceding analyses.

3.3.1. Rockefeller

Marcia had her student do independent projects to fulfill the State exam requirement. Her students collected and analyzed data before writing reports. In doing so the students used a number of CoVis resources including: (1) the email discussion groups where other teachers in the CoVis community provided help to students working outside Marcia's expertise, (2) visualization technology to track global temperature variation, and (3) portions of one CIA that included a data set tracking variation in atmospheric carbon dioxide[7].

Marcia had four goals for her students, and one for herself. She wanted her students to generate a hypotheses, conduct research to learn background information, collect either primary data or data from the Internet, and analyze that data. Her personal goal was to begin project science in her classroom. She said,

> Previously, as much as we said we were going to do projects, we never did. [Without CoVis and the change in State testing], we would never have gotten into projects at all.

During our interview Marcia shared several of her student projects. In one project the student tracked acid rain in her community. She collected rain water from three sites; one in a residential section of town, one near to an industrial plant, and another near a local lake. She analyzed her rain samples using a pH meter for evidence of acid rain. At first the student had difficulty finding evidence of acid rain. The rain water was equally acidic at all three site, but the student had anticipated that it would be higher near to the industrial plant. As Marcia relates the story, the student benefited a great deal from email mentoring. A teacher at another school recommended changes in the students rain water collection plan and helped her to understand that acid rain is not so much a local as a regional problem. Through email correspondence he convinced her that acidity should not vary by location as the student anticipated, but that she could look for variation in acidity in the rain water at the beginning and end of a storm. As a result, the student changed her data collection. She

[7]CIAs are project enhanced curricula written by CoVis researchers in conjuction with CoVis teachers. CIAs are intended to provide teachers with opportunities to engage in project-enhanced science.

began collecting two samples from each storm. One during the first ten minutes and the second after an hour or so. She found that the acidity of the early samples was higher than that of the later samples. Marcia was very happy with the student's project and reported that:

> Quite frankly, had she not gotten more direction, other than me, she would not have ended up with as nice a project as she did.

3.3.2. Central

On the surface, project work in Pam's class looked very similar. Pam had three goals for her students. She wanted them to use the Internet, collect primary data primarily outside of class, and write a written report. Her project work drew on her science fair model, but allowed students class time for Internet searching. Her interest in the Internet was in having the kids do library like research. Of this aspect of her project work Pam reported:

> [The Kids] did library research from the Internet. There is more material available in a different way than you would find in the library.

To illustrate, one student did a project measuring the growth rate of alfalfa plants by pH level in the soil. His study included three plants growing under base, neutral, and acidic soil conditions. He measured growth rate over time to test the hypothesis that plants in the high pH condition would suffer. His hypothesis was not born out. Rather than dying, the high acid alfalfa plants thrived and out grew the other plants. Unlike the student in Marcia's class the student simply reported his findings without investigating what accounts for his unexpected finding.

In addition to the independent projects described above, Pam also participated in one of the CoVis CIAs. It was a project on global warming that included a number of lab-like staging activities and then asked students to deeper investigation of global warming. Pam used the staging activities, but not the deeper investigations.

3.3.2.1. Comparing Practice

So it seems that the two teachers invented similar versions of project-enhanced science in their classrooms. Both teachers did projects, both used CoVis as a model to begin project work, both made projects a priority for some part of the school year, both used the staging activities from one CIA, and both used the Internet as part of their project-enhanced science work. But through the constraints and affordances lens and the program model lens discussed above, we begin to see a different picture. The next two subsection take a closer looks at practice in Marcia and Pam's classrooms as seen through these lenses.

Constraints and Affordances

Returning to table 3.1.1, there are a number of differences apparent between the two schools. These include differences at both the district and school level. In the interest of space, we can not address each of these differences here, instead we will focus on two; equipment and space.

Marcia's classroom is spacious by most standards. There are storage closets along the three interior walls and windows on the exterior wall that look out onto a courtyard area. The teacher's desk is a traditional black top lab table that stretches across the front of the classroom. The lay out of the room favors multi-tasking with some students working on the computers while others work at their desks or at group work areas. The students' work space is divided into three areas. Favoring the west wall there are individual student

desks. Toward the back of the room there are black lab tables set up for group work. Then, along the east wall Marcia's classroom has six computer work stations each with a networked Macintosh computer. The machines included a full suite of software applications.

Pam's classroom also has six networked computers, but unlike Marcia's classroom, Pam's does not favor group work. The western wall of the classroom is lined by windows which look out over the school parking lot. Under the windows there is a counter top and floor cupboards that stretched the length of the room and served as storage. Students sit at black lab desks, four to a row, seven rows deep, facing the front of the room. On each of the lab tables, in a line up the middle of the classroom, dividing each row of four into two groups of two students, sit seven IBM compatible computers. The machines are accessible to students by turning the monitor either to the left or the right. This means that only two students from each row can use the machines at a given time. As discussed previously, Pam did not have money to purchase software. As a result, students can not work on spreadsheets for data analysis or use word processors to write up their work. They have access only to Internet software provided free for educational use. With regard to the software problem Pam noted "...we never resolved the issue of who was going to buy the ... software, and I never got it."

Beyond the differences in these individual classrooms, space is a concern on another level. Project work is made easier when teachers have spacious classrooms to work in and can have those classrooms dedicated (i.e., not shared with other teachers) so that students can safely store their work there from day to day. Acknowledging this, the Rockefeller administrator explains that schools are crowded and it is difficult to dedicate space, but she makes an effort to do so:

> I think teachers like to have their space. If three or four people are sharing, then where is my stuff going to be?

In contrast the Central administrator simply says "Space is not available." In his school classes are being offered in every available classroom at all times in order to meet demand.

So, constraints and affordances bear on these two teachers as described above across all cases in this study.

Program Model

Likewise, the patterns described above relating to the elements of the CoVis program model, apply to the present cases. We will address two of those here; technology and pedagogy.

Technology

In Rockefeller the technology component of the CoVis project was viewed as an opportunity for school community members to learn appropriate use of instructional technology. During our interview the administrator put it this way:

> I think CoVis gave us the opportunity to use technology in the way its intended to be used.... [For Example,] word processing could be the extent of technology.... [but,] we are now communicating, we can look at each others scientific experiments and labs, we can have conversation going among educators in public school systems, research foundations and other practitioners

On the other hand, at Central the technology component of CoVis was viewed as an opportunity to get computers and networking into the building. One teacher noted that,

> You guys [CoVis] were a catalyst for getting things done here. There were deadlines. Without them, we would probably still not have Internet access in the building. Workmen came in saying, 'Yeah, we've got to do this because CoVis says we've got to do this because we need it by....

In other words, having a relationship with CoVis got the school moving with regard to technology. There was some external pressure on the bureaucratic mechanism in the district that help push the networking project through.

Once they had the equipment, the focused on it as a valuable opportunity for teachers and students alike to learn technological skill. Here they valued the opportunity for kids to learn as an equity issue. One teacher summed it up this way:

> We are taking kids who have probably had a deficit keeping up with the suburbanites in terms of access to the Internet. Our kids are less competitive. They don't have access at home, but they've got access here. .... Its an equity issue.

So for Rockefeller CoVis is an opportunity for them to use the technology that they already have in a more appropriate ways. But for Central CoVis is an opportunity to get computers into their school and to provide some equity for their students. By virtue of participation in CoVis the students at Central have an opportunity to learn skills usually reserved for wealthier students.

Pedagogy

Pedagogy is perhaps the most interesting lens through which to understand the underlying difference between Marcia and Pam's invention of CoVis. While Marcia articulates a rich description of the changes in her practice as a result of CoVis, Pam's articulation is relatively limited by comparison.

For example, both teachers talk about shifting roles between teachers and students, but Pam's discussion of this topic is cursory. She notes that "We [teachers] no longer have the answers," and discusses this in terms of a change in how she evaluates student work. When students write about topics that she is unfamiliar with she no longer grades it for its correctness, but on the quality of the evidence that students use to support their answer. She says: "If they say something, I say 'did you back it up with evidence?'" In addition, Pam pointed out that students were able to handle a higher degree of responsibility for their learning when working on projects:

> Students worked more on their own trying to figure things out. I was afraid at first that they weren't going to work, but they did. They got into it...."

These are certainly positive shifts in teaching practice. And we value them as such, but Marcia is able to present a much more highly articulated version of this story.

Marcia identified four ways that her relationship to her students shifted. First, she appealed to other authorities when she did not have an answer:

> Whenever there was a question that a kid would come up with that I couldn't answer, I just went on-line.

Second, like Pam, she asked that students support their work with evidence:

> You're really expecting the kids to do science. ...to come up with a hypothesis and actually investigate it.

Third, she employed peer teaching strategies where students knowledgeable about a topic help other students to learn about that topic:

> I can show one group how to use the Visualizer..., then they show the next group...."

Finally, Marcia argued that her students have more responsibility for their own learning - more student agency:

> They actually have to produce a project. They have to be engaged in what's going on. They can't just sit back and let me do the talking. They have to produce an end product.

Marcia's administrator valued that agency in terms of showing students respect:

> There's a healthy respect for adult learning possibilities. In Michelle's classroom, there is respect for the child's ability to learn.

Marcia was also able to identify two additional ways that her practice changed through her participation in CoVis. First, she spends more time teaching topics in greater depth. She opposes this to her previous practice where more topics were covered on a surface level:

> CoVis engages students in the whole process of doing science. Previously, we missed the big picture. We were spending so much time going to the nitty gritty, we were not getting the big picture.

Her administrator agrees with this assessment:

> With CoVis there's less concern about '...I have to cover everything,' and more concern about critical pieces that need to be learned well by children.

Second, Marcia engages in more group instruction and multitasking[8]. Marcia reports:

> The infrastructure of the classroom changes. You've got six computers in the room, and you're obviously not going to have everybody on the computer at once. I split the kids into 6 groups. Then those six groups split down into pairs so I have Group A and Group B. When Group A is on the computer, Group B is doing something else.

Again, her administrator confirms the observation:

> In Marcia's room ... its not one teacher talking to 25 kids, its clusters of kids engaged in different activities. With one cluster on the computer doing the CoVis curriculum....

The distinction between Pam and Marcia's articulation of changing practice is hardly surprising given the previous analyses. Pam works in a low SES school and faces a number of challenges in terms of bringing technology into her classroom. In addition, she was faced with district, school and community constraints that make pedagogical change in her classroom more challenging than similar change in Marcia's.

. . . . . .

So, while the teachers' reports of their practice during the course of the first year of CoVis seem very similar on the surface, a closer examination suggests that two very different things happened. Both teachers made changes in their instructional practice, but the changes in Marcia's practice were a deeper than those made by Pam. However, this does not devalue the progress that Pam made. Remember that she is working under more difficult circumstances than Marcia. Viewed from that perspective we might consider that the impact of CoVis on practice at Central was greater than the impact on Rockefeller. The discussion section takes one final look at invention in these two settings as informed by our two previous analyses.

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[8]In multitasking multiple student groups are working on different things at any given time. Here one group may be using visualization technology on the computer, while another is logging local weather conditions.

4. DISCUSSION

To return to the focus of this paper, we wished to understand how teachers in different schools invent CoVis to meet local needs. In particular this paper focuses on differences between the inventions of CoVis at high and low SES schools. A careful reader with probably have noted several questions in reading the analyses presented above. We anticipate and address a number of those here.

Are we arguing that practice in all high SES schools and low SES schools is the same?

Certainly not. As can be noted on tables 3.1.1 and 3.2.1, respondents at all five schools responded differently. If fact respondents within schools responded differently on most items. What we have described here are patterns that emerge from the data that seem to distinguish the high from the low SES schools. Do those patterns hold true at all schools? No. But they seem to explain our data and we present them here as a means of understanding implementation of the CoVis project. In the spirit of "thick description" (Geertz, 1973) generalization beyond this study is left to the reader. How closely do the cases presented here match your school context? To the extent that they match the generalizations presented here may apply.

We take this stance in recognition that implementations is a richly contextualized problem. Schools are complex organizations with equally complex cultures. Those cultures affect the way in which actors in schools implement innovations - or in the language used above - invent interventions. Any number of factors might tip the balance in one direction or the other. Especially good school leadership, for example, might tip the balance in even the most difficult school making invention of good teaching practice happen where it might otherwise have not. The reverse might also be true.

There are certainly differences among the schools presented here that make all five unique. For instance, while we argued that community capacity might be a particularly salient issue at low SES schools, community capacity didn't manifest itself at both low SES schools. Only the respondents at Central raised community capacity issues pointing out, for instance, that the community served by the schools is composed largely of first generation Spanish speaking immigrants. This results in a high demand for ESL instruction throughout the Central curriculum to address the language needs of the student body. In the teacher's eyes ESL instruction makes project based pedagogy difficult to enact. The other low SES school presented served a community where English is the primary language and; therefore, did not face the same challenge.

So there are clearly differences between the schools in presented here. That said, we believe that there important differences in the challenges that our high and low SES schools face. We have described several of those above and will return to some below.

Is it the case that high SES schools are simply better CoVis schools?

There is a danger that readers take our argument to mean that low SES schools are bad. This is not the case. In fact our argument is constructed to get beyond the traditional distinction between high and low SES schools. We think that SES is a blunt construct. It is simply a placeholder for the broad range of capacity issues that underlie it. For instance, as described above SES at Central is a place holder for high immigrant population with limited English language skills. The problem is not SES it is language skill. Moreover, it is not so much a problem as a reality. It is simply true that students in the Central community need basic level English instruction. We don't mean by suggesting that SES is a blunt measure to skirt the challenges faced by our low SES schools. Rather we mean to specify the exact

nature and range that those challenges take. We hope then to address those challenges in the design of our interventions.

Are high and low SES schools simply facing a different challenge with regard to inventing interventions that are consistent with the CoVis program model?

There are certainly differences between our high and low SES schools. For instance, one way to look at the analyses presented here is to consider that teachers working in high SES schools in general, and Marcia in particular, invent CoVis in terms much closer to the project vision than do teachers like Pam working in the low SES schools. The high SES teachers used classroom computers, talked about their use as tools to improve instruction, reported substantive shifts in pedagogy, and participated in the community of practice to help themselves along. On the other hand the teachers in the low SES schools had difficulty getting classroom computers and networking, valued them as resources to develop technological skills for themselves and their students, reported marginal shifts in pedagogy, and participated on the periphery of the community of practice.

However, we believe that this is too simple an explanation. Rather, we believe that the schools are working on two fundamentally different, yet connected, problems. We base this interpretation on the analysis of CoVis by examination of the program model. In that analysis teachers in low SES schools were shown to be concerned with issues of technology, its acquisition, its use, and the perception of technology as an equity agent. On the other hand, the high SES teachers had little difficulty with technology and concerned themselves directly with pedagogical issues. They became concerned with how technology could be used to foster better instruction. It may be that educators do two things when they incorporate technology into instruction. First they learn the technology and second they begin to understand the instructional role of the technology and work toward pedagogical goals. If this is the case, then it seems that our low SES teachers are grappling with the first part of the instructional technology problem, while our high SES teachers work toward the second.

Viewed from this perspective, we want to argue that it is a mistake to suggest that the high SES schools are performing better than the low SES schools. Rather, we wish to value the progress made in both settings as significant progress toward different goals. The high and low SES schools begin with a different set of constraints and affordances placing them at different starting points. Therefore their progress toward the CoVis vision proceeds along different trajectories.

In addition, teachers in the high and low SES schools face a different set of challenges. Teachers working in the low SES schools face a set of district, school, and community capacity issues that constrains their work on the CoVis project. Here, the district's tolerance for experimentation, the lack of space, and ESL challenges are examples from the preceding analysis. Teachers in the high SES schools on the other hand have a set of affordances at the district and the school level that permit them to focus on individual capacity issues. Thus, in terms of the CoVis program model we see that high SES teachers can more readily focus on substantive pedagogical issues. Consequently, we hear teachers in those schools describing multiple changes in their teaching practice. Whereas, in the low SES schools, teachers spent much of their first year dealing with district level bureaucracy in order to get computers and networking into their classrooms. Despite the extra challenges in their schools, we also hear these teachers beginning to describe changes in pedagogy. Among other things, they reflect on their own practice, participate in training, and take time to adapt CoVis curricula to meet local needs. Looked at from this perspective it seems that teachers in the low SES schools face a larger hurdle with regard to the

invention of CoVis than do the high SES teachers. Given this difference we might argue that the progress made by the low SES schools is more significant than the progress made by the high SES schools.

So, yes high SES schools are closer to inventions of CoVis that are consistent with our vision of project-enhanced science. However, low SES schools made substantial progress toward that vision despite longer odds. We hope, and we are encouraged, that as our work and research continues we will see the low SES schools engage in further pedagogical change.

What are the design implications of this work?

As noted in the introduction, CoVis is a testbed. Our goal is to design learning environments that foster project-enhanced science. We pursue that goal in an iterative fashion. Interventions are designed and then released to the testbed where they are studied in use. The intent is that research inform the re-design of resources in the testbed. There are a number of design recommendations that derive from the present research.

First, another way to look at the differences between the high and the low SES schools is as a design issue. That is, we might think that CoVis was designed in a fashion suitable to the high SES school, but not to the low SES schools. Such a perspective suggests that low SES schools are not lagging behind high SES schools with regard to their inventions of CoVis, rather CoVis is not fitted to the needs of low SES schools. This suggests that the project must be redesigned with the needs of the low SES schools in mind. Thus, CoVis as presented to low SES schools must be a different thing than CoVis as presented to high SES schools.

Second, attendance in low SES schools is a problem because teachers have difficulty determining what counts as make up work in a project enhanced science classrooms. This suggests the need for some sort of a project management support tool. Such a tool would help teachers keep track of the work their students are doing as they complete projects. Here, perhaps the tool would keep track of project milestones such that teachers can remain apprised of each student's progress at all times. The work of Soloway, Krajcik, Blumenfeld, & Marx (1996) on the PiVot tool may inform the design of such a tool.

Third, our analyses suggest that low SES schools value CoVis differently than high SES schools. Specifically, they value the opportunity to provide their students with marketable technological job skills. They see this opportunity as an equity issue in that their students are able to learn skills that high SES students take for granted. While this was not an explicit goal of the CoVis project, given the job market that students face it may be a very important side effect. To the extent that low SES communities see value in helping their students learn technological skills that will make them more employable, CoVis ought to design with that goal in mind. In addition to focusing on the development of critical thinking skills through project enhanced science – the attribute that attracts high SES schools to CoVis – we might focus curricula on the use of technology to develop skills with the technology itself. Here, we might be more deliberate in providing opportunities for students to use programming languages, develop web sites, use spreadsheet tools, and telecommunication technologies. The point is that rather than think about how we might bring urban schools along toward our vision of project-enhanced science, we might need to adapt our vision to meet the needs and goals of low SES communities.

What are the policy implications of this work?

It is clear from the analyses presented above that high and low SES schools enter their work with CoVis from different points of readiness. The two settings have different

capacities to engage in the use of technology and to change pedagogy. It is important that local administrators recognize these differences as they plan for their school to pursue similar projects. As they plan for such work local administrators should considered:

1. the existing technological infrastructure of the school (i.e., computers, their location in the school, their suitability to the demands of the proposed work, as well as networking);
2. the ease with which that infrastructure can be enhanced to meet project demands;
3. the technological expertise of the teachers and students expected to use the machines;
4. staff development needs and options;
5. the pedagogical goals that the school wishes to pursue;
6. and, the supports that the school can provide teachers as they pursue those goals.

A good policy is one that recognizes the current state of the school technologically and pedagogically, while setting reasonable classroom goals appropriate to both. Local policy makers should anticipate the problems that are likely to arise as technological infrastructures are developed. Those problems differ by context and need to be accounted for in planning. For instance, large urban districts may face special impediments regarding the contracting of classroom networking jobs. Policy makers in such contexts should plan for delays perhaps choosing to focus early on training teachers while classroom networking projects unfold. Conversely in some smaller high SES districts, policy makers might be able to move quickly to contract networking jobs. But, will the school be ready to use the network once it is built? Perhaps it would be wise to plan for phased implementation so that teachers can become comfortable with networking prior to using it in their classrooms.

What other dimensions of difference are insightful?

This paper has presented an analysis of our case study data by SES. There are a number of other dimensions along which we plan to pursue our analyses. Among these we wish to explore the affect of institutional culture on classroom practice. On a surface level we see differences between schools that are also members of research consortia (e.g., Co-NECT Schools or Comer Schools) or which for some other reason (e.g., administrative vision) have an organizational culture that is congruent with the goals of CoVis. Our future work includes an analysis of the case study data that explores those differences in order to understand what kinds of external supports are conducive to instructional invention. We also see differences between the work of our middle and high school teachers. Here the middle school teachers tend to be better risk takers than the high school teachers. There are obvious differences between the organization of schooling at middle schools and high schools. We wish to know what high schools can learn from the organizational structure of middle schools.

Future work also includes an expansion of the case study data corpus to include follow up interview data and classroom observations. Together these data will help us to develop richer descriptions of practice in each of our case studies. They will also help us to search our confirming and disconfirming evidence with regard to the analyses presented here and subsequently.

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Appendix A: Constraint & Affordance Categories

Constraint	Definition
Hard Work	The belief that changing teacher practice is hard work.
Inhibits	A sub-category of hard work where hard work is thought to prevent teachers from attempting to invent CoVis.
Curve L.	A sub-category of hard work where the work is in a front end learning curve after which work inventing CoVis becomes easier
Planning	A sub-category of hard work where finding time to plan projects is described as difficult. Here, teachers might be requesting planning periods be built into their work schedule
Attitude	A belief that some teachers are jaded by change and are therefore resistant to engaging in change in general and CoVis in particular.
Creativity	Where creativity is invoked as a means of overcoming constraints associated with CoVis (e.g., "some of our creative teachers find ways to address the curriculum while doing CoVis)
School Work	Where the kind of work students do in CoVis does not match some conception of what counts as student work. Usually it is parents described as having a problem understanding the new school work.
Attendance	When poor attendance interferes with project work in classrooms (i.e., its easier to have dittos to hand out for make up)
ESL	Where the language skills of students inhibits project work (i.e., we have a hard enough time doing traditional school work)
Time	Various references to time as a constraint (see sub-categories)
Internet Home	A sub-category of time where having Internet access at home is described as helpful
Block Sched.	A sub-category of time where teachers argue the need for longer blocks of time for project based classes.
Planning	A sub-category of time where teachers ask for additional time for planning project work and to coordinate with other teachers.
Class Size	There are too many students in my class to do projects
Course Load	I teach too many classes and therefore can't do projects
Equipment	References to the amount of computer equipment available to teachers and students.
Money	Discussions of need for additional money needed for project supplies.
Experimentation	The district is/isn't supportive of innovation/invention in the classroom.
Space	Project science requires more classroom space than traditional science instruction (e.g., for students to store projects over time).

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