Chapter V

Building Educational Technology Partnerships Through Participatory Design

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Over more than five years, we worked with a group of public school teachers to define, develop, and assess network-based support for collaborative learning in middle school physical science and high school physics. From the outset, we committed to a participatory design approach, in part to explore what issues and possibilities arise when participatory design is pursued more extensively. The nature of our interactions, and in particular the nature of the roles played by the teachers did change significantly through the course of the project. We suggest that there may be a long-term developmental unfolding of roles and relationships in participatory design.

Technology development is often seen as a waterfall process, a cascade of activities each feeding the next: New technologies are invented, then elaborated and refined in demonstration applications, then transferred to real developers and deployed in real applications, and finally adopted by users. This conception derives from the belief that technology innovation is inherently good for people and organizations, and that the key engineering challenge for technology development is efficiency. However, linear waterfall processes maximize the risk that inappropriate technology will be deployed, that the technology will solve the wrong problem or conflict with commitments and practices of the people who are to use the technology.

Educational technology provides many examples of how "efficient" development and deployment is not enough. Teachers work in a complex and dynamic context in which measurable objectives and underlying values collide on a daily basis. Traditionally, teachers work in isolation from their peers; individual teachers have well-established personal practices and philosophies of education. Teachers have enormous discretion with respect to what goes on in their classrooms, yet are also routinely interrogated by supervisors, by parents and other community members, and by educational bureaucracies. This has led to an abiding tension in the culture of schools: Teachers' innovative practices are often not adequately acknowledged or valued, and at the same time, teachers often passively resist school reforms that are imposed top-down.

Technology is a particularly problematic element in the culture of schools. The isolation and discretion of the teacher's work environment requires that technology for classroom use be highly appropriate and reliable. Yet it is generally assumed that teachers are to be *trained* on new technologies, not asked to *define* what those technologies should be. From the teacher's standpoint classroom technology often is itself the problem, not the solution. This culture of technology development in the schools has been singularly ineffective — film and radio in the 1920s, television in the 1950s, computer-assisted instruction in the 1980s, among others, have been notable failures (Cuban, 1986; Hodas, 1993; Tyack & Cuban, 1995).

An alternative to merely efficient technology development is *participatory design,* the inclusion of users within a development team, such that they actively help in setting design goals and planning prototypes. This approach was pioneered, and has been widely employed, in Europe since the 1970s, and now consists of a well-articulated and differentiated set of engineering methods in use world-wide (Greenbaum & Kyng, 1991; Muller, Haslwanter, & Dayton, 1997; Schuler & Namioka, 1993).

In 1994, our research group began a design collaboration with two public school teachers. We wanted to investigate whether and how the teachers could contribute to a design collaboration; we were specifically interested in exploring the utility of a scenario-based design approach in this context (Carroll, 1995; 2000). We were guided by beliefs that the teachers could participate effectively in the design of educational applications, that their expertise in education could be especially critical, and moreover, that the teachers had a right to such participation. Our hypothesis was that the principal obstacles to achieving such an interaction were the culture and professional jargon of software design. Our initial investigation addressed these barriers by creating a cooperative relationship, spanning more than a year, between the teachers and a software developer who worked with them to create several novel educational applications (Laughton, 1996).

In 1995, with the support of the US National Science Foundation (NSF), we formed the LiNC project (for "Learning in Networked Communities"), a partnership between Virginia Tech and the public schools of Montgomery County, Virginia, USA. The objective was to develop and investigate a high-quality communications infrastructure to support collaborative science learning. Montgomery County is located in the rural Appalachian region of southwestern Virginia. In March 2000, one of its high schools was listed among the top 100 in the US by *Newsweek* magazine. However, in others, physics is only offered every other year, and to classes of only 3-5 students. Our initial vision was to give students in this diverse and dispersed school district access to peers through networked collaboration.

We wanted to create and study a broad framework for participatory design interactions. The NSF program that sponsored our work was directed at producing models for how new computer networking infrastructures could facilitate systemic change in public education (as opposed producing specific curricular innovations). Thus, an important orienting goal was enhancing the autonomy of teachers with respect to our technology infrastructure. In other words, we assumed from the start that in order to succeed, we must someday fade from the project, and leave the teachers to maintain and develop its achievements. This meant that the teachers' involvement could not be limited to requirements interviews, or even to relatively active roles in conceptual design. We needed to think of them as collaborators in implementation, deployment, testing, and refinement, and as leaders in the development of courseware and classroom activities that would exploit the software.

STAGES OF COOPERATIVE ENGAGEMENT

Looking back at the past five years, we can distinguish four stages in our collaboration with the teachers: At first, the teachers were *practitioner-informants*; we observed their classroom practices and we interviewed them. Subsequently, the teachers became directly and actively involved in the requirements development process as *analysts*. Some two and half years into the project, the teachers assumed responsibility as *designers* for key aspects of the project. Through the past year particularly, the teachers have become *coaches* to their own colleagues within the public school system.

We use the term “developmental” in the sense of Piaget and Inhelder (1969) and Vygotsky (1978). We believe that the teachers have developed qualitatively different roles through the course of our collaboration. In some cases, these roles were suggested to them, in other cases, they defined and claimed new roles. But in all cases, these transitions exemplified the defining characteristics of *developmental change*: active resolution of manifest conflicts in one’s activity, taking more responsibility, and assuming greater scope of action. Each successive stage can be seen as a relatively stable organization of knowledge, skills, and attitudes that resolves the instigating conflict.

In a classic Piagetian example, a child in the pre-operational stage perceives single dimensions of quantity. This produces conflicts: A given quantity of liquid poured from a short, wide container into a tall, thin container appears suddenly to be more, but of course cannot be more. These conflicts eventually precipitate a cognitive reorganization called the concrete operational stage, in which constant quantities are perceived as constant regardless of varying shapes and arrangements.

Developmental change in adults is of course more complex. The stages we describe are not singular competencies, but relatively complex ensembles of collaboration, social norms, tool manipulation, domain-specific goals and heuristics, problem-solving, and reflection-in-action. They are social constructions achieved through enculturation, constituted by the appropriation of the artifacts and practices of a community (Vygotsky, 1978).

In the Piagetian notion of stages in child development, successive stages build upon the cognitive structures and enabled activity of prior stages, but ultimately replace those structures. A child who enters the concrete operational stage can no longer function at the pre-operational stage. Adult growth, however, is not static achievement, but continual elaboration. The teachers are still practitioners whose classroom practices we regularly observe and whose classroom expertise we still interrogate; they seem to us and to themselves to be representative practitioner-informants. However, they are now *also* analysts and designers, and often coaches. Indeed, effective design coaches probably must be experienced designers, successful designers must be skilled analysts, and analysts must have attained significant domain knowledge.

A third modulation of the developmental perspective in our analysis is our relativistic viewpoint with respect to the nature of expertise. In classic developmental work, it is the child who is developing, and indeed doing so by becoming more like the adult. In contrast our situation is one of mutual learning. Through the past five years, the faculty and graduate student researchers in our group have learned a vast amount about the practices, the exigencies, the values, and the politics of public schools. The teachers could present a complementary analysis of the development of *our* capacities to collaborate in the design of educational activities and technologies. Such reflexivity is inherent in any participatory design project. We acknowledge this, and thus offer a partial analysis of the long-term development of participatory design, from a single perspective, as a start toward a more complete understanding.

THE PRACTITIONER-INFORMANT

Our project began in the summer of 1994. Stuart Laughton, a Virginia Tech graduate student at the time, initiated an investigation of how teachers could contribute to the participatory design of educational software. He worked with two teachers from the Montgomery County school division, one a middle school physical science teacher, the other a high school physics teacher. In this investigation we used ethnographic interviews as a means of understanding the teachers' concerns and requirements, and scenarios as a means of conveying and developing visions of how the new software could impact teaching and learning interactions. The focus of the research was on bridging the communication gap between classroom expertise and software development expertise.

This effort was successful, not only in producing several educational tools for the teachers, but in demonstrating that the teachers could play a creative and effective role in the design process. Specifically, it showed how the techniques of ethnographic interviewing and scenario-based design could facilitate cooperative design interactions involving teachers and software developers (Laughton, 1996).

The teachers Laughton had worked with also became part of the large team that developed a proposal for the US National Science Foundation (NSF) in 1995. They provided sanity checks for plans to develop a virtual school networking infrastructure that could leverage teachers, students, and other resources in a sparsely populated region in southwestern Virginia. But the teachers' role was somewhat peripheral. There is a revealing asymmetry in this: Although the university researchers could take the initiative to enter the teachers' context and establish a genuine two-way cooperation, the teachers were less able to reciprocate in "our" project-planning and grant-writing activity.

This asymmetry was over-determined. The teachers did not understand the culture of projects and grants as it exists in research universities. The project proposal we constructed was fairly typical of its idiom, which means we spent a lot of time discussing how to position our work with respect to national priorities, how to manage various threads of dependency among research actions and subgoals, and how to allocate and coordinate specific technical roles and responsibilities among various departments and faculty members. In the teachers' culture, grants are usually far smaller and more limited projects with budgets that barely cover the purchase of materials. Their proposals are generally 1-3 page workplans.

The university researchers are used to doing whatever is necessary and appropriate to plan and carry out research. This often involves learning about other people's work and activity, including visiting and even living in other sites and circumstances. Learning as much as we possibly could about the teachers and their work practices was a normal part of our research activity, and essential to this particular project. In contrast, understanding the university research model and the various individual researchers was not something that is normal for the teachers to try to do in educational research relationships. After all, the teachers are usually the subjects of the research, or part of the research manipulation, they are rarely seen by researchers as partners. And finally, understanding us was not something that the teachers were encouraged or supported in doing by the school system.

We later learned that at this point in time the teachers were both amazed and shocked by aspects of our virtual school proposal. They could barely believe that computer networking could support real-time collaborative classroom activities effectively, for example, allowing students to jointly carry out simulation experiments and writing projects. Figure 1 is the vision scenario for the virtual school that guided the development of our NSF proposal.

Perhaps more significantly, the teachers could barely believe that anyone would *want* to create a virtual school. However, these strong reactions were not conveyed to the university researchers at the time. Instead the teachers continued to serve as supportive domain experts. In part the teachers believed that they had relatively little to contribute, and that the researchers knew what they were doing. Of course, the teachers were confident of their own expertise as public school educators, but they did not see that expertise as a critical determinant in the virtual school vision. In this, they—and implicitly we—reflected the values of contemporary society: somewhat skeptical of public education and public school teachers, while at the same time accepting of computer technology tout court.

The LiNC project ramped up in the spring of 1996 with an influx of graduate student research assistants funded by the NSF grant. We focused a great deal of effort on understanding needs and opportunities in the class-

Figure 1: The Marissa Scenario (fall 1994) was our initial vision of the virtual school

- Marissa, a 10th-grade physics student, is studying gravity and its role in planetary motion. She goes to the virtual science lab and navigates to the gravity room.
- In the gravity room she discovers two other students, Randy and David, already working with the Alternate Reality Kit, which allows students to alter various physical parameters (such as the universal gravitational constant) and then observe effects in a simulation world.
- The three students, each of whom is from a different school in the county, discuss possible experiments by typing messages from their respective personal computers. Together they build and analyze several solar systems, eventually focusing on the question of how comets can disrupt otherwise stable systems.
- They capture data from their experiments and display it with several visualization tools, then write a brief report of their experiments, sending it for comments to Don, another student in Marissa's class, and Ms. Gould, Randy's physics teacher.

rooms. University faculty and students became regular visitors in the classrooms of the four teachers who worked with us, videotaping classroom activities, and interviewing teachers and students. This extensive direct presence in the classrooms was one way in which we hoped to expand upon Laughton's work, which had relied on interviews with teachers outside the context of classroom activity.

We initiated a series of bi-weekly project meetings involving the teachers, the university faculty, and the central graduate student researchers. The topics of these meetings through the spring of 1996 was always dominated by the on-going collection of materials and observations from the classrooms. Although our interaction with the teachers became far more regular and intensive in this period, their role was largely the same as it had been from the start: they provided information and interpretations based on their domain expertise and in response to requests from us. The teachers remained very cooperative and responsive, but we had to actively prompt and evoke their expertise. Their primary concern seemed to be that we not diminish learning opportunities for their students. They were interested in the project, willing to talk about trying things out, as long as it did not distract from their "real" goals and needs too much.

In the spring of 1996, George Chin — a Virginia Tech graduate student at the time — conducted a series of structured interviews focused on the teachers' practices regarding collaborative activities and their initial attitudes towards the project.

Figure 2 presents responses of four teachers to one of the interview items that specifically queried their expectations about project roles. Even after more than a year of working with us to develop the NSF project, which centrally emphasized teachers as designers, and the need for participatory approaches to the design of educational technology, the teachers still felt that their role was chiefly to test, or to facilitate testing with students. This is particularly striking since two of these four teachers are the same people who worked with Laughton. They had already participated in the design, not merely the testing, of new educational technology.

A major and long-lived challenge during this stage in the project and in the teachers' development as designers was to convince them that we truly wanted their ideas and not merely their compliance. One issue was the establishment of trust and mutual understanding. In figure 2, T4 clearly is suspicious about the project's true goals. T4's reaction can be dismissed as extreme, but it is important to recognize that this sort of reaction is awkward to articulate. Perhaps what is significant is that T4 was willing to say out loud what others might have felt and repressed. At the stage of practitioner-informant, in which the main role of the user is to provide domain information and expert interpretations, it is easy to mistake users who are just "going along" with participatory design for users who are truly engaged and committed to a collaboration.

Figure 2: Responses of four teachers to an interview question (spring 1996)

Prior to the start of the project, what role did you anticipate for yourself on the LiNC project?

T1: I think I was expecting to be more of a guinea pig - you build it and I test it - you pick my brain and leave.

T2: I did not truly understand the LiNC project but thought I would be asked to try out programs with my students written by Tech people.

T3: I thought the programs would be developed and we would test them with the students and evaluate them - make suggestions for changes if need be.

T4: Initial expectations were to function as contact with students. I thought we'd be involved mostly with trial runs of software and possibly some data collection. The possibility that this was a double blind experiment was also present.

A second, more prosaic issue was the development of skills that would support critical evaluation of design ideas. In the early stages of our collaboration, the teachers' stance with respect to design proposals can be summarized as positive, with some skepticism about feasibility and effectiveness. For example, they accepted the Marissa scenario (figure 1) and our subsequent design proposal involving a shared lab notebook, but both their support for these ideas and the qualifications of that support were somewhat vague. In retrospect, it seems clear that the teachers were not able to use the textual descriptions to envision these proposals in their own context. None had had much relevant experience; they were tentative, uncertain, and intimidated. When they subsequently had the opportunity to experience the proposals in analysis exercises and classroom prototypes, they were able to critique and extend the design in specific ways.

Although the teachers' interaction with the university researchers was most salient to us, they were at the same time also developing working relationships with one another. We were surprised to learn that including two high school-level physics teachers in our project, in effect included all the county's high school physics teachers: There were only two, and one taught physics only part-time. No one in the school system had mentioned this to us during the development of the grant proposal. We were also surprised to find that most of the teachers had not worked closely before, and knew one another only casually. This is a further manifestation of our own initial naiveté with respect to the culture of schools.

The teachers exchanged perspectives on teaching styles and pedagogical objectives during the early months of the project. Indeed, this exchange became a central topic in the project as it became clear that it entailed the requirement that our software be sufficiently flexible to support a variety of teaching styles and strategies. More specifically, the teachers had differing perspectives on collaboration among teachers and their classes. None felt that such collaborations would be sufficiently easy for them to manage or beneficial for their students so as to be immediately self-justifying. To varying degrees and in varying ways they were intrigued, but not fully convinced or committed to the vision in figure 1.

Later, we learned that two of the teachers had been slightly coerced into joining our project by the school administration. In retrospect, it is hardly shocking to find that expert practitioners might not be champing at the bit to join a technology development project whose objectives would have the effect of discombobulating their own established practices. Indeed, the ambivalence and tension the teachers' felt is absolutely appropriate. What was unfortunate is that this issue remained submerged for the most part.

Powerful organizational forces impinged upon our participatory objectives from the start. Laughton's investigation was an independent research project; it was relatively small in scope and depended on the teachers' personal commitment, indeed on their personal time. Our NSF grant provided far better resources; it meant, for example, that part of the teachers' time was compensated. Although several teachers later remarked that this helped them to believe that their participation was really valued, it inevitably also diluted "pure" intrinsic motivation with material rewards. The larger, better-resourced project also had a greater scope and intensity of commitments and responsibilities, with more coordination and management overheads — schedules, dependencies, reminders, requests, meetings, and so on.

The grant comprised a legal relationship between Virginia Tech and the Montgomery County school division. Thus, the teachers, as well as the university faculty who were principal investigators, became institutional representatives and the work became official work. The management structure of National Science Foundation grants differentiates among "principal investigators," who have final financial and management responsibility, "co-principal investigators," who share in overall decision-making, and "investigators," who usually have narrower technical roles. The number of co-principal investigators is limited (usually to four). One school administrator was among our co-principal investigators; the teachers were classified as "investigators." In context, this is somewhat radical: teachers and administrators are often left out of grant management teams entirely.

However, our management structure reified a power structure in which the university faculty and one school administrator were the "principal investigators," with financial and technical management responsibility, and the teachers were "investigators" who reported to them. This relationship validated the assumption on the part of the teachers that they were supporting our effort, rather than collaborating in a shared endeavor. Indeed, making project activities part of the teachers' official work emphasized that their role was to meet expectations of the school administration. In our initial euphoria about having significant resources for the project, it was easy to underestimate the downsides of having such resources (Greene & Lepper, 1979).

THE ANALYST

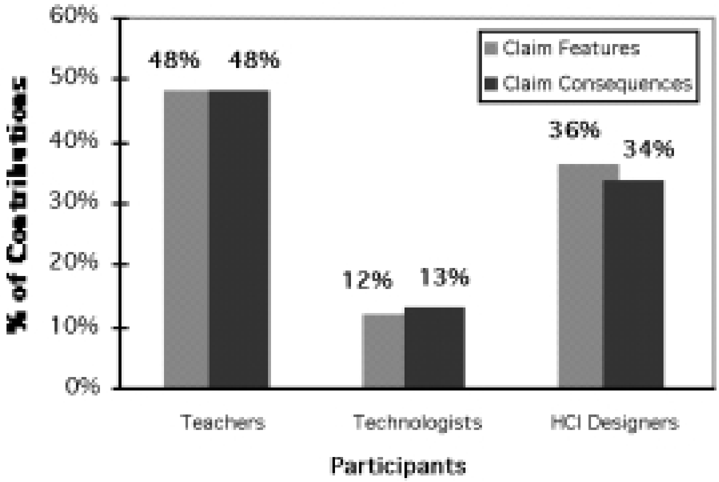
In July 1996, we held a two week workshop for all project members. One of the central objectives was to analyze the ethnographic data that had been collected during the preceding spring. In particular, we made a detailed analysis of several videotaped classroom interactions. As a group (four teachers, four human-computer interaction designers, four software technologists) we used claims analysis (Carroll & Rosson, 1992) to identify salient features in these scenarios, and the desirable and undesirable consequences of these features for students. This kind of work is exciting but demanding. It is directed brainstorming in which lines of causal reasoning are rapidly improvised, questioned, and refined. The teachers, of course, knew a lot already about classroom matters. However, they were not used to explicitly identifying tradeoffs for human activity in classroom situations. As one teacher commented: "It intruded on the way I design activities—I like to brainstorm and think out loud, [but] every time you say something, it gets analyzed." The teachers seemed exhausted after these sessions.

Nevertheless, the teachers were remarkably effective in these participatory analysis sessions. They were at least as productive as any other constituency in the project team at identifying teaching and learning issues, key situational features, and tradeoff relations in consequences for students. An example claims analysis is a discussion we had about student leadership in groups. We analyzed videotape of a group activity in which students measured kinetic energy for collisions involving model trains. One issue we identified was leadership style. We contrasted a consensus-building style, in which the leader ensures that all ideas are considered and enhances group dynamics and the self-esteem of members, with an individual initiative-taking style, which is efficient, challenging, and provides opportunities for group members to play leadership and supporting roles.

Our claims analysis identified upsides and downside consequences of each style, but focused on the efficiency of initiative-taking in group leadership. At this point in the discussion, the teachers emphasized that while task-oriented productivity is important, a more critical consideration is that all group members have the opportunity to hypothesize and test their individual ideas, and to participate fully in the group activity. This led to a more complete tradeoff analysis of student leadership, and had specific ramifications for issues of floor control and group formation in the virtual school environment.

In figure 3, we have analyzed two days of the workshop during which a total of 32 features and 220 associated consequences were generated. We associated each claim feature and consequence with the participant who originally identified it. Of all the claim features generated, 48% originated from teachers. Of the consequences generated, 48% originated from teachers. The corresponding figures were lower for both the software technologists (12% and 13%, respectively) and for the human-computer interaction designers (36% and 34%, respectively; see Chin, Rosson & Carroll, 1997).

Figure 3: Contributions to claims analyses by teachers, software technologists, and HCI designers (from Chin et al., 1997)



We also noticed that teachers were likely to contribute in the discussion of a claim schema even if a teacher did not originate the claim. We further examined the videotape to see for which features and consequences teachers had significant input. We considered a participant to have significant input if s/he originates, modifies, extends, or elaborates a feature or consequence. In the discussion of a lab notebook feature, for example, each teacher provided input into the discussion by describing how students use lab notebooks in his/her class. General discussions would often lead to a more rich and comprehensive view of the feature or consequence. From our evaluation, we found that teachers provided significant input to 88% of the features and 68% of the consequences (Chin, Rosson & Carroll, 1997).

One of the immediate and long-lasting changes in the project dynamics arising from the workshop was that the teachers became more active advocates for the importance of classroom situations. The teachers already believed that understanding and addressing real classroom issues was critical to the project, and recognized that they were in the best position to recognize and articulate these issues. What changed in the summer of 1996 is that they became far more willing to proactively share that perspective with other members of the project.

The only way to become an analyst is to analyze. In the workshop, we not only emphasized what we could see happening in a classroom activity, but also how we made sense of it. Teachers were confronted by a situation in which they had to transcend the role of informant, to make proposals about why some aspect of a learning situation might be good or bad. Analysts value the skills and knowledge of practitioner-informants, but at the same time it is the analysts who are in control; analysis, not raw data, drives design. By publicly objectifying their own knowledge in the workshop, the teachers appropriated the license not merely to testify about events in the classroom, but to make sense of those events with respect to the project's goals.

The teachers were even affected *as teachers* by this analytic work. For example, during the workshop, the teachers articulated some rationale for assigning students to groups—students with complementary skills and leadership styles can be grouped together, known personality conflicts can be avoided, natural mentoring relationships can be set up. Prior to this analytic work, the teachers had been quite relaxed about group formation, allowing students to choose their own partners (generally friends). However, in the year following the workshop, the teachers became much more proactive in creating groups, requesting and using online tools for group assignment.

Both informants and analysts must understand the problem domain. However, analysts must additionally understand the problem domain in the context of system capabilities. Through the course of the project the teachers have learned a great deal about the various networking mechanisms incorporated in the virtual school software (text chat, video conferencing, whiteboards, email, Web-pages, shared editors). Structured interviews indicated that through the first three years of the project they also developed an understanding of how computer technology can be used to support their own teaching objectives, and of how students can remotely collaborate (Chin, in preparation).

In the fall of 1996, we designed and carried out a series of classroom collaborative activities. For example, middle school students at different schools used text chat, synchronous audio, and video teleconferencing to collaborate on a melting/freezing point experiment. Each group was given one of two possible substances; collaborating groups compared measurements from their lab experiments in an attempt to determine which group had received which substance. The teachers played a central role in conceiving of and analyzing these activities. For example, they identified the opportunity of pooling data as an appropriate and intrinsically motivating application of networking among classrooms in the virtual school. They led the analysis of how students groups might use various networking mechanisms to collaborate in these activities.

This was a process of reflection-in-action (Schon, 1983): the teachers analyzed the technology by "auditioning" it in classroom activities. They tried to predict educational benefits and assess them by formulating activities involving sharing of data, equipment, and expertise.

THE DESIGNER

During the early spring of 1997, the teachers participated in a series of paper prototyping sessions. Scenario descriptions of classroom interactions were used as task-oriented representations that could help to articulate features of the learning environment. This was real design work that actually directed subsequent development of our virtual school software. For example, the teachers prototyped a milestone-tracking capability to help manage student groups. They developed the idea that teachers would provide templates in the collaborative notebook tool to convey assignments to students. They analyzed the problem of student and group authentication and developed a group-logon design. They also designed a folder scheme for partitioning student work. These contributions moved the teachers beyond the analyst role; they were not just articulating the problem, they were suggesting solutions.

In April of 1997, the teachers met on their own and formulated an approach to classroom activity design that they called “projects”. They had concluded that the pedagogical value of the relatively brief and technology-oriented classroom activities investigated in fall 1996 was too limited, that the overhead of initiating these activities was too high relative to their value. They urged a different approach for the 1997-98 school year, one involving activities that extended over several weeks, even months.

This episode is truly a turning point in the LiNC project. This is not because the teachers wanted to focus on long-term, rather than short-term activities; other members of the team also wanted to focus on more realistic activities, and on more ambitious activities that would drive our software ideas more vigorously. What is significant is that the teachers took the initiative to develop and articulate a central design concept to the group as a whole, and that this design concept entailed more responsibility and more work *for them*. There is no way to see their proposal as less than fundamental to the project’s design strategy. Rather than responding to our visions (e.g., figure 1), they were contributing a vision; rather than agreeing to a workplan, they were providing a strategy for the workplan. Perhaps most importantly, through this episode, the teachers embraced the virtual school as a major tool in their own pedagogical planning. This sharply contrasts with the earlier principle of cooperating as long as the project did not diminish learning opportunities for their students.

The teachers’ transition to activity designers in the project was a sharp punctuation in the project’s course of development. After this point, the teachers regularly met as a subgroup within the larger project. Their efforts to understand one another’s teaching styles and pedagogical objectives became far more pointed and considered, as they tried to develop an integrated curriculum with common objectives, timing, scale, and grading. It was understood that the design of the classroom activities belonged to them, and that this was the primary source of requirements for the software design efforts. To a great extent, the teachers' planning drove other aspects of project activity.

The teachers' paper prototype design work was scaffolded in the sense that their efforts were supported and guided by experienced software designers on the project team. Nevertheless, the ideas came from the teachers. When this design was subsequently presented to the full project team, there was a spirited discussion of the specific features that had been proposed. Afterward, the teachers felt their design had been attacked, that they were put on the defensive. This is not a positive result; designers should not be defensive about their proposals, and their colleagues should be careful to avoid making them feel defensive. But what is equally notable, is that is that the teachers felt ownership of the design, and wanted to defend it. They became embroiled in the typical give and take of design work.

Prior to this point, the teachers, as designers, had been coddled to some extent. Their ideas and perspectives were received with gratitude, generally in design sessions designated for teacher input, like the paper prototyping sessions. After this point, the teachers were treated much more normally; they neither received nor seemed to need or want special handling.

This has led to a productively eclectic design framework. Some members of our project start from architectural considerations about collaborative software, albeit constrained by classroom activity requirements and overall deign concepts. Some start from scenarios of project interactions for individual students and groups. The teachers, as designers, tend to start from classroom activities, pedagogical objectives, curriculum plans, and so on. What is true now, and was less true in the past, is that we are able to move convergently towards common goals from these diverse starting points. A key factor seems to be that even though different people take different approaches and represent different knowledge and skill, everyone understands everyone else well enough to see how we complement one another, and how things can fit together.

During the 1997-98 school year, the teachers introduced various innovative classroom activities. In one activity high school and middle school students collaborated on the design of a robot; the middle school students designed a grasping arm, and the high school students designed a mobile base. Many of these longer-term projects involved the development of mentoring relationships by community members in areas such as the optics of photography, mechanics in the context of amusement parks, the astrophysics of black holes, the engineering principles of bridge building, and the aerodynamics of kites and model planes. In some cases, the mentoring was carried out using combinations of video conferencing, email, and chat, raising many issues for our developing virtual school software, and indeed even for the concept of what the virtual school is intended to be. Our original concept had not developed the concept of community participation in the schools, but the teachers' initiatives helped to re-emphasize this theme in the project throughout the year.

The software we developed strongly reflects the design concepts championed by the teachers. Our original plan emphasized support for high-bandwidth, real-time interactions; our vision was of a graphically-enhanced multi-user domain. Early development work focused on creating a shared whiteboard that would allow students to collaborate on simulation experiments (e.g., Koenemann, Carroll, Shaffer, Rosson & Abrams, 1999). However, the teachers' emphasis on long-term projects led us to reweigh goals having to do with maintaining work context. Our current virtual school is a Java-based networked learning environment, emphasizing support for the *coordination* of synchronous and asynchronous collaboration, including planning, note taking, experimentation, data analysis, and report writing (Isenhour, Carroll, Neale, Rosson & Dunlap, 2000). The central tool is a collaborative notebook that allows students to organize projects into shared and personal pages; it can be accessed collaboratively or individually by remote or proximal students.

In July 1998, the teachers circulated a detailed specification for a fall collaboration activity, which would last for two weeks, and which would orient students to the virtual school software; this would be followed by a long-term project, which would run from mid-November through late April. In retrospect, this phased use of the virtual school can be seen as a sophisticated response to the ongoing software development process. Through the summer, the overall system had been coming together, and the teachers knew we expected them to use it in their classrooms. Yet at the same time, they felt the need to scaffold their use of the software, to be certain that it would effectively support curricular activities.

The specification of major classroom activities for the 1998-99 school year was generated entirely by the teachers, and included several specific new functions they needed in order to carry out the planned activities (see figure 4). For example, the teachers described an "info" button for the collaborative notebook; the button would open a browser on teacher-defined help for using the notebook in the current project. They described a bibliography tool as a notebook page with fields, supporting entry of various sorts of reference materials, as well as student notes derived from the references. They described a planner tool as a notebook page displaying projects checkpoints and due dates. The teachers also requested software support to allow students (and teachers) to access the virtual school from home.

The teachers described a "message" tool for the collaborative notebook that could be used to attach comments to notebook pages. The tool would be used to approve student work (that is, to convey to groups that they were on track) as well as to answer student queries. It would also convey at a glance to other teachers that a given notebook page had been approved. The teachers were explicit that they would grade student projects as a team and trust one another's assessments. Even planning to try such an arrangement is quite radical from the standpoint of the culture of schools (Dunlap, Neale & Carroll, 2000).

We are still in the midst of evaluating the software and activity design outcomes of the LiNC project, a complex matter in itself (Gibson, Neale, Carroll & VanMetre, 1999; Neale & Carroll, 1999). However, our design method objectives have been achieved. The teachers all function now as ordinary members of the design team. They are empowered and feel that they have both the capabilities and the right to participate in all facets of design work. One teacher recently summarized this:

> "Actually, my role in LiNC has been much more than I expected. I like feeling like I am an expert at something and that my experience is valued. I like feeling comfortable talking to all other players as

Figure 4: General functionality and specific features introduced by teachers through their design scenarios

General Functionality	Specific Features
• long-term projects • mentoring by members of the community • integration of synchronous and asynchronous collaborative work • interaction with virtual school from home as well as school	• assignment templates presented as notebook pages • info button providing access to teacher-generated help • structured editor for bibliography entries • planning page with project checkpoints and due dates • teacher comment tool

equals. I like to truly collaborate and I like to be treated with respect. Finally, I like honesty even if I disagree."

This is precisely what we wanted to achieve. It is not a state of user buy-in, but a state of mutual respect and engagement.

THE COACH

In August of 1997, the LiNC group organized a training program for middle and high school science and mathematics teachers throughout the Montgomery County school division; this effort was supported by the federal Eisenhower Teacher Development Program administered in Virginia by the State Council of Higher Education. Twelve teachers spent two weeks learning about various networking communication and collaboration mechanisms, and developing ideas and materials for using these resources in their classrooms. The university faculty and graduate students from our project helped to organize and run the training program as lecturers and coaches; indeed, the program proposal we wrote assumed that the teaching would be handled by the university faculty and graduate students (as is typical for the Eisenhower program).

As we planned the Eisenhower program, the four teachers in the LiNC project assumed more and more responsibility for various aspects. They began by coordinating plans and schedules among the twelve teachers, who after all were their colleagues. Soon though, the teachers were added to the program schedule, to share personal classroom experiences from the preceding school year. Finally, their role expanded to include coaching the other teachers during the Eisenhower program, and managing the year-long follow-up program during the 1997-1998 school year.

This was not a deliberate plan, though perhaps it should have been. The teachers were clearly able to inspire their colleagues. And they also seemed to benefit from the exercise of externalizing and reconstructing their experience in order to convey it others. This put them in the interesting role of helping other teachers embark on the same journey they themselves had taken. Participating in the Eisenhower workshop as technology specialists, facilitators and coaches, and ultimately as organizers, allowed the LiNC teachers to more vividly appreciate their own development, to reflect upon their new expertise, their changed skills and practices as teachers.

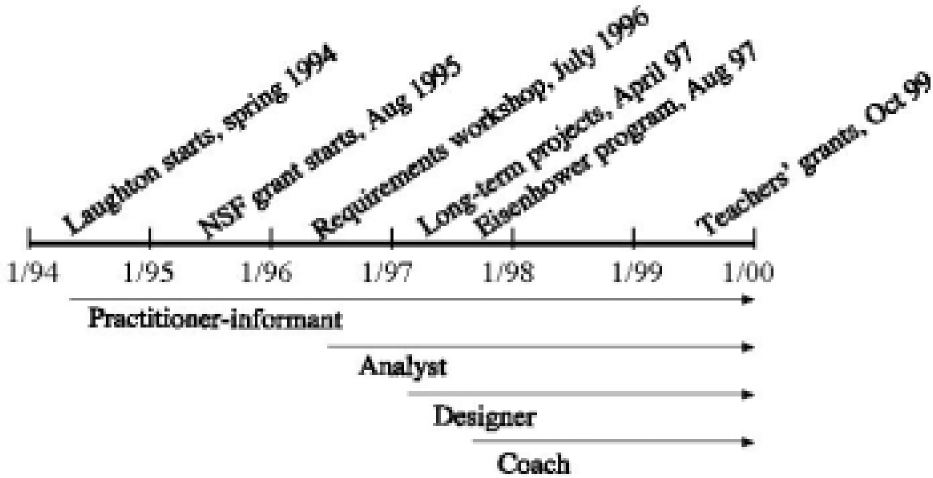
The highest stage of intellectual development in Piaget's developmental theory is the formal operational stage in which people reflect upon their own thinking processes (Piaget & Inhelder, 1969). Coaching others is a natural way to evoke reflection on one's experience. As the teachers assumed responsibility for the training and development of their colleagues, they considered their use of collaborative technologies, and of LiNC tools in particular. In the two and half years since the Eisenhower program, there are many examples of the teachers becoming leaders within the Montgomery County schools.

For example, the teachers have helped to recruit and train new teachers for the LiNC project. One veteran teacher (interestingly the one who was least experienced with technology at the outset of the LiNC project) has formed a partnership with two other teachers. In a group discussion in the spring of 1999 (a Web-forum; Carroll, Neale & Isenhour, 2000), this teacher argued that the time had come for the teachers to take even more responsibility in developing new activities. Subsequently, she identified a set of new activities she felt would be good candidates for collaborative learning (involving lego constructions), and organized the effort to select and design classroom projects, place materials in virtual school notebooks, and carry out an extensive long-term collaboration during the 1999-2000 school year. Such teacher autonomy is essential to the sustainability of collaboration infrastructures like the virtual school, and indeed it is precisely the kind of outcome one almost never sees in educational technology interventions.

Another veteran teacher initiated contacts with another Virginia school division (Giles County), arranging an activity in which his students would use the virtual school's collaborative notebooks to mentor writing projects of younger students. We went along to the meetings and agreed to play a supportive role, but it was clearly the case that this initiative would have gone forward with or without us. The teacher, at this point, needs only the tools to implement his designs.

To operate at the coach level, people need to see beyond particular applications; they must appreciate the patterns of utility that motivate *types* of examples. Many teachers interested in classroom computing are familiar with word processors and web browsers, and can make creative use of these. However, few are familiar with the potential of computers as collaborative systems. Some of the new teachers joining the LiNC project were sophisticated with respect to the educational potential of multimedia, film, virtual museums, and graphics, but did not readily grasp the value of advanced communication tools and integrated collaboration. The veteran LiNC teachers do see this underlying pattern, which enables them to innovate and lead as coaches. This willingness and ability to conceive of new applications is a critical step in sustainability of a technology infrastructure and systemic reform of practices (as in educational reform). It shows that users have truly appropriated the technology as their own. This creative adaptation can be seen as the highest level of development.

Figure 5: Timeline of the LiNC project



Several of the teachers expressed interest in writing their own grants to continue aspects of the LiNC project. In fall 1999, two teachers, one of the veteran teachers and one of the new teachers submitted two proposals. Figure 5 summarizes the timeline of the LiNC project, indicating the approximate span of each stage.

TRANSITIONS BETWEEN STAGES

Developmental theory explains transitions between stages as resolutions of conflict. Thus, the pre-operational child's conflicting perceptions of quantity based on single dimensions, such as height and width, are resolved in the abstraction of quantity as an invariant in the concrete operational stage. For development to take place, the child must have attained the requisite competencies to experience the triggering conflict, and then be able to reconceptualize the situation in such a way that the conflict dissolves.

This analytical schema seems to fit the transitions between the stages of cooperation we have described. The general mechanism seems to be that successive increases in knowledge, skill, and confidence empowered the teachers to resolve conflicts, by assuming successively greater scope of action and responsibility in the project. In the July 1996 workshop, the teachers faced the conflict that their pedagogical concerns and perspectives would be adequately represented and fully considered by the group only if they themselves represented those concerns. This went beyond the role they had played in the project up to then. But they were both motivated and competent to resolve this conflict by assuming the analyst role in the project.

Once the teachers were functioning as analysts in the project team, further conflicts and resolutions arose. In spring 1997, the teachers experienced a conflict between their own analyses of requirements, and the current state of the virtual school software and development plans. They resolved these conflicts by formulating their own design proposals, ultimately a radical reorientation of the project's vision of classroom activity. Subsequently, the teachers recognized that they were the best qualified project members to administer the Eisenhower program, and more recently, that they are best qualified to pursue specific curricular extensions of the LiNC project.

The teachers' behavior also reflects development *within* the four general stages we have described. For example, during the requirements analysis workshop, scaffolding (examples, reflective prompts) was needed to engage the teachers in the novel and abstract activity of claims analysis. But as the project progressed, teachers spontaneously presented claims as a way to articulate personal positions, and frequently identified "upsides" or "downsides" as part of our design discussions. This of course is quite consonant with the general notion of learning as movement through a zone of proximal development (Vygotzky, 1978).

The designer stage also reflects several different levels of development. Initially, the teachers were able to collaborate with a research assistant in focused design sessions, co-writing scenarios of technology-mediated activities for their classroom. Later they banded together as a subgroup, pooling their goals and expertise to develop a scenario that specified a new vision of collaborative learning activities. Ultimately, each learned to function as an independent designer, with the result that they can now envision and specify activities optimized for their own teaching styles, objectives, and classroom environments. In their coach role, the teachers again worked first as a group in the Eisenhower workshop, but have now begun to recruit and mentor colleagues in a 1:1 fashion.

In sum, it appears that the transitions among stages were triggered by conflicts with respect to the teachers' role in the project. In each case, a series of scaffolded activities enabled them to attain the knowledge, skill, and confidence that led them to expand their role.

One natural follow-on question is whether and how the developmental process we described could be accelerated. Must it take five years for technologists to work effectively with teachers? In the case of cognitive development, the timing of stage transitions cannot be altered substantially because the capacities for resolving the triggering conflicts depend on brain development, in other words, they are governed by sequencing of physical development. In our case, the relevant capacities are not biological, but they are quite fundamental. Trust, empathy, and commitment are critical, and cannot be manufactured; they emerge from significant shared experience — joy and insight, as well as confrontation of external threats and resolution of inter-personal conflicts.

Some things we did more or less inadvertently, or at least intuitively, seemed to facilitate teachers' development as autonomous members of the project team. For example, at the outset of the project, one student research assistant took the initiative to identify and articulate teacher concerns to the rest of the group. This clearly helped the teachers to assume this role for themselves. A further technique we think might have been useful, but which we did not employ, would be to designate a "lead teacher". Especially in the early stages of the project, teacher concerns might have come to light too slowly because no one was specifically designated as responsible for representing those concerns to other constituencies.

Further efficiencies are definitely possible. We believe that we could accelerate the practitioner-informant stage by at least one year, and possibly a year and half. However, we are concerned that further compression would compromise the coordination of participatory and ethnographically-driven approaches to requirements development—to a great extent a project such as this is tied to the natural rhythms of the school year. Other stages could be structured more deliberately, to ensure that teachers attain prerequisite competencies, and that they directly encounter and resolve role conflicts. In the LiNC project, the transitions among states was more or less organically driven by project needs, and by our evolving ideas for how to broaden the framework for participatory development. But trusting fortune in exploratory technology development can be bumpy: We believe that with experience, long-term projects can be managed to better align project needs and human development opportunities, as a sort of workplace "curriculum". We can imagine an overall speed up on the order of a factor of two.

We see this case analysis as positive and hopeful. If technologists and teachers can cooperate more effectively, can develop the knowledge, skills, and sensibilities to combine their different expertise more successfully, perhaps educational technology can become more effective. Perhaps it can have a more positive and profound impact on education. Other recent work seems to support similar themes. Davies (1991) describes the importance of teachers working together to articulate and analyze new strategies for schooling—and receiving stipends for their research efforts. Krasnow (1990) describes the new thinking and reflection produced in schools by empowering teacher-researchers. Shields (1994) emphasizes that research should study comprehensive relationships among parents, communities and schools, as opposed to quantifying piecemeal relationships (like the correlation between test scores and parental attendance on school council). Wadsworth (1997) emphasizes that the engagement of parents, teachers, and community takes place through action—agreeing on needs, committing to actions, and reporting results, not through new ways to talk about problems.

LESSONS LEARNED

We originally committed to a long-term participatory design method because we conjectured that such an approach would be appropriate, if not crucial, for success in this educational technology setting. This appears to have been correct. We believe we could not have succeeded to the extent we have had we not made this commitment. Working from the national agenda for school reform, educational technology, and science education (American Association for the Advancement of Science, 1993; Goals 2000: Educate America Act, 1994; National Science Teachers Association, 1992) and from our own vision of a virtual school (figure 1), we would have built the wrong system, we would not have had effective support from teachers, and little or nothing would have been sustained after the initial project funding ended.

Participatory design is fundamentally a process of mutual learning, and thus of personal development for participants. But it is often exemplified by rather singular and ephemeral learning interactions. Our study expands the scope of the design participants' personal development by examining a case of long-term cooperative design interaction, and by describing a developmental sequence of roles with constituent capacities and responsibilities.

Much research on participatory design has focused on relatively short-term collaborative relationships. This is especially true in North America; for example, the well-known PICTIVE technique is directed at brief user interface design interactions of perhaps one hour (Muller, 1992). Such methods are both effective and democratic, but it seems unlikely that the experience of manipulating a user interface mock-up during a brief participatory session can have a significant developmental effect on a person's knowledge, skills, self-confidence, or other professional capacities.

Our case study is different in that user interface design per se has been a secondary issue. We have used brief participatory exercises since 1994, but this level of engagement is more a starting point than the objective of our work. More specifically, we wanted the teachers to have a significant voice in designing the functionality and the use of the virtual school, not merely its appearance. We needed to learn about pedagogical goals and practices, classroom management, school system politics, the relationship of community and the schools, and so forth.

Where participatory design investigations *have* focused on longer-term interactions, chiefly in Europe, these often involve extremely well-organized user groups with well-defined roles and prerogatives in the design process. In many cases, the users are represented by labor unions whose personnel provide legal representation of user interests in the design process. In these cases there is sometimes a clear demarcation, even conflict, between the user (union) interests and management's technology strategy. Indeed, this is an important element of the context for many of these studies. Because the user role in many of these studies is both specified a priori and representative (versus individual), the personal development of user-designers is not a central issue. These case studies also typically involve situations in which the development and deployment of new information technology is a given, and the challenge is to define appropriate technology for the users and their activities (Bødker, Ehn, Kammersgaard, Kyng, & Sundblad, 1987).

In the educational domain, the deployment of new information technology is far from a given. Indeed, the introduction of new technology has historically almost always failed in school settings. One of the key questions for us was whether a concept for appropriate technological support could be developed at all.

The users in our domain are very loosely organized. As mentioned earlier, teachers traditionally work in isolation from peers; they manage their own work practices and environments (classrooms). The notion of "user community" in this domain is almost ironic. Teachers unions in the US are also extremely weak, and play no role in the introduction of classroom technology. Indeed, school administrations in the US rarely have technology strategies at all. Thus, unlike the European case studies, the issue is almost never one of recognized conflict, but rather finding a direction at all.

The teachers in our team do not represent other teachers; they are individuals who, as members of our team, have become teacher-designers. This is precisely why their personal development as designers is a central issue in our study. Of course, we do hope that they are representative teachers—allowing us to generalize our investigation to other teachers participating in similar development projects—but this is a separate issue. The point is that in our project, and unlike many long-term participatory design efforts in Europe, the teachers act as individual professionals, just as university researchers do.

An interesting aspect of the teachers and their development is that the four original teachers are now among the most senior members of the LiNC team: only the two faculty participants have also been part of the project from the start, with students and post-docs joining and participating for shorter periods of time. Undoubtedly this has increased the teachers' sense of expertise and confidence, as they have seen numerous issues and ideas raised, addressed, incorporated, or discarded. More importantly, perhaps, they have seen these issues play out *in the context of their own work.* Thus these four individuals own a central element of the LiNC project's organizational memory—the activities of the classroom.

The stages we have described here are specific to our project; they emerged through specific things that we did, and are rooted in the specific goals of our project. At the same time, they suggest a schematic programme for developing cooperative engagement more generally. Most participatory design work engages users at the practitioner-informant stage. This would seem to be an obvious and general starting point for any participatory design collaboration. In our project, the teachers transitioned to the analyst stage through their inclusion in a requirements analysis workshop and a significant process of iterative requirements development (Carroll, Rosson, Chin & Koenemann, 1998). This is perhaps not typical of participatory design practice, but it is a modest extension. Nevertheless, the teachers found it quite stimulating to be invited to objectify their own experience, to dissect it and not merely describe it.

CONCLUSIONS AND DIRECTIONS

In the fall of 1994, we created an envisionment scenario (figure 1) that helped us win a large federal grant and energized local teachers with whom we shared it. But it did not address all of the relevant requirements and described what we later realized was the wrong system. The participatory process we engaged in allowed us to understand further requirements and to create a better system. Achieving the quality of participation required took time and effort, but was worth it.

Teachers' work is "invisible" in the sense that their work organizations (their school divisions) do not explicitly analyze its nature or support (Suchman, 1995). However, teaching is even more invisible than that of the legal personnel studied by Suchman, because it is only very loosely coupled to organizational workflow. As emphasized by Tyack and Cuban (1995), it is difficult for anyone to see what is happening in a given classroom. The personal control inherent in teachers' work is what makes participation in technology development so important. It is not just a matter of accurately describing the work, or even of designing appropriate support; the teachers also must accept and deploy "appropriate" solutions. When users have total discretion throughout the entire development cycle, a long-term participatory approach is essential.

We are planning further projects in a variety of community areas, developing networked access to a local natural history museum , support for new kinds of citizen participation in town government, and a regional approach to teacher professional development.

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