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Designing Social Infrastructure: Critical Issues in Creating Learning Environments With Technology

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If design research involving technology-based tools is going to impact educational settings, the design process must be extended beyond the tool itself to encompass a broader range of factors such as the classroom social structures (e.g., beliefs about learning and knowledge, learning activities and participant structures, configurations of both physical space and cyberspace). Although prior research has underscored the importance of classroom social structures in technology integration, it has failed to specify the critical design variables that must be taken into account. Only by understanding the critical variables involved is it possible to develop a deep understanding of how and why things work. The Social Infrastructure Framework systematically frames the critical design elements in terms of 4 dimensions: (a) cultural beliefs, (b) practices, (c) socio-techno-spatial relations, and (d) interaction with the "outside world." This article details the design issues associated with each dimension based on examples drawn from a range of educational technologies. This article also describes how the framework can serve to advance the methodology of design research by serving as a tool for both design and analysis.

Since the 1990s, starting with papers by Brown (1992) and Collins (1992), there has been a growing movement to develop a new methodology for carrying out studies of educational interventions under the labels *design research*, *design experiments*, and *design studies*. Various researchers have contributed to the effort to specify for the educational research community what such a research methodology entails (e.g., Barab, 2004; Barab & Kirshner, 2001; Kelly, 2003; Sandoval & Bell, 2004). Although different researchers have emphasized different aspects

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and issues of importance, they have all agreed upon one thing: Design research is still clearly in its early stages. This article aims to contribute to the development of a more rigorous set of methods and tools that can serve to guide design research.

Design research aims to develop a deep understanding of what makes for successful educational practices. It takes analysis and theorizing to determine what the critical elements are and which combinations of those elements make an effective learning environment. It is possible to refine practice without any understanding of how and why things work. However, to make major progress in the field, it is necessary to develop a theoretical understanding of why some practices are effective and why some are not. If design research is going to have a large impact in educational settings, it will have to build much more robust theories of why certain practices are effective and how learning occurs in context.

For this reason, when carrying out design research involving technology-based tools, it is critical to extend the design process beyond the tool itself to encompass a broader range of factors such as the classroom social structures (e.g., learning activities and participant structures, configurations of both physical space and cyberspace). Although prior research has underscored the importance of classroom social structures in technology integration, it has failed to specify the critical design variables that must be taken into account. Only by understanding the critical variables involved is it possible to develop a deep understanding of how and why things work.

Whether or not they are conscious of how their actions and decisions impact the construction of classroom social structures, developers and teachers engage in making design decisions that affect social infrastructure. I have developed the Social Infrastructure Framework to make such decisions explicit and to organize them into a systematic framework that highlights the critical design factors. The Social Infrastructure Framework focuses on classroom social structures that impact the type of learning environment created with technology-based tools. The framework includes a variety of critical design elements, including beliefs about learning and knowledge, learning activities and their associated participant structures, and configurations of both physical space and cyberspace. A tool such as the Social Infrastructure Framework provides support to design researchers in both developing a design and in assessing how effectively the implementation of a design is working and ways the design might be improved—a dual functionality that characterizes the types of tools needed to carry out design research (Barab & Squire, 2004; Bielaczyc & Collins, in press-a; Collins, Joseph, & Bielaczyc, 2004).

The first section of the article details the four dimensions of the Social Infrastructure Framework. The second section focuses on the usefulness of the framework in carrying out design research. This includes a discussion of the ways in which the Social Infrastructure Framework can serve as a tool for both design and analysis.

THE SOCIAL INFRASTRUCTURE FRAMEWORK

One of the central claims of this article is that to gain a deeper understanding of how to create successful learning environments with technology-based tools, the design process needs to extend beyond the tool itself to include the design of social infrastructure. Recognition of the importance of social infrastructure is not new. Classroom social structures have been found to play a critical role in the integration of technology-based tools in kindergarten through 12th-grade (K–12) classrooms. This is particularly true of studies comparing different *models of use* or implementations of a given tool across different classrooms (e.g., Bereiter & Scardamalia, 1992; Bruce & Rubin, 1993; Bruckman & DeBonte, 1997; Schofield, 1997; Sheingold, Hawkins, & Char, 1984), the same classroom over time (e.g., Hewitt, 2002), and classrooms in different cultures (e.g., Lin, 2001). These studies have highlighted the importance of classroom social structures in learning with technology-based tools and have begun to identify central features. However, what is missing is a systematic account of what the critical variables are. Further, the current literature does not help us to answer the question of *how to design* social infrastructure such that a technology-based tool is used in ways that create effective environments for learning. Classroom social structures are not fixed. We need to go beyond understanding the impact of a *given* classroom social infrastructure on the integration of a technology-based tool and begin to systematically identify and analyze the aspects of social infrastructure that are amenable to design.

What are the critical dimensions of classroom structures that are amenable to design? From the literature on classroom interventions, epistemology, and teacher learning, as well as a wide variety of technology integration and design projects, four basic dimensions emerge:

1. The *cultural beliefs dimension* refers to the mindset that shapes the way of life of the classroom. Such beliefs influence how a technology-based tool is perceived and used. For example, we would not expect a classroom where knowledge is viewed as a fixed, objective entity—"in the back of the book" or owned by the teacher—to create an ethos favorable to a scientific inquiry tool focused on exploration and student-generated hypotheses.
2. The *practices dimension* concerns the ways in which teachers and students engage in both online and offline learning activities relating to the technology-based tool. This includes issues such as whether students work individually, in groups, or both; and how such groupings are organized. It also includes the various roles a teacher assumes in using a technology-based tool with his or her students. The norms and structures of these learning practices have implications for students' level of engagement, sense of autonomy, and the ability to transfer what they learn to other contexts.

3. The *socio-techno-spatial relations dimension* refers to the organization of physical space and cyberspace as they relate to the teacher and student interactions with technology-based tools. The various arrangements among humans, computers, and space within a particular classroom context impact the dynamics of the learning environments created. This dimension becomes even more interesting with the introduction of wireless handheld devices that permit mobility and modularity. This dimension influences accessibility, connectivity, and communication among students and teachers.

4. The *interaction with the "outside world" dimension* refers to the ways in which students interact, online and offline, with people outside of their immediate classroom context. Such interactions can impact learning with the tool by broadening the scope of resources available for learning. For example, students may be exposed to models of expert ideas and processes not available in the classroom. Students may also work on authentic problems in real-world contexts. This dimension influences student motivation, presentation skills, and ability to communicate with others.

Although treated separately, these dimensions of social infrastructure are interdependent, as will be discussed throughout this article.

The Social Infrastructure Framework highlights the dimensions of social infrastructure essential to integrating technology-based tools into classroom practice. Below I draw from the literature on educational technology and the learning sciences to show the rich set of issues associated with each dimension. Further, I categorize the types of design decisions that need to be considered in constructing appropriate social infrastructure. I conclude the section with a table that summarizes the dimensions, the design issues raised for each, and the types of questions associated with each issue.

The Cultural Beliefs Dimension

Cultural beliefs might not usually be thought of as something that is designed. *Cultivated* may perhaps be a better way to describe the approach required. The point is that the beliefs held by teachers and students within a classroom setting can indeed be changed. In fact, for a tool to be successful it may be necessary to develop new ways of thinking about learning and working with the tool. There are several major areas of cultural beliefs that designers need to be concerned with: (a) how learning and knowledge are conceptualized, (b) how a student's social identity is understood, (c) how a teacher's social identity is understood, and (d) how the purpose of the tool is viewed.

The conceptualization of learning and knowledge concerns issues such as: How is the process of learning viewed by teachers and students? What does it mean to "know"? For example, students may have a fixed view of intelligence ("He's smart") or a view that intelligence can be achieved through learning (Dweck, 1999). Cohen (1988) described a common conceptualization of scientific knowledge as a fixed entity, as "factual, objective, and independent of human distortion" (p. 11). For the designer, it is important to determine what types of conceptualizations of learning and knowledge best support the use of the tool. As stated earlier, we would not expect a classroom where knowledge is viewed as a fixed, objective entity—"in the back of the book" or owned by the teacher—to create an ethos favorable to a scientific-inquiry tool focused on exploration and student-generated hypotheses. Instead, designing the appropriate learning environment would involve conceptions of the sort where students see themselves as generators of knowledge and conceive of knowledge as the result of a process of continually improving ideas.

The conceptualization of a student's social identity refers to how students view themselves as learners and how they perceive the role that other students in the class (and others in their social network) play with regard to their own learning. Designers need to consider: How should students view their purpose in the learning environment? How are students meant to view each other—as learning resources, as team members, as competitors? Are students meant to develop expertise and skills consistent with professionals in the "real world"? Many of the current technology-based tools for science learning are premised on the model of students as members of a scientific community (e.g., BGuILE; Reiser et al., 2001; ThinkerTools; White, 1993, 1995). In such a model, students are meant to view themselves as investigators of scientific phenomena. Other students in the class depend on what one learns and serve as coinvestigators. If students do not take on such a social identity, the desired learning objectives will not be met. Work by Sheingold and her colleagues (1984) highlighted the possibility for students in LOGO classrooms to develop different areas of expertise and to serve as learning resources for each other and for their teachers. However, students accustomed to traditional classrooms may not readily see themselves, and each other, in this way. For example, in one case students were working on LOGO programs in pairs in front of shared computer screens. The social identity seen by one partner was revealed when she told the other member of the pair that she should sit at the keyboard: "I'm the thinkist, you're the typist." As pointed out by Sheingold and colleagues, even though new types of interactions and identities are possible, "these must be valued and supported by the overall learning environment in order for important changes to take place in the long run" (p. 59). Harel (1991) explicitly introduced a new social identity, one of *students as instructional designers*, to help students engaged in LOGO programming to see themselves as designers developing shareable skills and valued products.

The conceptualization of a teacher's social identity concerns the ways that teachers view themselves and how students perceive the teacher's role in the learning process. Simply introducing a technology-based tool into the classroom has been found to shift a teacher's role from the central authority figure toward a facilitator (Schofield, 1995, 1997). This phenomenon is known in the field as the Trojan Mouse effect. For example, Schofield (1997) discussed how having students distributed around the classroom working at computers led to changes from whole-group instruction toward one-on-one instruction between teachers and students. This change "appears to be accompanied by a change in the nature of teachers' instructional behavior" (Schofield, 1997, p. 31) and the ways in which the role of the teacher was perceived. However, beyond the Trojan Mouse effect, designers must determine in what ways teachers' social identity and the roles they assume promote the creation of an effective learning environment with the tool. Thus, teacher social identity becomes a matter of design involving questions such as: How should teachers view their purpose in the learning environment? How are students meant to view the teacher? Are the teachers meant to be perceived as a fellow participant in the learning process (an active learner) or as an authority figure? If students are meant to see the learning process as a continual advancement of understanding, where knowledge can always be improved, then viewing the teacher as a colearner may be more consistent with such an epistemological view than perceiving the teacher as the source of all knowledge.

Cultural beliefs about the purpose of the tool concern how students and teachers view the purposes and uses of a particular technology-based tool. Design questions include: What is the purpose of the tool? How are students meant to use the tool to carry out the learning objectives? How is the tool meant to fit into the overall workings of the classroom? Sheingold and her colleagues (1984) described how the purpose of a particular computer-based simulation tool was interpreted quite differently by different teachers, which affected how they used the tool with their students. The simulation "was designed to motivate students to apply mathematical principles to the real-world problem of ocean navigation" (p. 55). One group of teachers viewed the simulation as a means for teaching math skills in the context of ocean navigation. Others saw navigation as the main focus of the software; that is, as "a game about boats and navigation" (p. 55). Because the second group saw little connection with their core curriculum, they did not use it within the context of teaching mathematics. Instead they relegated it to game status—something the students could play with during free periods. Similarly, a tool such as Broadcast News (Schank, Fano, Bell, & Jona, 1994), which is designed to teach writing within the context of creating a news show, could be understood either as an innovative approach to the teaching of writing or as a tool for teaching how to put together television news broadcasts.

The cultural beliefs dimension is presented first because it provides a substrate in which the remaining dimensions of the Social Infrastructure Framework operate. That is, the way that teachers and students conceptualize the elements discussed here sets the stage for the classroom practices, the socio-techno-spatial organizations, and the ways that outsiders interact with the classroom. However, two classrooms could have similar cultural beliefs, yet differ along the other dimensions. Thus, the cultural beliefs dimension influences and pervades the other dimensions but does not determine them. Conversely, the other dimensions can influence the types of cultural beliefs held by teachers and students. For example, if students share their work with people outside of the classroom (interaction with the "outside world" dimension), they may come to see that their ideas are valued by others, impacting their sense of social identity.

The Practices Dimension

The practices dimension focuses on the norms and participant structures of both the online and offline learning activities. In thinking about the practices dimension, designers need to consider (a) the activities in which to engage students, (b) the associated participant structures of students, (c) the associated participant structures of teachers, and (d) the coordination of on-tool and off-tool activities.

In determining the activities in which to engage students, teachers must consider the following: Should activity selection be left open to students, semistructured, or tightly sequenced? Should all students carry out the same activities, or should the activities differ according to the needs of particular students? Should remediation activities be provided if students have difficulties? A critical issue when working with technology-based tools concerns how to learn the functionality of the tool. Should this be a separate activity, or is the tool to be learned in the course of the broader set of activities? Other issues to consider in designing activities are what kinds of products the students should produce and how they should reflect on their work. Sometimes the product is simply the result of doing the activity, but other times there may be some kind of culminating event or summative product, such as a presentation to parents or a set of posters depicting what the students learned. Some kind of reflective activity can be very beneficial, such as evaluating one's work with respect to a number of criteria (White & Frederiksen, 1998) or discussing with other students what has been learned. Reflection is particularly useful if the students are engaged in a cycle of activity, where the reflection can guide their future actions to enhance their performance.

For each activity, designers need to also decide the associated participant structure of students—how student groupings are organized and the ways their interactions are supported. This issue is often forced to be resolved pragmatically rather than pedagogically with regard to technology-based tools due to limited technological resources in classroom contexts. That is, the developer of a particular technology-based tool may envision a classroom context in which all students are working at the computer at the same time, but in the local context the teacher may need to design participant structures suited to a 5:1 student-to-computer ratio.[1]

[1]The national average student-to-computer ratio in public school classrooms reported by Cattagni and Ferris (2001) is 5:1.

Pedagogical reasons for grouping students include research showing that working together can foster explanation and coconstruction of knowledge (e.g. Bielaczyc, Pirolli, & Brown, 1994; Brown & Palincsar, 1989; Forman & Cazden, 1985; Roschelle, 1992). However, having students work in pairs or groups does not necessarily lead to articulating ideas or using the technology-based tool in ways that lead to deep learning. A striking example is the pair of students working together on LOGO problems described earlier (Sheingold et al., 1984). A collaboration based on the notion that "I'm the thinkist, you're the typist" is obviously *not* a role differentiation designed to foster joint problem solving. Also, Roschelle (personal communication, May 21, 2006) found that when pairs of students worked together on a computer environment for envisioning physics, some pairs tended to discuss what actions to take in the environment rather than discussing the physics content knowledge. Thus, designing the participant structures must include decisions concerning how to foster and support the desired interactions.

Another consideration involves determining the associated participant structure of teachers. Designers need to consider how teachers are meant to participate in the learning activities: Are the teachers meant to observe or intervene over the course of particular learning activities? What level of control do teachers take over the course of learning? How is teacher control balanced with helping students to learn how to direct their own learning experiences? The teacher can serve as a coach, who monitors the student progress through the various activities, or the teacher can try to model how to do things, perhaps by engaging in the same activity the students are engaged in. Afterward the teacher might have students compare their work to what the teacher produced, and all might talk about the difficulties encountered and the decisions made. Another possibility is that the teacher plays the role of discussion leader, when the class or groups within the class sit down to discuss what they should do or have done. Teachers tend to participate in the learning activities in a variety of ways, as each occasion demands. Designers need to consider the types of demands that arise with a particular tool and what participant structures are best suited for particular contexts.

The degree to which the teacher exercises control or specifies what students do can vary from a complete script and tight teacher control to student determination of the course of learning. By carefully scripting what students do, the teacher can make sure that students encounter the key ideas that the tool is designed to teach. But a high level of teacher control cuts into the sense of ownership and autonomy of the students. The risk of a student-directed approach is that students may not know how to structure their learning productively. Hence, they may miss critical learning opportunities (see Baker & Bielaczyc, 1995, for a discussion of "missed opportunities"). Most designs seek a balance between these two ends of the spectrum, usually with teacher support and scaffolding provided during the initial stages and continuing on an "as needed" basis, then fading as students acquire the knowledge and skills needed to direct their learning experiences.

The final issue is the coordination of on-tool and off-tool activities. On-tool activities are any activities carried out using the technology-based tool. Off-tool activities are activities carried out away from the tool. The blending of on-tool and off-tool activities serves several purposes. One is that the off-tool activities can help students see the generality of what they are learning with the technology-based tool and how it transfers to the real world. Another is to provide multiple modes for learning, particularly body-kinesthetics (as will be described later). In addition, integrating on-tool and off-tool activities can help ensure that students focus on the salient features of the tool by reifying concepts in different forms.

One example of the coordination of on-tool and off-tool activities comes from the work of Tabak and Reiser (1997) in classrooms using the BGuILE environment. The tool developers found that

> interacting with these environments may not be enough to help students develop understandings and ways of communicating that are consistent with scientific views. A support system that combines interactions with these environments with teacher–student interactions in both small group and whole class formats, provides more comprehensive support. (p. 294)

Working with teachers in the off-tool activities "can encourage students to attend to particular features of the environment, to reflect on their findings and to help students describe their conclusions in the language of science" (Tabak & Reiser, p. 295). The developers examined how to design the classroom environment in ways that would capitalize on the strategic scaffolds provided by the technology-based tool, the support that teachers can provide in a small-group format, and the sharing of interpretations that can occur at the level of whole-class discussions.

Another example of the coordination of on-tool and off-tool activities is found in TERC's collaboration with the developers of SimCalc (Noble, Nemirovsky, Cara, & Wright, in press). Developers at TERC designed offline activities to teach students about velocity and acceleration. One of the activities involved students walking at different speeds and dropping a beanbag at fixed time intervals, allowing them to see the relationship between walking speed and the spacing of the beanbags. This corresponded to the way SimCalc represents the velocity of different objects by displaying dots at different intervals. Such offline activities are meant to help students to see how the online representations capture features of the real world, and to create a body-kinesthetic relationship to the simulation's mathematics.

A critical aspect of the practices dimension concerns whether the design specifications for the activities and participant structures are *fixed* or *principle-based*. This refers to the level of adaptability explicitly designed into the set of practices. Sometimes the tool developers try to specify exactly how students will work in carrying out the designed activities. For example, the Carnegie-Mellon Tutors embed a fixed sequence of activities for students directly in the tutor design (Anderson, Boyle, & Reiser, 1984). In other cases, developers have tried to articulate a set of principles that characterize the goals and design rationale, so that teachers can implement the design in different ways. For example, in describing the design for Fostering a Community of Learners (FCL), Brown and Campione (1996) outlined the set of principles that the design is meant to embody, and suggested that different activities and participant structures might be used as long as they are consistent with the principles. By making explicit the principles underlying the design of learning activities and participant structures, the designers may enable teachers and students to adapt the designs in a more flexible manner, which may be useful in addressing the variations that can occur across classrooms.

Socio-Techno-Spatial Relations Dimension

The socio-techno-spatial relations dimension focuses on how the organization of physical and cyberspace support student interaction with the technology-based tool. The design considerations of the socio-techno-spatial relations dimension include (a) student–teacher–machine–physical-space configurations, (b) student–teacher–cyberspace configurations, and (3) cyberspace–physical-space relations.

Student–teacher–machine–physical-space configurations concern issues such as: Are the computers located in the classroom or the computer lab? If students are using handhelds or wearable technologies, do they remain with the students, or are they kept in a central location under the control of the teacher? What is the formation of the computers—rows, circular arrangements, wherever there is space in the room? Is there space for students to put learning materials beside the machines as they work? Where and what are teachers doing while students work online?

The simplest example of how this design aspect can impact the learning environment created around a technology-based tool comes in considering how the student–teacher–machine–physical-space configuration affects the ease with which students can access the technology-based tool and share their work. At Hennigan School where Papert (1980) and his colleagues worked for many years, a large number of computers were arranged in a circle in a foyer just outside the classrooms. Students could work individually, because there were enough computers, but they could also easily share their work with others or collaborate on projects, because there was enough space for students to gather around each computer (Harel, 1991). One of the critical ideas behind the BGuILE project is to provide students with the same types of tools that real scientists use (Reiser et al., 2001). However, one would expect differences in the quality of the learning experiences between two classrooms where, in the first, the machines are an integral part of the classroom structure and available for students to work with their scientific ideas versus, in the second, the machines are down in the school computer lab, only available by special appointment.

Differences also exist between contexts where a given technology-based tool is located on fixed-location computers as compared to laptops or handhelds (Roschelle & Pea, 2002; Soloway et al., 2001; Tinker & Krajcik, 2001). The increased mobility can affect accessibility as well as the sharing of ideas and engagement in coconstructed activities among students. Consider the differences in the quality of conversations that can take place concerning one's learning with a technology-based tool if the tool is readily available to guide the discourse or not.

The student–teacher–cyberspace configurations concern student and teacher formations within the cyberspace of the technology-based tool. This design aspect may not be relevant to all technology-based tools but is important in tools where student work is shared in common cyberspaces or students are able to interact online. Design issues to be considered include: Do students work separately or collaboratively in cyberspace? How are student products organized in cyberspace—for example, are they grouped into categories, indexed alphabetically, or randomly arranged? If student products are grouped categorically or hierarchically, how are such groupings determined? Is online work visible and/or accessible to all, or do students have private work areas in cyberspace? The design issues become much more interesting in virtual-world environments where avatars or virtual personas occupy cyberspace (e.g., Dede, Salzman, Loftin, & Sprague, 1999; Nelson, Ketelhut, Clarke, Bowman, & Dede, 2005). In such environments, designers need to consider how avatars are meant to interact and work together within the virtual world.

The teachers' use of the tool and their configuration in cyberspace is another important design factor. Are the teachers meant to get online and use the tool themselves or shape the online activities by working with students in the offline arena? For example, in virtual-world environments such as RiverCity, teachers could have their own avatar that participates with the students within the virtual space, or could coach students from "outside" the space. A critical design issue regarding teacher as coparticipant in the online space concerns authenticity. For example, in the Quill work (Rubin & Bruce, 1990) one teacher tried to participate in a bulletin-board writing activity by posing as a fellow student. The students in the class became confused due to the inauthenticity of the role she assumed, and as a result, they did not work toward the desired writing goals.

The cyberspace–physical-space relations concern ways in which students' physical world is brought into the cyberworld, and vice versa. Design considerations include: What are the trade-offs between using data captured from the students' physical world as compared to other sources of data? Is it helpful to bring student online work into offline forms? What are the affordances of the different means of displaying and interacting with student work? Elements from the students' physical world may be brought into the online environment for many reasons, including giving students more ownership or deepening their personal relationship to the online work. Further, the use of probeware permits the creation of activities incorporating body-kinesthetics. For example, tools such as SimCalc offer the possibility for students to use motion probes to transfer their actual movements in the physical world into representations in the cyberworld of the SimCalc environment (Nemirovsky, Kaput, & Roschelle, 1998; Roschelle, Kaput, & Stroup, 2000). Conversely, it is possible to bring work from the cyberspace of the technology-based tool into the physical realm of the classroom through projections onto a public screen, or simply paper printouts of online elements of student work. Printouts permit students to work on the materials away from the technology environment and also provide a method for displaying student work in low-tech forums. Printouts might also be used to improve the scannability of the online space in ways that might not be possible with the software interface. For example, Reeve and Lamon (1998) reported that teachers were having trouble "seeing" what was happening in their Knowledge Forum databases. So they printed out the contents to display on the wall for a better sense of the overall content and structure.

The Interaction With the "Outside World" Dimension

The interaction with the "outside world" dimension refers to the ways in which students interact, online and offline, with people outside of their immediate classroom context. There are three aspects of student interaction with the outside world that are important to consider: (a) bringing in knowledge from the outside (students as receivers), (b) extending the audience for student work (students as producers), and (c) interacting with others (students as both receivers and producers).

There are a number of ways that knowledge might be brought in from the outside. The students can use the Internet to find information or tools that are useful for their work. They can visit experts in their workplaces or have them come into the classroom (physically and virtually). For example, the past decade has seen a growth in the use of telementors (e.g., Bennett, 1996; Harris & Jones, 1999; O'Neill, 2001). One of the major advantages of drawing from knowledge resources outside of the classroom is that it breaks out of limitations on learning that occur as students get into areas of inquiry beyond what their teacher or local resources can handle. It opens up possibilities for building a deeper understanding, as well as developing the types of interactional and resource-gathering skills necessary to find and use external resources. However, Brown, Ellery, and Campione (1998) pointed out that difficulties can arise when the outsiders do not understand the classroom goals and culture, or the outsiders have subject-matter expertise but little experience teaching children. In such cases, their interactions with students may not be very helpful. In fact, sometimes students take expert comments as criticism, which dampens the students' enthusiasm for further effort. Designers may need to consider some type of training for people serving as outside resources.

The outside world may also be used to extend the audience for student work. Making presentations to a "real" outside audience can provide an important incentive for students to do a good job and to critique their own work. Reaching an outside audience gives students a sense that they are doing authentic work that the world might be interested in. They gain a better sense of purpose and motivation for the work. The outside audience may be active in responding to students' work, as when an audience is convened on a parents' night at the school, or work is posted on an interactive Web site. Alternatively, the outside audience may be more passive recipients, as when student work is part of a museum exhibit, a television show, or simply displayed on a Web site. However, even preparing for passive recipients can have learning benefits as when a museum exhibit of students' Lego LOGO creations forced students to clearly articulate the implications of their work to "unseen others" (Resnick & Rusk, 1996; Resnick, Rusk, & Cooke, 1998).

The interactions with the outside world can also be bidirectional. Students may use face-to-face or virtual means to exchange ideas with peers in other locations, or participate in a wider community (which may also involve adults) around a common tool or investigation. They might also form forums around strategies for how to use the technology-based tool itself (such as the NetLOGO exchange Web site where students might go to see how others are creating code for NetLOGO simulations[2]). Bidirectional interactions can motivate students to present their work clearly and persuasively and help them learn to listen to others' ideas and views.

Summary

The Social Infrastructure Framework highlights four dimensions of classroom social structures that play a critical role in integrating technology-based tools into classroom practice. Table 1 summarizes the Social Infrastructure Framework by showing the four dimensions, the design issues raised for each, and the kinds of questions associated with each issue. The goal of the present section was to make explicit the design variables that must be considered in going beyond the design of the technology-based tool itself to attend to the design of the social infrastructure. In the next section, I examine the ways in which the Social Infrastructure Framework can be used in carrying out design research.

THE ROLE OF THE SOCIAL INFRASTRUCTURE FRAMEWORK IN CONDUCTING DESIGN RESEARCH

There is an adage in the field of educational technology that "it's not the tool, it's how it's used." For the design researcher, it is critical to frame "how it's used" as a design issue: How should the environment be designed to facilitate the desired implementation of the technology-based tool? The scope of the design process must

[2]http://ccl.northwestern.edu/netlogo/models/community/

TABLE 1
Summary of Social Infrastructure Framework Design Considerations

Dimension	*Design Considerations*	*Example Questions*
Cultural beliefs	How learning and knowledge are conceptualized	How should the process of learning be viewed by teachers and students? What does it mean to “know”?
	How a student’s social identity is understood	How should students view their purpose in the learning environment? How are students meant to view each other—as learning resources, as team members, as competitors? Are students meant to develop expertise and skills consistent with professionals in the “real world”?
	How a teacher’s social identity is understood	How should teachers view their purpose in the learning environment? How are students meant to view the teacher? Are the teachers meant to be perceived as a fellow participant in the learning activities or as directors of the students’ activities?
	How the purpose of the tool is viewed	How should the purpose of the tool be viewed by teachers and students? How are students meant to use the tool to carry out the learning objectives? How is the tool meant to fit into the overall workings of the classroom?
Practices	The planned learning activities	Should activity selection be left open to students, semistructured, or tightly sequenced? Should all students carry out the same activities, or should the activities differ according to the needs of particular students? Should remediation activities be provided if students have difficulties? Should learning the functionality of the tool be a separate activity, or is the tool to be learned in the course of the broader set of activities?
	The associated participant structures of students	How are student groupings organized? In what ways are student interactions supported?
	The associated participant structures of teachers	Are the teachers meant to observe or intervene over the course of particular learning activities? What level of control do teachers take over the course of learning? How is teacher control balanced with helping students to learn how to direct their own learning experiences?

	The coordination of on-tool and off-tool activities	What is the relationship between on-tool and off-tool learning activities? Can off-tool and on-tool activities serve to reify concepts in different forms? Can off-tool and on-tool activities provide multiple modes for learning? Are there ways that offline activities can help students see the generality of what they are learning using the technology-based tool?
Socio-techno-spatial relations	Student–teacher–machine–physical-space configurations	Are the computers located in the classroom or the computer lab? If students are using handhelds or wearable technologies, do they remain with the students, or are they kept in a central location under the control of the teacher? What is the formation of the computers—rows, circular arrangements, wherever there is space in the room? Is there space for students to put learning materials beside the machines as they work? Where and what are teachers doing while students work online?
	Student–teacher–cyberspace configurations	Do students work separately or collaboratively in cyberspace? How are student products organized in cyberspace—for example, are they grouped into categories, indexed alphabetically, or randomly arranged? Is online work visible and/or accessible to all? Are teachers meant to get online and use the tool themselves or to shape the online activities by working with students in the offline arena?
	Cyberspace–physical-space relations	What are the trade-offs between using data captured from the students' physical world as compared to other sources of data? Is it helpful to bring online work into offline forms? What are the affordances of the different means of displaying and interacting with student work?
Interaction with the "outside world"	Bringing in knowledge from the outside	What sources of outside help might be useful? What is the best way to access such sources? What is needed to make the interaction successful (e.g., Is training of outside resource people necessary)?
	Extending the audience for student work	Will the outside audience be active in responding to students' work or passive recipients? What types of supports are required?
	Collaborating with others outside of the classroom	What will be the common activities of the co-collaborators? How will their interactions be structured? Will the technology-based tool itself be used to facilitate the interactions?

extend beyond designing the technology-based learning tool itself to encompass designing a classroom learning environment with the tool. To create a successful learning environment with technology in K–12 classrooms, designers have to consider a constellation of interacting educational factors:

- The software.
- The technical infrastructure and specifications of the hardware.
- The social infrastructure: the social structures that support learning with the tool.
- The ways in which learning with the tool fits into the curriculum and relates to standards.
- The teacher's knowledge of the functionality of the tool.

The list provided here is meant to highlight the critical factors designers must consider within the *local* classroom context. It should be noted that factors within the broader educational context (e.g., factors at the school, district, and/or community levels such as student socioeconomic status, school culture, and degree of parent involvement) also impact the creation of the desired learning environment. In fact, programs such as LeTUS attempt to work with design variables at these broader levels of the educational context (e.g., Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Fishman, Marx, Blumenfeld, & Krajcik, 2004).

Although I recognize that designing a classroom learning environment with a technology-based tool involves a design researcher in working with a system of factors, my focus here is on deepening our understanding of one specific component of the system, namely the social infrastructure. In discussing the role that the Social Infrastructure Framework can play in design research, I consider two central issues: (a) What process should design researchers follow to determine the specific elements of the social infrastructure for a given technology-based tool? (b) What form should the specification of such design elements take? Each is discussed, in turn.

The Process of Designing Social Infrastructure

We begin with the folowing question: What process should design researchers follow to determine the specific elements of the social infrastructure for a given technology-based tool? The Social Infrastructure Framework contributes to the work of design researchers by making explicit the classroom social structures that need to be specified in designing technology-based learning environments. The design elements and questions along the four dimensions of the Social Infrastructure Framework as shown in Table 1 can be used to direct a methodical approach to the design of the classroom social structures. To ensure consistency among the design elements of the learning environment as a whole, answers to the various questions in Table 1 should be guided by the goals of the designers and grounded in theories of learning and teaching.

What becomes immediately apparent is that, even when guided by design objectives and underlying theories of learning and teaching, the answers to many of the design questions associated with the Social Infrastructure Framework are not straightforward. For example, without empirical data it may be difficult to answer questions such as: How should student groupings be organized? Where and what are teachers doing while students use the tool? This is why the methodology of design research is critical. Design researchers test theoretical constructs through *embodied conjectures* in the design (Sandoval, 2004). Thus answering the design questions of a particular element of the social infrastructure is viewed as a conjecture to be empirically tested. Grounded in theoretical foundations, a design is created and then put into the world to see how it works. The design is then revised based on feedback from practice settings. Through progressive refinements of such embodied conjectures, design research is intended as a way to test out and optimize specific elements of the design. This is not meant to imply that this process results in a single correct design. Rather, this process of testing embodied conjectures may result in formulating fixed specifications or the development of a set of principles that guide the design of particular social structures. Further, the process should contribute to a deeper theoretical understanding as to why certain designs contribute to an effective learning environment.

One point to note is that there are already design studies concerning the integration of technology-based tools into classroom practice underway that were not implemented with such explicit specification of design decisions at the outset. In such cases, the Social Infrastructure Framework can be used to reverse engineer the decisions concerning the design of the classroom social structures. That is, the designs of particular social structures can be determined by mapping back from classroom implementations to the elements laid out in the framework. By identifying specific design elements and examining their relationships to the success or lack of success of a particular implementation, a design researcher can create hypotheses about the importance of a particular design variable within a dimension of the Social Infrastructure Framework, which can be further tested as an embodied conjecture in a new design iteration.

As an example, consider the extensive research and development program centered on Computer-Supported Intentional Learning Environments (CSILE) and its successor, Knowledge Forum (Scardamalia, 2001, 2002, 2004; Scardamalia & Bereiter, 1991, 1994). CSILE and Knowledge Forum have been integrated into numerous classrooms since the software was first prototyped in 1983. Knowledge Forum is currently being used in K–12 classrooms and university settings, as well as health care, community, and business contexts, across North America, Asia, and Europe. A corpus of papers and conference presentations detailing various classroom implementations has grown over the years (e.g., Bereiter & Scardamalia, 1992; Bielaczyc, 2001; Caswell & Bielaczyc, 2002; Chan, Lee, & van Aalst, 2005; Hewitt, 2002; Ow, Low, & Tan, 2004; Reeve & Lamon, 1998).

Whether implicitly or explicitly, as the Knowledge Forum developers and teachers integrate the tool into classroom settings, they make design decisions concerning classroom social structures. However, neither the developers nor the teachers have been explicitly guided by the Social Infrastructure Framework. What might we learn if we use the framework to reverse engineer the developers' and teachers' design decisions concerning social infrastructure? At the very least, looking at specific classroom implementations through the lens of the Social Infrastructure Framework would make such design decisions explicit and permit design elements across these settings to be classified into a common form, providing a systematic basis for comparisons and contrasts. This alone would be a powerful way to bring together this robust but disconnected corpus of work on Knowledge Forum classroom implementations. Further, some implementations have been more successful than others and the framework provides a systematic way to investigate the elements of the social infrastructure that may be contributing to such outcomes. In this manner, using the Social Infrastructure Framework to reverse engineer the design elements of social infrastructure can help formulate better informed decisions in subsequent design studies of Knowledge Forum.

An example of the usefulness of the Social Infrastructure Framework in generating hypotheses as to why particular designs of social infrastructure are more effective than others comes from my own research in Knowledge Forum classrooms. The example comes from a larger project focusing on teacher and student reflections on creating classroom learning communities (e.g., Bielaczyc & Blake, in press; Bielaczyc & Collins, 2005; Caswell & Bielaczyc, 2002), specifically my work with a team of sixth- and seventh-grade teachers who integrated Knowledge Forum into the daily rhythm of their classrooms.

The teachers worked at Whitman Middle School, a suburban school in the midwestern United States serving approximately 600 students in Grades 6 through 8. During the period of my research, the Whitman Team consisted of 4 teachers with classrooms of roughly 25 students each. The teachers and students stayed together for 2 school years, starting in sixth grade when the students first came to the Whitman Middle School and continuing through seventh grade. Knowledge Forum was a part of the learning environment throughout the entire 2 years. Each teacher on the team specialized in one subject matter area: math, science, social studies, or personal development. However, the Knowledge Forum investigations were independent of these divisions. Over the course of a school year, all students worked on the same research unit, with three research units covered each year.

In the seventh-grade year, students used Knowledge Forum to support the following research units:

- Fall Term: *Global Understanding*. Student investigations focused on countries from around the world.
- Winter Term: *World Religions*. Student investigations focused on six major world religions: Buddhism, Christianity, Hinduism, Islam, Judaism, and Taoism.
- Spring Term: *Astronomy* or *History of Technology*. Student investigations focused on either astronomy or the history of technology.

The Whitman teachers were continually experimenting with ways to help their students get the most out of working with Knowledge Forum. This resulted in variations in the social infrastructure across the three units. Using the Social Infrastructure Framework to reverse engineer the teachers' design decisions concerning social structures, I began to characterize how the elements of social infrastructure played themselves out across each of the units. My interest was in determining whether these variations affected student work in the Knowledge Forum databases. Because this wasn't an experimental study, it is not possible to be conclusive. But it is possible to make hypotheses about what factors of social infrastructure seem to be the important ones.

The Knowledge Forum database has what is called the Analytic Tool Kit (ATK), which permits users to run analyses on different types of activities in the database. I used the ATK with the Whitman Team databases to determine the level of student knowledge-building activity across the three units, Global Understanding, World Religions, and Astronomy/History of Technology. The data indicated that the most interactive knowledge-building activity was going on in Unit 2 (Bielaczyc, 2006). This led to examining the variations across elements of the social infrastructure to generate hypotheses about why the knowledge-building measures of Unit 2 were significantly higher than those of the other units.

For example, one of the variations in social structures involved variations in the design of the unit participant structures. The structure of participation for each unit is described in turn:

- Unit 1. Global Understanding: *Informal discussion groups*. In Unit 1, individual students investigated individual countries from the continents of Asia, Africa, and Europe. Roughly halfway into the unit, discussion groups were formed with students from similar regions within a continent (e.g., Northern Africa, Middle East). Although students in the regional discussion groups shared with each other what they were learning about countries in the region, there was no formal expectation to build a communal understanding of what was learned at the level of a continent, or the globe. The incentive to participate in the discussion groups came from classroom norms and personal interests.
- Unit 2. World Religions: *Jigsaw teams*. In Unit 2, students investigated a particular religion, namely Buddhism, Christianity, Hinduism, Islam, Judaism, or

Taoism, as part of a team. The teams had a jigsaw structure (Aronson, 1978). Each religion team had five students, with each student taking on one of five unique roles: anthropologist, historian, journalist, politician, and theologian. Across the religion teams, students in similar roles formed "common-roles" teams (e.g., the historian team). Students were expected to develop expertise in their own areas and then work together with the members of their religion team to form a collective understanding. Part of developing the expertise associated with a particular role involved working with other members of one's common-roles team to learn how the focus area played itself out in other religions (e.g., the historians were meant to work together to examine the historical traces across their various religions).

- Unit 3. Astronomy or History of Technology: *Topic teams*. In Unit 3, students worked in five- to eight-person teams to investigate various topics within astronomy or the history of technology (e.g., space exploration, planets). Each topic team determined a set of relevant subtopics, and each team member investigated a specific subtopic of interest. For example, members of one of the planet teams decided that each member would study a specific planet. As in Unit 2, the purpose was to create interdependency among team members. Students were expected to develop expertise in their own subtopic and then work together to form a collective team understanding. However, because each topic team worked independently to determine their subtopics, common subtopics across the teams were rare. Thus cross-team groups (such as the common-roles teams in Unit 2) were not formed.

Why might the variation in the design of unit participant structures across the three units explain the greater amount of student knowledge-building activities in Unit 2? Teaming can foster a sense of group identity and an incentive to engage in database interactions and communal knowledge building. In Unit 1, the regional discussion groups did not have the same formality and expectations of communal knowledge building as the team structures in Units 2 and 3. Unit 1 brought together students studying the countries of a continental region to discuss regional issues, whereas Units 2 and 3 set up a construct of "formal coinvestigators" into a common topic, with each student charged with an individual responsibility as part of the larger investigation. The notion of formal coinvestigators created specified resource people to help in one's own investigations and also provided a sense of responsibility to contribute toward group efforts to build a common understanding. Differences also existed between the team structures of Units 2 and 3. In Unit 2, the interaction patterns extended across all of the teams through the interlocking structure of the jigsaw, whereas in Unit 3 the interactions tended to stay within the individual topic teams. The reason the jigsaw might have led to the higher interaction patterns is that students were part of multiple teams. So one might expect the interactions fostered by teaming to be amplified within the jigsaw structure.

Although the Social Infrastructure Framework was not part of the original design process, use of the framework permits the design of social structures to be made explicit for investigation. Looking at the variation in the unit participant structures across the three research units and their relation to the greater knowledge-building activities of Unit 2 permitted a way to gain a better understanding of the role these social structures may be playing. Clearly, one should not simply conclude from such an analysis that the jigsaw participant structure should be used in all implementations of Knowledge Forum. A possible next step is to analyze the participant structures of other implementations of Knowledge Forum in relation to outcome measures to gain a deeper understanding of the role such participant structures play in classroom implementations of Knowledge Forum. It is also critical to gain a deeper understanding of the classroom contexts and why the particular participant structures are used. The idea is to build a robust understanding of this element of the social infrastructure to generate well-informed hypotheses that can be tested as part of a process of progressive refinement in carrying out design research.

Design research is intended as a way to test out and optimize specific elements of the design. The Social Infrastructure Framework introduces a new set of variables into the analysis process that design researchers must undertake in carrying out progressive refinements of a design. The framework is not meant as a rigid checklist but rather as a guide to critical design variables to be considered in creating the relevant social structures for a given technology-based tool. My colleagues and I have described elsewhere the methods used by design researchers to analyze the multiple variables involved in progressive refinement (Bielaczyc & Collins, in press-a; Collins et al., 2004). The central point for the present discussion is that whether it is used from the initial design stages or as part of a reverse-engineering process in a design study already underway, the Social Infrastructure Framework organizes this process of progressive refinement in a systematic way.

Specifying Social Infrastructure in Terms of Implementation Paths

Although the Social Infrastructure Framework indicates which elements to consider in designing the social infrastructure for a given technology-based tool, it is also important to consider what form the specification of such elements should take. One particular form is that of *implementation paths*. An implementation path is conceived of as a trajectory that teachers traverse in moving from an initial state of introducing the subject matter and skills of a new curriculum or a new technology-based tool to more sophisticated student engagement in the curriculum or in working with the tool (Bielaczyc & Collins, in press-b). With regard to integrating a new technology-based tool into classroom practice, this trajectory involves more than gaining familiarity with the functionality of the tool itself. Advancing toward effective use of a tool may require shifting the mindset of students, engaging students in new types of learning activities, and moving toward new means of interaction among students and others outside of the classroom. For example, many of the current technology-based tools for science learning are premised on the model of students as members of a scientific community (e.g., BGuILE; Reiser et al., 2001; RiverCity; Nelson et al., 2005; ThinkerTools; White, 1993, 1995). In such a model, students are meant to view themselves as investigators of scientific phenomena. Students in the class depend on what other students learn and share with them. However, operating in this way is quite different from the traditional science classroom, and students will need to be supported in making a shift from traditional approaches to science learning if they are to use these tools effectively.

A given classroom has a social infrastructure—whether explicitly articulated or not—that guides its workings prior to the introduction of a technology-based tool. The types of social structures that are necessary for the successful integration of a given technology-based tool may "go against the grain" of regular classroom functioning. Designers need to consider not only the types of social structures that they want to cultivate but also the current social infrastructure of a given classroom context, along with the methods and trajectory of change. Consistency is important, and classrooms that attempt to change aspects of the social infrastructure for only a short period per day or a short period during the course of a school year may have a difficult time creating a successful learning environment. Providing sufficient time for any needed changes to occur is a critical design factor.

The reason that an implementation-path conception of design may be useful can be further understood by examining the limitations in the way that the elements of social infrastructure for a given tool are typically specified. One problem is that when a new technology-based tool is described in the literature or in accompanying documentation, it is usually portrayed in terms of its most effective use. Hidden from the reader are the problems and failed attempts in constructing the means necessary to support the most effective use of the tool. Further, professional development materials tend toward a best-practices approach depicting optimal uses of the tool. There is clear value in a best-practices approach. Showing the best practices allows teachers to see the desired goal states, giving them a sense of the direction they are able to take their students in using the tool successfully. The ability to see what other teachers have accomplished with the tool and the accompanying student outcomes can be very motivating. However, such literature and professional development materials tend to focus solely on the end states and to project a sanitized a view of what is involved in successfully using the tool with students. This often leads to surprise and frustration for teachers when they discover that implementing the tool with their students does not go as smoothly or as quickly as such materials imply. A better approach would be to specify the design of social infrastructure in terms of a trajectory or a progressive set of phases that teachers need to move through with their students to progress from initial to effective use of a technology-based tool.

Based on the elements of the Social Infrastructure Framework, the trajectory milestones and advancement strategies would include

- *Cultural beliefs.* There is a need to specify what steps teachers and students should carry out to move from the traditional conceptualization of classroom knowledge and learning (where students typically are intended to assimilate basic knowledge and skills by reading, listening, and doing exercises) to the conceptualizations appropriate to the technology-based learning environment.
- *Practices.* There is a need to specify what sequences of practices and participant structures will build up the skills and knowledge necessary to participate in the technology-based learning environment. This might include specifying offline activities that prepare students for the online activities and/or illustrate how both online and offline activities are to be integrated over time.
- *Socio-techno-spatial relations.* There is a need to specify different ways the technology might be arranged in the classroom and among the teachers and students, and how the arrangements evolve over time.
- *Interaction with the outside world.* If the tool involves students in interacting with adults and students outside the classroom, then there is a need to specify how to help students acquire the skills to do this effectively over time. It may also help to guide mentors and/or collaborators in how to interact with students.

In this manner, teachers can be provided with more than a final or sanitized description of the tool's use with respect to the dimensions. The Social Infrastructure Framework can be used to structure the stages they should expect to go through to reach effective tool use along with a set of strategies for advancement.

An example of specifying elements within the practices dimension of the Social Infrastructure Framework using an implementation path approach comes from the ThinkerTools environment (White, 1993, 1995; White & Frederiksen, 1998). ThinkerTools is designed to teach scientific inquiry in the context of Newtonian mechanics. The environment is composed of a set of microworlds, where students are able to test out various mechanics concepts. Typically, the microworlds provide students an opportunity to control a moving object by giving it impulses in a particular direction. The object moves faster or slower depending on the number of impulses given and their direction. The object leaves behind dots at regular time intervals, so that the speed of the object is reflected in the distance between the dots. The microworlds also contain various representations corresponding to the movement of the object, such as a data cross that represents the moving object in terms of real-time vector components and graphs showing the object's velocity over time.

Over years of working with teachers to use ThinkerTools in classrooms, the tool designers have developed an activity sequence meant to support students through progressive stages toward effective use of the tool. The students start out with a set of activities in which they attempt to control the motion of the object in a one-dimensional microworld, with and without friction, before moving to a two-dimensional microworld. When the students have mastered the activities in two dimensions, gravity is added to the mix so that students can analyze trajectories. A typical activity might be to get the object to move within the confines of a path and stop at a particular point in the path, using only impulses in the horizontal and vertical directions.

Another aspect of the sequencing of activities involves an activity cycle built into each of the microworlds. First, the students are posed a motivational question, such as, "What will happen if a stationary object is given an impulse in one direction and then given an equal impulse in the opposite direction?" Different students will have different answers, with some suggesting the object will slow down, and others saying it will stop, or move in the reverse direction. After they have made their conjectures, they carry out the experiment in ThinkerTools to see the outcome. After they have worked a number of problems, they try to develop formal rules to characterize the object's behavior, such as, "Whenever you give an object an impulse, it changes speed." They then try to decide which rules are correct and which are most general and useful. Finally, they carry out experiments with objects in the real world, where friction is minimized, such as on an air table.

When students have worked with the basic motions and the concept of testing conjectures, the ThinkerTools curriculum introduces them to an inquiry cycle, which is presented as a sequence of goals to be pursued. The students start by formulating a research question. They then generate alternative hypotheses related to their question. Next, they design and carry out experiments in which they try to determine which of their hypotheses, if any, is accurate. They carry out these experiments in the context of both the computer simulation and the real world. After the students have completed their experiments, they then analyze their data and try to formulate a model to characterize their findings. Once the students have developed their model, they try to apply it to different real-world situations to investigate its utility and its limitations. Determining the limitations of their conceptual model raises new research questions, and the students begin the inquiry cycle again.

In this phased manner, the ThinkerTools curriculum carefully stages student activities, progressing through a series of microworlds, into practice in testing conjectures, and culminating in working with an inquiry cycle. In the process, students initially learn the basic operation of the microworlds and how to carry out simple investigations, and over time, progress to learning how to map between the simulation, the more abstract representations included in the microworld (such as the data cross and graphs), and the real world.

Although meant to highlight useful aspects of an implementations path appproach, the example is limited in scope. Clearly there is a need for further research to detail the content of implementation paths and the process of their construction more fully. Such research will need to determine the form and means of representation necessary to communicate the trajectory milestones and strategies. Further, there is a need to better understand how progress along one dimension of the Social Infrastructure Framework promotes or detracts from progress along other dimensions. Research will also need to explore ways in which features of the technology-based tools themselves can be designed to support progress along the implementation path.

CONCLUSION

The Social Infrastructure Framework highlights critical design considerations concerning classroom social structures such as beliefs about learning and knowledge, learning activities and their associated participant structures, and configurations of both physical space and cyberspace. The framework is meant to aid the work of design researchers by making explicit an important set of variables that need to be considered in testing out and optimizing the design of a classroom learning environment with a given technology-based tool. Only by understanding the critical variables involved is it possible to develop a deep understanding of how and why things work.

There is value in using the Social Infrastructure Framework as both a design tool and an analytic tool within design research. As a design tool, it can be used to extend the scope of the developer's design beyond the technology-based tool itself to include the specification of critical elements of the classroom social structures. This is not to say that there is one single way to design the social infrastructure, but rather that understanding the success or lack of success of a design is greatly improved when such design decisions and their theoretical underpinnings are explicitly investigated. As an analytic tool, the Social Infrastructure Framework can be used in the evaluation of a classroom implementation of a technology-based tool. As part of the design research methodology, this includes tracing the initial design elements of the social infrastructure throughout the multiple phases in the progressive refinement of the design. As both a design tool and an analytic tool, the Social Infrastructure Framework helps to specify which variables the researchers should be paying attention to as they create measures to assess the effectiveness of a design in classroom settings.

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