

Getting in on the (Inter)Action: Exploring Affordances for Collaborative Learning in a Context of Informed Participation

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ABSTRACT

Although considerable attention in the CSCL community has been on distributed-, Web-, or distance-learning applications, there is evidence suggesting that much of learning, particularly in open-ended problem-solving activities based on tacit information, does not occur in isolation but in face-to-face settings. This has led our research to explore ways to develop technologies and media that enhance participation, collaboration, and learning in face-to-face, copresent settings.

This paper explores the history of our research on developing such technologies in the context of our Envisionment and Discovery Collaboratory at the Center for LifeLong Learning & Design at the University of Colorado at Boulder, and discusses my research on interface design to support learning and participation in collaborative settings.

Keywords

Interface design, augmented reality, atoms and bits, participatory design, face-to-face interaction

INTRODUCTION

Considerable attention in the CSCL community has been on distributed-, Web-, or distance-learning applications. Certainly, it is appropriate to explore the new landscape that is opened by the removal of barriers of required copresence, and to understand the far-reaching implications of ready access to widely dispersed sources of information. However, there is evidence suggesting that much of learning, particularly in open-ended problem-solving activities [Arias, 1996] based on tacit information [Collins et al., 2000], does not occur in isolation but in face-to-face settings. Indeed cooperative learning advocates Johnson and Johnson include face-to-face interaction as one of the key features of their approach in which students discuss, teach, and explain to each other in promotive ways that "assist, encourage, and support each other's efforts to learn" [Johnson & Johnson, 1994]. Although it is may be possible to support such interaction at a distance, my research is exploring ways to develop technologies and media that enhance participation, collaboration, and learning in face-to-face, copresent settings.

Often the ability to access new, abundant stores of information is seen as a major breakthrough. However, for learning situations where the answer does not exist, access to all existing answers may be of little use. This is particularly true when the information needed to resolve a problem is tacit—part of the life experiences of multiple individuals who are impacted by the problem or may have crucial insights to bring to bear. Our work focuses on design problems that are typically "wicked" [Rittel & Webber, 1984]—ill-defined, ill-structured, unique, no completion criteria, no single "right" answer, large universe of solutions and potential steps, each problem may be a symptom of another problem, and whose solution path is strongly influenced by framing. Resolving such problems involves drawing on various viewpoints and perspectives and requires collaborative learning where participants learn from each other. In such situations, access to information alone is not sufficient [Arias et al., 1999].

It is also important to realize what the goals are for learning in a particular situation. Whereas much learning is focused on acquiring the skills and expertise necessary to operate within a domain in some competent, expert, or professional role, there are many situations where the goals for learning are quite different. Music appreciation does not necessarily have the goal of nurturing musicians, but of allowing people to enjoy the context, history, and to recognize various forms of music. Science and Technology Literacy has the goal of allowing a broader segment of the population to make these domains meaningful to their everyday lives—not necessarily to "do science." Our research has been exploring ways to support and encourage a similar form of learning in the area of citizen participation in decisions that affect their lives.

A CONTEXT FOR CITIZEN PARTICIPATION IN DESIGN

How can more than 261 million individual Americans define and reconcile their needs and aspirations with community values and the needs of the future? Our most important finding is the potential power of and growing desire for decision processes that promote direct and meaningful interaction involving people in decisions that affect them. Americans want to take control of their lives.[PCSD, 1996]

For citizens to have greater say within their community and for communities to benefit from the valuable insights that its citizens have to contribute, individuals need to become engaged in activities for which they have often had no training and in which they may have no desire to act in an expert or professional capacity.

Focus: Informed Participation

The key challenges for moving toward new forms of citizen participation include (a) addressing the paradox that citizens cannot really be informed unless they participate, yet they cannot really participate unless they are informed [Brown et al., 1994]; and (b) understanding that participation has limits that are contingent on the nature of each citizen's situation, the issues, the problems, and the institutional designs [Arias, 1989], as well as the available technology and media. However, a benefit of coming to grips with these challenges is that informed participation leads to ownership and a stronger sense of community.

Collaborative work vs. collaborative participation

Much of the focus on computer-supported collaborative work has been on using technology to support existing work cultures, i.e., communities of practice (CoPs) [Brown & Duguid, 1991; Wenger, 1998], which consist of practitioners who work as a community in a certain domain undertaking similar work. Some examples of CoPs are architects, urban planners, research groups, and software developers.

Even approaches aimed at interdisciplinary activities have tended to proceed from the assumption that those engaged in the activity are highly skilled in their respective field. However, the goal of collaborative participation is often different. Communities of interest (CoIs) [Fischer, 2001] bring together stakeholders from different CoPs, as well as those who may not be members of any established CoP to solve a particular (design) problem of common concern. Two examples of CoIs are (1) a team interested in software development that includes software designers, marketing specialists, psychologists, programmers, and users; and (2) a group of citizens and experts interested in urban planning who are concerned with implementing new transportation systems.

CoIs are characterized by their shared interest in the framing and resolution of a design problem. CoIs often are more temporary than CoPs: they come together in the context of a specific project and may dissolve after the project has ended. CoIs have great potential to be more innovative and more transforming than a single CoP if they are able to exploit the "symmetry of ignorance" [Rittel, 1984] as a source of collective creativity. Although there is a need to become informed about a domain in order to participate in design, decision-making, and input-giving processes, the goal is not generally to become more of an expert in the domain nor to become a member of the culture of the domain. The goal is to gain enough of an appreciation for the domain to be able to communicate with members of that culture while retaining the valuable views and perspectives from the participant's culture.

Fundamental challenges facing CoIs are found in building a shared understanding of the task at hand, which often does not exist at the beginning, but is evolved incrementally and collaboratively and emerges in people's minds and in external artifacts. Members of CoIs must communicate with and learn from others [Engeström, 2001] who have different perspectives and perhaps a different vocabulary for describing their ideas. Learning within CoIs is more complex and multi-faceted than *legitimate peripheral participation* [Lave & Wenger, 1991] in CoPs, which assumes that there is a single knowledge system towards whose center newcomers move over time.

Learning in CoIs requires *externalizations* [Bruner, 1996] in the form of *boundary objects* [Star, 1989] that have meaning across the boundaries of individual knowledge systems. Boundary objects allow different knowledge systems to interact by providing a shared reference that is meaningful within all systems. Computational support for CoIs must enable mutual learning through the creation, discussion, and refinement of boundary objects that allow the knowledge systems of different CoPs to interact. The interaction between multiple knowledge systems is a means to turn the symmetry of ignorance into a resource for learning and social creativity.

A BRIEF HISTORY: EXPLORING SUPPORT FOR INFORMED PARTICIPATION

We have found that an effective approach for understanding how to support participation is to look at other domains and how they have approached the problem. One of the foundations for our work on supporting collaborative participation is in the approaches pioneered by our urban planning colleague, Ernesto Arias, in the creation of physical simulations and games for use in fostering community participation and as learning tools for students in that domain [Arias, 1994].

Although our work focuses primarily on the processes our technologies must embody and interact with in order to support informed participation, it is impossible to create systems that operate solely at that abstract level. What we need is the context of a specific design domain to act as an "object to think with" and allow us to build a particular concrete instances to demonstrate the ideas and goals of our approaches. Urban design and planning is an ideal domain for this purpose as it gives rich domain content and environments as well as models of processes for design, problem solving, and interaction among people.

Physical Simulations & Games in Urban Planning



Figure 9: The Cole Neighborhood Redevelopment Project

As early as 1984 [Arias, 1984], this research recognized that early phases of design operate with what are known as *potential environments*—abstract representations of “the way things could be” such as plan drawings and maps that experienced designers manipulate with considerable ease. However, involving user communities in the design process requires communicating these potential environments to those communities who may not be as skilled at working with these abstract representations. This approach began to use *effective environments* to address this problem. (In the planning literature, the term “effective environments” connotes physical and social environments *as people experience and define them*. This is not a claim that these environments are effective for some specific goal.) Whereas physical models have been used extensively to display potential environments, they were not generally used as effective environments—to draw participants into interaction with the models and with each other and to support new forms of learning and creativity.

There are many examples of this approach—a notable example is the Cole Neighborhood Redevelopment Project [Arias, 1996]. In this project, models of the neighborhood were collaboratively constructed providing citizens a way of participating in the design process by interacting with problem through physical models (see Figure).

There were some limitations for this environment. It included computational support through a geographical information system (GIS) “on the side;” however, it was not integrated into the model. This caused a change in focus from the face-to-face interaction around the model to the GIS when issues appropriate to that system arose, resulting in a cognitive interruption. The system provided no means to model the dynamics of the neighborhood or the design process.

Information generated in the process of the design sessions had to be manually gathered and recorded, which limited the ability to reuse and build on previous work.

The unique nature of each neighborhood required construction of a new model to match that particular situation. However, the creation of effective environment models can be viewed as developing languages of design that support human-to-human interaction, similar to Alexander’s pattern language approach [Alexander et al., 1977]. From this perspective, many components and issues specific to these neighborhoods can be generalized and used to support learning in community, classroom, and design studio settings. This led to the creation of games that modeled the processes that took place (in the form of game rules) and reused the languages (the game pieces) that were developed in the neighborhood settings.

The Mr. Roger’s Sustainable Neighborhood board game [Spencer et al., 1997], developed by urban design students, is an instance of such a game (see Figure 8). By abstracting issues from real situations such as Cole neighborhood, the game confronted players with decisions on the social, economic, and environmental decisions that are faced in addressing issues of neighborhood development. In this game, participants take turns navigating through the neighborhood and are presented with various community design decisions (should a parking lot be added here, should a neighborhood focus be created there) that the players address as a neighborhood team.

The game supports learning in that it exposes students to issues of community development and to the challenges of achieving

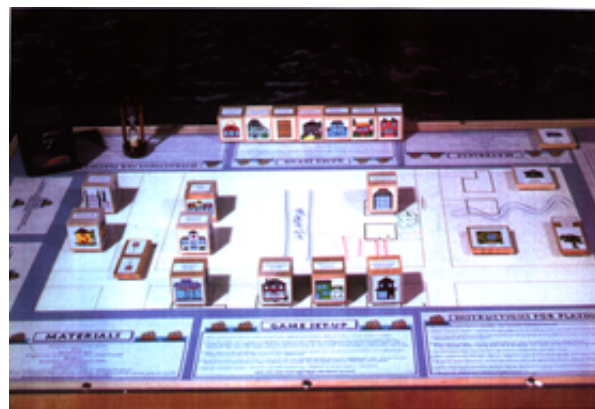


Figure 8: Mr Roger's Sustainable Neighborhood board game

consensus in a community. However, the game situations are static and there is no support for extended exploration of the issues facing the players, which limits learning potential.

Computational simulations

As we began to explore how computational media might learn from and contribute to this work, an initial effort was made to explore how computational simulations could be used to enhance the board game approach. As a result, the Mr Roger's Sustainable Neighborhood simulation game [Perrone et al., 1997] was created (see Figure 9). The game board became a dynamic simulation that updates neighborhood situations based on decisions made by the players. Web support allowing the players to explore information and argumentation related to the issues they face enhances the learning experience.

However, the face-to-face, around-the-table nature of the board game was displaced by a computer environment that more naturally supports one person "driving" while others look over that individual's shoulders.

Based on the experiences and observations from creating these physical and virtual environments, we determined that it would be useful to develop an approach to draw on the complementary nature of the strengths and weaknesses of both forms of media (see Table 4).



Figure 9: The Mr. Roger's Sustainable Neighborhood simulation game

worksurfaces and projection systems could be used to accomplish our goals, we developed the EDC (shown in Figure 10). By using a horizontal electronic whiteboard, participants work "around the table," incrementally creating a shared model of the problem. They interact with computer simulations projected onto the worksurface by manipulating the three-dimensional, physical objects that constitute a language for the domain [Arias, 1996; Ehn, 1988]. The position and movement of these physical objects are recognized by means of the touch-sensitive projection surface. In Figure 10, users construct a neighborhood through the use of a physical language appropriate for the problem by placing on the worksurface. This construction is a description of the setting of concern to the stakeholders and becomes the boundary object through which they can collaboratively evaluate and prescribe changes in their efforts to frame and resolve a problem. In the upper half of Figure 10, a second vertical electronic whiteboard presents information related to the problem-at-hand for exploration and extension. In the figure, a user is filling out a survey constructed from the model presented on the horizontal worksurface. The results of this survey are stored (for future exploration) and are also fed to the simulation, where the ramifications of the decisions specified in the survey can be explored. This work is described in more detail in [Arias et al., 2000] and more issues related to this paper are discussed in [Arias et al., 1999].

The Envisionment and Discovery Collaboratory (EDC)

After some initial experiments with how horizontal



Figure 10: The Envisionment and Discovery Collaboratory

Table 4: Complementary strengths and weaknesses of physical and virtual environments and associated implications for learning (based on [Arias et al., 1997]).

Weaknesses of Computational Simulations	Complementary Strengths of Physical Games & Simulations	Potential learning support through combination
user must learn and work the interface	direct, naïve manipulability and intuitive understanding	from learning about the interface to learning about the domain and the problem
(sans haptics) little or no tactile feedback	tangible, tactile interaction	manipulative learning
individual interaction with computer the usual focus (either each with own computer or one person driving shared system)	mediation of communication and social interaction through 1. common focus 2. forms of “body language” in manipulation of physical	social interaction and collaborative learning
complex modeling needed to realize all constraints	natural constraints of physical objects (boundaries of the physical enforced)	constraints can provide structure to learning, can point out conflicts
Weaknesses of Physical Models	Complementary Strengths of Computational Simulations	
models passive, static representations, behavior not easy to visualize, all interpretation of meaning and dynamics by users	well-suited for dynamic models and visualization of behavior	learning aided by dynamic models and visualization
automatic feedback on consequences of decisions not provided	dynamic models can reflect the results of decisions	learning by understanding consequences of decision
fidelity to reality limited due to problems such as scaling. Alternate realities not easy to model	virtual models can span scales and constraint systems	learning effects of scale and interactions between levels of scales, learning in alternate realities, relaxed constraints
management and capture of information is difficult	can capture information and design results for analysis and future use	assessment tools, seeds for learning can be built upon, evolved, and reseeded

Informal assessment of the EDC.

We have used this system in numerous demonstrations of our work to transportation planners, urban designers, community members, researchers, and other visitors. The current state of development both at an overall system level and from the standpoint of low-level interaction has made it impractical to deploy in realistic settings as was our initial goal. However, in the context of our demonstrations, we have engaged the observers as pseudo-participants asking them to perform some basic design interactions and have observed several aspects of the interaction that pose limitations to the usability of the system. These observed limitations include

- The touch-screen technology of the SmartBoard was designed for single-user-at-a-time (single cursor) interaction. This required that users take turns (simultaneous actions created error situations, e.g., a row of houses between the two touches rather than just two single houses).
- The use of an interaction style characterized as “select-object/select-action/perform-action” causes the user to have to “work” the interface. This led to frequent “mode” errors [Lewis & Norman, 1986] (e.g., the user tried to delete an object when the “add” mode was active). Certainly, there are alternate interaction techniques that could lessen the overhead for the users, but the single-cursor limitation still requires that a linkage be made between the physical cursor and the current virtual object and allows only one object type to be active at a given moment.
- The user had to take explicit action to make the physical-virtual connection by pressing the object onto the touch screen rather than just placing it on top of it.
- Taken together these require the user to have a more abstract mental model of the interface to guide how they interact with the system. Often this model is separate from their model of how the domain object being manipulated should behave. Although individuals who are continuously engaged in these sorts of activities may be willing to learn this model as they work with the system, participants who have limited exposure to the system may not have the opportunity to form that model and may be left out of interaction. The challenge is to make it more accessible to them.

FOCUSING ON INTERACTION ISSUES TO PROVIDE ACCESS FOR LEARNING

As Table 4 describes, there are many ways that the blending of the physical and the virtual could create improved interaction for learning. Based on our assessment of the EDC, the most critical aspects necessary to make that environment available to users in realistic situations is to make the interface more accessible to participants. Specifically, the advantages of physical elements for naïve manipulability and mediation of communication will be the focus for the remainder of this paper. Others of the issues raised there are discussed elsewhere (e.g., [Scharff, 2002]) or will form the basis of future work.

Using a DGT Electronic Chessboard, we have created prototypes of the Participate-in-the-Action Board (PitA-Board, see Figure 11). The underlying technology consists of an 8-by-8 sensor grid that can determine the location and identity of 15 distinct transducers.

The new forms of interaction support that this technology provides include

- Multiple “points of control” rather than a single interaction cursor.
- Sensing pieces automatically when placed on board (rather than needing to explicitly press the piece onto the surface).
- Parallel interactions (rather than single-threads of interaction and errors when multiple simultaneous accesses are attempted)



Figure 11: The PitA-Board

These interaction capabilities form the basis for our initial investigation into direct and natural interaction techniques aimed at improving accessibility to our simulation environments.

Naïve manipulability

Utilizing the multiple “points of control” provided by the PitA-Board allows us to create a broader repertoire of direct interaction styles more closely tuned to the type of domain object being represented. For example some interactions that might be useful in the domain of transportation are

1. Tracking behavior: the virtual representation follows the physical piece (this could represent an individual moving through the space or an object whose location is subject to change)
2. Placing (Rubber stamp) behavior: placement of physical piece creates a virtual representation that remains when physical piece is removed (used to place items with known, fixed location—a house, store, or school)



Figure 12: This multiple-exposure photo shows the user tracing out a bus route (enhanced for clarity) using a bus-route-drawing object.

1. Drawing behavior: piece is used to trace out a series of points that make up the object being created. (e.g., a road, a bus route—see Figure 12)
3. Launching behavior—placing a dynamic item: the physical piece indicates the initial location of an object that has dynamic behavior—if appropriate, the virtual object begins its dynamic behavior from that point. (e.g., bus, auto)

In addition to the interaction attached to domain-grounded objects, there will still be the need for interaction pieces that support control or inspection of the environment. For example, by having some virtual representations that no longer have corresponding physical pieces (such as a “placed” object) means that there needs to be some way to indicate that the virtual representation needs to be removed when it is no longer needed, which might require an “eraser” piece. A magnifying glass may be useful in some contexts to examine the attributes of an object.

The underlying idea is that the system allows the creation of affordances that are more natural to the situation being modeled and the design process being supported by the technology. The examples that are given here are only for purposes of illustration and were developed in an ad hoc manner (though based on observation of prior interactions) to demonstrate the concept. Future work will involve interaction with use communities to determine what affordances are best suited to the needs of users and to develop a repertoire of objects for a particular domain.

Mediation of Communication

In Arias' work with physical games and models it was observed that the physical pieces often become extensions of the speaker, allowing the speaker to provide emphasis or to extend her/his body language. In the hybrid environment, we envision that interaction using physical objects will allow the speaker to project that sense of extension into the virtual space.

By supporting a group interaction with the simulation, it is no longer just a user-computer interaction, but the environment becomes a form of media supporting conversations among participants (i.e., human-human communication mediated by the artifact) as well as collaborative "conversations with the material." [Schön, 1992] In this regard, the ability to interact in parallel becomes an issue. The question could be raised whether a conversational paradigm really requires parallelism and that problems with that aspect of the current interface might not be better mitigated by using concurrency control (e.g., locking or other turn-taking approaches).

Certainly, a top-level view of the conversational paradigm is one of turn taking based on a need (especially in larger groups) to avoid everyone talking at once so that participants can hear and be heard. However, a finer-grained inspection of conversations reveals that they are not strictly based on turn taking. Sometimes there are back-and-forth volleys as meaning and understanding are negotiated and grounding is achieved [Clark & Brennan, 1991]. Extra-verbal utterances (gestures, nods, shrugs, hyphenated glances) certainly happen without turn taking—and are also important parts of conversational grounding.

Furthermore, not all group interaction is conversational—there may be situations in which participant input could happen in tandem (e.g., a group leader asks everyone indicate where their house is in the neighborhood and each person places their house).

It seems that the goal for interaction with the computational environment is to match the characteristics of the interface/medium as closely as possible to the characteristics of the rest of the face-to-face environment. It is highly doubtful that anyone would bring a group of people into the same room and then ask them to use the telephone to talk to each other. The availability of parallelism provides a means to tune the interaction to the needs of the situation but does not imply that all interactions must occur in parallel.

Emerging opportunities for future evolution

The development of new ideas and approaches are generally accompanied by corresponding limitations that need to be acknowledged and understood. These limitations do not necessarily represent flaws or barriers to the use of this approach, but need to be understood as opportunities for further development and evolution.

By introducing multiple physical objects into the interface, they now have to be kept track of (where did that bus-drawing object go...?). In a completely virtual environment, the palettes organize tools and objects very neatly so that they, as well as the single physical object (the mouse), are generally easy to keep track of. A possible solution might be to create a "storage tray" to organize and keep track of the items.

This could also impact how many interaction objects one could manage. For example, in virtual palettes, there can be techniques, such as pop-ups or multiple palettes that provide access to a large number of tools/objects. Attempting to provide more and more features under this approach would create an unmanageable proliferation of physical cursor objects. On the other hand, the general goal of our approach is not upon an "experts" interface where every feature that anyone ever wanted is available—rather on a participant/learner interface, where the features important to the task at hand are there and directly accessible.

One could also argue that this approach violates some well-known principles of interface design, such as consistency of interaction: Why does this piece have one sort of behavior and another act differently? As I have discussed, I believe this is a desirable feature, but I would think that careful application of this feature—matching the behavior with the sort of object represented—is critical to its success.

There are also limitations based on the specifics of the "borrowed" technology. Since it was designed specifically as a chessboard, the granularity of resolution is coarse. Even so, the interface appears to be surprisingly effective. This may be because the interactions of groups in design settings are usually not focused on fine-motor tasks. The grid technology also produces dead spots when the piece is at the edge of a square or placed between two squares, which is problematic in our

system since the domain being modeled may not fit as neatly into a grid representation. The current system has a limited number of distinct sensors, which makes it difficult to have a large number of objects and track them reliably.

In our current system, we have tried to emphasize the grid outline to decrease the occurrence of problems, but it is not completely successful. These experiences with limitations will serve to guide future developments to better meet the goals that we have for participant interaction.

Related Work

Although the focus of this paper has been on the history and development of our current research and its implications for learning, it is important to acknowledge that it has been strongly influenced by a broad, rich research landscape. The perspective of ubiquitous computing movement [Abowd et al., 1998; Weiser, 1991] toward “breaking out of the desktop box” gave an initial, powerful impetus to think about how physical models could be enhanced by computation in varied ways. The importance of the tangible nature of physical interaction and its interaction with computations is underscored by the tangible media [Ishii & Ullmer, 1997] and graspable interfaces [Fitzmaurice et al., 1995] work. There are many efforts underway to address issues related to shared interfaces such as the Collaborage [Moran et al., 1999] and DiamondTouch [Dietz & Leigh, 2001] projects.

CONCLUSIONS:

This paper presents some promising approaches to interaction that focus on needs of face-to-face interaction among a group of users. Although it has been based on multiple prototyping cycles, there is still a need for closer evaluation and evolution with user communities. Limitations that we have encountered have resulted in tradeoff decisions, but strong initial indications that this may be well suited to face-to-face participant interaction.

Future work on this system includes assessment in more realistic settings using role-playing scenarios and application to actual community settings (e.g., the design of a new local bus route). Throughout these interaction with use communities there will be continued evolution of interaction techniques and studies of how the evolving systems supports participation and learning.

ACKNOWLEDGEMENTS

I would like to thank Gerhard Fischer, Ernesto Arias, Andy Gorman, Eric Scharffe, and Kyle Bygott for their collaboration in the development of the EDC concepts and prototypes and for feedback on drafts of this paper. Ben Bulsink of DGT Products, NL has been extremely helpful in providing us with materials to continue to develop the PitA-Board further. All of the members of L³D have provided encouragement and feedback in the continued development of this work, which has been supported by NSF grants REC-9631396 and CDA-9529549 and the Coleman Family Initiative.

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