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Children's Development Of Planning Tools For Managing Complex Software Design Projects

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Abstract: Managing complex, project-based learning activities poses challenges for children and has spawned the development of tools to support students' learning in particular domains. Taking an alternative approach, this study investigated children as tool makers to support their own planning performance in a software design project. Teams of upper elementary students in a science class engaged in a ten week project to design an educational simulation for younger students. They created their own project planning artifacts with a blank planning board and a set of open-ended tools. Study results report on the similarities and differences between teams in the functional organization of their planning space and the use of artifacts to support project planning. We also report on shifts over time between physical, virtual, and social spaces in the function and use of team-generated planning artifacts. We conclude with a discussion of considerations for future tool development and for classroom practice.

1. Introduction

Current educational research and practice has recognized the importance of contextualizing students' learning within personally meaningful, cognitively complex, and socially situated activities [Brown, Collins, & Duguid 1989; Collins, Brown, & Newman 1989; Resnick 1987], where they can become more autonomous thinkers and managers of their own learning [Brown 1992; Blumenfeld et al. 1991; Harel & Papert 1990]. While many would agree that self-managed learning is an important skill, students are often unprepared to manage tasks completely on their own [Bjorklund 1991; Friedman, Scholnick, & Cocking 1987]. Recent research has focused attention on ways to support learners in complex project environments. Key questions are how much support to provide, how to provide it, and for what purposes. Different forms of scaffolding support, including recent advances in software-based tools, have been developed to answer these questions.

While much is being learned about developing useful tools to support learning in project-based environments, this study proposed a less explored question: what can we learn about the differences and similarities between students when they generate and use their own support, given a set of open-ended tools? In particular, we were interested in how students developed their own planning tools to manage a long-term, software design project. Learners' experiences and backgrounds, knowledge, and developmental levels can vary, so a "one form fits all" model for providing support tools may not always be appropriate. We wanted to better understand the variability and unique functions that learners may assign to tools they have developed to support themselves, as well as the phenomenon of fading for learner-generated support. The study reported here focused on upper elementary students engaged in collaborative software design as part of a ten week project-based science intervention. Student teams received a blank "planning board" and a variety of open-ended supplies for generating, organizing, and displaying any desired aspects of their project plans and work in progress. Study results report on the similarities and differences between teams in the functional organization and use of artifacts displayed on the boards to support project planning, as well as the changes over time in the function and use of this team-generated planning tool.

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2. Review of Research

Our understanding of the use of mediational tools to support collaborative performance in planing or other learning activities is informed by a growing body of work on electronic and other types of scaffolding in project-based learning environments, as well as by past research on ways to support planning performance.

Scaffolding tools for project-based environment. Interest in collaborative, project-based learning has spawned research on the development and use of software-based tools to support different aspects of the learning environment, including: 1) participation in the *processes* of inquiry, design, reflective practice, and collaborative dialogue; and 2) development of *conceptual understanding* in a particular domain. Tools to support conceptual learning include computer-based data visualizers for creating dynamic diagrams, graphs or other representations of scientific or mathematical phenomena [Enyedy, Vahey, & Gifford 1997; Pea 1994; Pea, Edelson, & Gomez 1994]. There has been an equal amount of interest in supporting practices that are essential to participation in a particular learning community. For example, in science, electronic tools have been developed to help students manage various aspects of the inquiry process in complex, data-rich projects, including posing questions, making predictions, recording observations and other data, testing hypotheses, interpreting data, constructing arguments and drawing conclusions, and planning and reflecting on progress for all of these inquiry components [Loh et al. 1998; Bell 1997; Tabak et al. 1995; Guzdial 1994; O'Neill & Gomez 1994]. The tools make the inquiry process explicit and guide learners through the process by delineating the separate inquiry components, and by providing a virtual, sharable space for recording relevant information and making links between process components. Others have developed tools to scaffold processes relevant to collaborative design projects [Collings & Walker 1998; Puntambekar et al. 1997]. In an investigation of simulation design, Hmelo and Guzdial [1996] distinguished between "glass box" scaffolding, used to make explicit the important processes needed to coordinate and understand design and science principles, and "black box" scaffolding used to support simulation programming processes so learners could focus on other important learning goals.

Scaffolding tools have also included support for social dialogue and reflection between project partners about learning and process goals, as well as inter-group scaffolding to support dialogue between various members of a learning community, including those who are connected via telecommunications [Collings & Walker 1998; Bell 1997; Enyedy, Vahey, & Gifford 1997; Hoadley & Hsi 1997; Puntambekar et al. 1997; Tabak et al. 1995; Pea, Edelson, & Gomez 1994]. Support is provided through structured, sharable spaces for annotations, comments, and conversations in online notebooks, journals, portfolios, kiosks, and other formats.

Scaffolding planning performance. The notion of scaffolding to support planning performance has been investigated from both cognitive and sociocultural perspectives [Friedman & Scholnick 1997]. Like the research on electronic scaffolding cited above, task complexity has been an issue. Support of planning performance has been discussed in terms of external aids used to modify task complexity and support the amount of information to be coordinated in memory. Various planning problems have been investigated, including the Tower of Hanoi [Anzai & Simon 1979; Klahr and Robinson 1981] and planning efficient routes or schedules for grocery shopping [Gauvain & Rogoff 1989], running errands [Radziszewska & Rogoff 1988], or scheduling chores [Pea & Hawkins 1987]. These tasks are difficult for children because they demand coordination of task constraints, search for alternative solutions or strategies, formation of a sequence of subgoals, and monitoring of plan execution. To help children, researchers modified the tasks to provide support for conceptualizing different states of the problem representation, for coordinating constraints, and for forming subgoals. For example, in the Tower of Hanoi problem, which includes rules that constrain movement of a "tower of rings" from one peg to another on a board, Klahr and Robinson [1989] provided children with two physical apparatus that showed both the initial and final state of the problem, and modified it to make violations of constraints more obvious. The investigations of children's plans for efficient grocery, errand, or chore scheduling routes provided support with physical representations of the spatial layout where the task was situated, and with written lists as memory aids to assist in the formation of subgoals.

Those who view learning from a sociocultural perspective have discussed the mediational role of cultural tools that support participation in communities of practice [Cole 1996; Wertsch, Del Rio, & Alvarez 1995]. From this perspective, planning research has looked at the supporting role of cultural tools or artifacts by participants in collaborative planning. Rogoff [1995] found that in the social practice of planning for Girl Scout cookie sales, children gained skills and demonstrated increased levels of participation through the use of artifacts such as order forms and post-it reminders, and through language in the form of interaction in talk-aloud strategies with customers, and increased articulation of vocabulary to describe common cookie selling practices. Other studies have found evidence that in social interaction between less experienced children and more experienced adults, children can learn to participate in more abstract planning of errand or grocery shopping routes, show foresight in searching ahead for alternatives, and coordinate more than one idea at a time, if there is sharing of responsibility for decision making and sharing of strategies in talk-aloud interaction between partners [Gauvain & Rogoff 1989; Radziszewska & Rogoff 1988]. In these studies, language and communication became tools for children and adults to engage in joint decision making and reaching a shared representation of the task goals.

The bodies of research cited above have investigated the need for support of developing conceptual understanding and practices in complex domains. Less attention has been paid to collaborative learning environments where learners become the tool makers to support their own activities. Roth and McGinn [1998] have argued for the design of learning environments where learners become the tool makers to support their own activities. Marshall and Kafai [1998] investigated collaborative planning of a Tinkertoy™ building task, and found that participation in developing a shared understanding of team plans was supported if team members manufactured their own external planning artifacts to represent the evolving plan problem space. This study further pursues the issue of children as tool makers, including differences, similarities, and changes over time in the use and assigned function of team-generated planning tools.

3. Method

Participants and project description. Study participants were 31 fourth and fifth grade students from a self-contained classroom at an urban Los Angeles elementary school. As part of a ten week science unit on the brain and neuroscience, seven student teams engaged in a project to design and program a piece of educational software to teach neuroscience concepts to younger third grade students. Programming was done with MicroWorlds™ Logo. The design project was an integral part of the science unit that also included inquiry, hands-on activities, and reflective class discussions. Teams spent approximately five hours per week on science and design-related activities. They were composed of four or five members, and included mixed grades, gender, and experience. (Some team members had past experience in a similar long-term science project the previous year.)

Planning tools. In the first week of the project, each team received a blank planning board constructed from three connected foam board panels, each three feet long by two feet wide. At week five, two additional panels were added to each planning board for extra space. Each team also received a tool box with the following contents: three pads of square post-it notes, four sheets of self-adhesive colored dots (.75 inches in diameter and 35 dots per sheet), 50 white index cards (8.5 by 5.5 inches), colored markers, a 3-month project calendar, and a dispenser of two-way, removable tape. Teams also had access to a class supply of plain white paper and to photocopies of software screen design templates they could use for drawing screen ideas. Teams were free to post any project information, in any arrangement, on their boards. During weeks three, six, and nine, teams met with a researcher for a formal planning session, at which time they were also asked to post on their planning boards any screen printouts from their software product “in progress.”

Data sources and analysis. On a weekly basis, a researcher videotaped and wrote field note descriptions of the contents and arrangement of artifacts on each team’s planing board. For the purpose of this study, the planning board data was grouped into three longitudinal time periods named T1, T2, and T3, to represent the state of the planning boards at the end of weeks three, six, and ten, respectively. For each time period, the arrangement of planning board space was catalogued to identify the placement of artifacts and changes in placements over time. The planning board artifacts themselves were catalogued and classified using a coding scheme to identify their planning function. Qualitative analyses revealed similarities and differences between teams in the organizational principles used to arrange planning board space, planning functions assigned to planning board space and planning artifacts, and changes for planning board use and function over time.

4. Results

4.1 Similarities and Differences in Team-Defined Planning Functions

With the planning boards, each team created a space that represented their evolving plans for their project. While each team developed unique methods of representing and spatially arranging their plans, they demonstrated the need to use their planning space to manage some *common* planning functions (identified by Marshall and Kafai [1998] in previous planning studies) related both to the design task itself and to managing other aspects of the collaborative project:

1) *Software screen designs:* drawings and text to represent ideas for software screens
2) *Programming*: information relevant to programming code used to develop the software
3) *Science research:* identification of research questions, information sources, and research findings to be included in the software
4) *Work schedules:* Methods of sharing and scheduling computer use, and work to be done on and off the computer
5) *Timeline:* calendar-related information about deadlines and dates for special project activities
6) *Collaboration management for software design:* information and team feedback about the selection of software ideas
7) *Collaboration management for team communication:* methods of communicating project information, ownership of ideas, concerns, and suggestions to fellow team members (everything not related to software screen design)

There were observed *differences* in the ways particular teams arranged their planning board space and used different planning tool elements to help self-scaffold the key planning functions listed above. The planning board space, consisting of five two-sided panels, offered the teams natural separators, which they all used to organize different aspects of their project plans. Teams were systematic about assigning different planning functions to different panels, thus representing a team's categorical thinking about project plans, which varied across teams.

In general, teams employed one of two spatial organization models for arranging information on separate planning board panels: 1) organization by *planning function*, or 2) organization by a combination of *individual team member space and planning function space*. The *planning function* model was used by five of the seven teams to assign different project plan functions (described above) to individual panels. Some planning board panels served a single function; others were multipurpose in function. The second *combination model*, employed by two teams, used team member space as a primary organizing principle and function as a secondary organizer. Each team member had his or her own planning board panel for posting planning artifacts relevant to that individual. Some remaining panels were used to post planning information relevant to the whole team.

Panel labels provided one obvious indicator that teams used separate board panels to categorically organize their plans. Labels were typically written on post-it notes or index cards, were placed at the top center of a particular panel, and described a function or team member assignment for that panel. Out of ten panel sides per planning board, the number of panels that were labeled ranged from zero to six. With the exception of blank panels, panels without a label also served one or more planning functions as evidenced by the artifacts that were posted to them. There were an average of 1.7 blank panel sides.

Function as an organizing principle. The five teams that used the function model all assigned a *screen design* function to one or two of their board panels to display drawings and information related to proposed software screen ideas. These panels had labels such as "Ideas," "Ideas we are going to use," or "Rough Sketches."

Function assignments for the other panels displayed more variability across the five teams using the function model. The teams chose different methods to represent *science research* and link it to other components of their software. One team created a panel just to display research information that had been gathered. Another group joined its screen designs and associated research information on one panel. Four of the five teams displayed the research questions posed by each team member on multi-function panels; in one case the research questions were joined with a list of useful websites for gathering research.

Two teams created panels that acted as memory aids for remembering *programming* information. One used a panel labeled "Commands" to list MicroWorlds Logo commands they had used or wanted to remember; another created a panel for posting numeric data they had included in some of their code, and needed for future reference. It was labeled "Important things to remember."

Time was another important planning function addressed by the students. They developed their own *work schedules* to split work and share one team computer, and they used calendars as *timelines* to track project deadlines and relevant project events. One team's panel labeled "Schedule" was used to determine which team members had computer time on which days. Two teams generated an unlabeled panel just for their project calendar, and two other teams combined a work schedule with other planning functions on a multipurpose panel.

Each team received a set of colored dots in their planning supplies, and each created a legend or *color key* to explain the meaning of colored dots that were affixed to other elements on the planning boards. While most teams combined their color keys with other planning functions, one created a "Color" panel to display its two color keys.

For some teams, the planning boards offered a space for *collaborative management of team communication* through the posting of messages and suggestions to other team members. One team created a panel for messages to absent members called "Messages for people who miss," and a different panel for messages called "Read me." Two other teams created panel space designated to air complaints.

The five teams that used planning function, rather than individual member space, as a primary organizing principle for their planning board space still found different ways to represent individual contributions to the design project. Members often wrote their names on the software screen designs and research questions for which they were responsible. One team color coded the contributions and ideas of different team members on their board. In contrast, the next section discusses teams that used individual member space as the primary means of organizing their plans.

Team member space and function as organizing principles. Using a *combination* model for spatial arrangement, two teams assigned *individual member panels* for each team member, and used the remaining panels as multipurpose space for the whole team. One example was the team that labeled member panels with a student's name and job title (team jobs had been assigned at the beginning of the project). Four of the five team members used their personal space to post a screen design idea and their individual research questions. One also personalized his space further with some science-related song lyrics. The remaining member chose not to post anything to his panel. The second team that used this model labeled member panels with only a job title. Two members used their space to post their own screen design ideas and/or research questions, but the other team members did not use their space. The creation of team member panels afforded a space for posting notes from one team member to another, for example, a note on one member's panel suggesting that she and the note-writer talk more about having a credits screen.

4.2 Unique Uses and Affordances of Planning Tools

Of the various planning tools given to each team, the use of colored dots and post-it notes best illustrate unique ways in which different teams assigned functionality to the tools as they self-scaffolded their project plans. The colored dots were too small to write on, but their size and multiple colors made them suitable for affixing to other tools on the board panels, to categorize them using a team-defined coding scheme. All teams developed a color coding scheme, but the functions and actual codes varied across teams. Two teams developed a color coding scheme for identifying how likely it was they would use a software screen idea, for example: *red = what we are going to do; blue = might use;* and *yellow = need to find out.* Six out of seven teams developed a color scheme for prioritizing project work with examples such as: *red = urgent; blue = for tomorrow; yellow = later;* and *green = maybe*. Other unique uses included using a particular color dot to denote messages that should be read, or to identify the team member who posted information on the board. While most teams generated a four-color coding scheme, one team increased their options with a second coding scheme based on two same-color dots stuck next to each other.

Post-it notes afforded a range of functions, because of their size (large enough to write on, but small enough to affix to other tools on the planning board if necessary) and removable nature. Most of the panel labels were generated with post-its during the first time period, T1. While the majority remained intact throughout the project, a few panel labels were changed when a panel's function changed, or were removed later in the project. One team created temporary panel labels with post-its initially, and then later removed them and wrote the label text permanently on the panel surface with a marker. There were examples of post-it notes used for other functions during T1, then moved or removed later in the project: 1) research questions individually written on post-its, but removed when they were modified and/or incorporated into the software; 2) a small handwritten calendar replaced by a printed project calendar; and 3) a series of post-it suggestions for one team's software, later removed as the software was more fully developed. Finally, post-it notes were frequently used to communicate messages and comments to fellow team members. One team went a step further and used post-it notes in an on-going discussion about dissatisfaction with some members' work habits, which lasted one class period. The post-its were all positioned on a "complaints" panel, in a non-linear format that evolved as particular comments were posted next to others to which they were responding. The post-its were removed the next day, possibly out of concern that the teacher might disapprove.

4.3 Changes Over Time in Uses of Board Space and Functionality

Most of the categorical organization of space for the planning board panels was determined during the first time period T1. With only a few exceptions, the panel functions remained intact through T2 and T3. Additionally, as the project progressed, fewer modifications or item additions were made to the boards. The decreasing changes to the planning board space through time periods T2 and T3 appeared to coincide with the increased development of software screens (an average increase from 6.5 to 14 screens). Our fieldnotes supported the notion that over time, planning functions moved from the physical space of the planning boards to the virtual software space where teams' design ideas took shape. In general, between T2 and T3, the teams' software products became a better representation of their design plans, programming routines, research questions, and place holders for work that remained to be done by different team members.

While planning functions moved from a physical to a virtual space over time, we also observed examples of teams assigning new functionality to their planning boards in a social space in the latter half of the project. The board panels, which could easily fold to accommodate different shapes, were used by some teams as identity and territory markers to delineate their team work areas and separate them from other teams.

5. Discussion

This study identified both similarities and variability in children's self-scaffolding through the generation and use of planning tools. Teams applied a set of organizing principles to the categorical arrangement of their physical planning space, and they all found ways to address a common set of planning functions needed for a collaborative software design project. However, there was variability displayed across teams as each found unique methods of generating and arranging planning space within chosen organizational principles, and unique ways of using the planning tools to represent their plans. Because of the long-term nature of the design project, we were also able to observe change in planning needs and assigned functions of tools over time. While primary planning functions were situated in the physical space of the board panels in the beginning of the project, many of these functions gradually became situated in the virtual software space as teams' designs were realized on software screens. As the planning boards became less useful for various planning functions, they took on a different function as a territory marker for social space.

Children as tool makers. In this study student teams participated in the making and using of what Vygotsky [1987] referred to as "mediational tools," and Cole [1998] referred to as "artifacts." They modified material objects (planning boards and associated planning board tool elements) as a means to regulate their interactions with one another on an interpsychological plane, as they negotiated their understanding of what it means to plan a collaborative software design project. The material objects used to create the planning board space gained meaning as teams shaped their use in an attempt to represent an organizational structure for their project plans. Board panels became spaces to categorically decompose a complex project into smaller functions. Teams assigned agreed upon meaning to planning tool elements such as colored dots to provide additional support for managing different planning functions. While there was a shared understanding of the organizational structure and assigned tool functions within a team, there were between-team differences as each team shaped the meaning and function of their planning tools in different ways.

Implications for tool development. This study provides some insights for the development of tools to support learning in project-based environments. Developers should keep in mind the possibility that one size does not fit all; our study of children as tool makers points to some universality in conceptions they have about planning functions, as well as idiosyncratic differences in how planning functions are represented to suit team needs and styles. Additionally, in a long-term project, tool developers should consider how tool functions may fade or change over time. Our results also point to a need for flexibility in providing tools in multiple spaces, including physical and virtual. Both have different affordances for representations and learning at different time points in a project. The computer monitor provided limited screen real estate for representing all aspects of project plans. Alternatively, the planning boards offered more flexible use of space, they were easily modified and easily seen by participants in team planning meetings and presentations to the class, they were easily expanded if needed, and they were portable once they were folded up. However, as the software took shape and designers had more fully conceptualized its contents and behaviors, the virtual space afforded a better representation of the product design and the work that still needed to be done. Developers of technology-based tools continue to consider ways to maximize the use ubiquitous computing tools that allow for greater distribution of resources. We suggest that the physical and virtual planning spaces in this study offered students ubiquitous planing tools to which they assigned functionality as they moved from one to the other.

Educational insights. This study suggests some relevant insights for educators about the use of open-ended planning tools in a project-based classroom. By looking at both the physical planning board space and the virtual software space that team members create, students and teachers can observe a visual history of teams' planning over time and use them as tools for reflection about students' thinking. Teams in our study used their planning boards and software for reflection during scheduled planning sessions, and during "work in progress" presentations to the rest of the class and to third grade users. The boards and software provided an artifact around which reflective discussion about learning and design processes could be centered.

Outlook. Beyond this study, further investigation is needed to gain a more complete understanding of other kinds of planning and project management support structures in the learning community. We plan to explore multiple ways in which teams co-construct shared team plans through the mediation of cultural artifacts including language and external representations (including the planning boards), and through patterns of participation and by more and less experienced community members.

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