Project-Based Learning In a Middle School: Tracing Abilities Through The Artifacts of Learning

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Abstract

The purpose of this study was to explore how individual differences—specifically abilities—were used in the construction of computer-mediated learning artifacts while working within a project-based learning environment. A case study design was used with five participants purposively selected from 61 eighth grade geography students at a small, private day school in the southeastern United States. Data were collected through a self-report inventory, interviews, observations, and artifacts. Results indicated that learning artifacts reflected individual differences through blends of abilities while other abilities identified by the participants went untapped or unrecognized. Second, the learning artifacts represented the learners' knowledge in three ways: system knowledge, domain knowledge, and metacognitive knowledge. However, some knowledge, such as process decision making, went undocumented. Finally, the flexibility in the project-based learning environment allowed the participants to make decisions about their abilities, resources, and plans. Recommendations and implications for teacher educators as well as inservice and preservice teachers are also presented.

Proponents of individual differences acknowledge aptitudes, skills, and preferences inherent to learners. The complexity of learning is reflected in these differences: An individual must be willing or motivated to learn, he or she must be able to learn, the environment must foster learning, and the instruction must be effective for the learner (Jonassen & Grabowski, 1993). In an attempt to understand how and under what conditions individuals learn best, researchers have attempted to isolate these variables independent from one another, including cognitive styles (Renninger & Snyder, 1983; Riding, 1997; Saracho, 2003), learning styles (Burke & Dunn, 2002; Dunn & Dunn, 1979; Gregorc & Ward, 1977; Honigsfeld & Dunn, 2003), learning modalities (Dean, Yekovich, & Gray, 1988; Samples, 1992), and various individual cognitive and psychomotor abilities (Doxey & Wright, 1990; Eliot & Hauptman, 1981; Gardner, 1983; Karma, 1982; Sugrue, 1995). More recently, researchers (e.g., Rayner & Riding, 1997; Snyder, 2000) have suggested an integration of these learner differences to understand the learner as a whole.

In the past decade, the emphasis on student-centered learning appears on the surface to take into account these aptitudes, skills, and preferences of learners. Project-based learning—one example of a student-centered learning pedagogy—attempts to provide the student autonomy over and responsibility

for what is learned (Means, 1994; Means & Olson, 1994; Wilson & Cole, 1991), moving learners toward expert knowledge. Project-based learning encourages individuals to explore and examine a variety of problems and resources to construct personal strategies for handling these problems, as well as negotiate *and* share solutions (Barrows & Tamblyn, 1980; Bransford et al., 2000; Harel & Papert, 1991).

Computer-based technologies such as hardware, software, and networks within project-based learning have been used to replicate vocational practices such as the work of scientists (Blumenfeld et al., 1991), reduce cognitive load through cognitive tools and scaffolding (Jonassen & Reeves, 1996; Lajoie, 2000; Oliver & Hannafin, 2000), and provide access to electronic databases and digital resources (Dodge, 1995, 1998; Land & Greene, 2000). In addition, with the current increased national attention on educational technologies in our schools (No Child Left Behind Act of 2001, 2002), project-based learning often capitalizes on technology tools for analyzing, presenting, and communicating results (Grant, 2002; Morrison & Lowther, 2005). Technology tools in project-based learning mediate (or can be used to create) digital artifacts (e.g., electronic presentations and Web pages) as well as analog artifacts (e.g., posters and essays).

FOUNDATIONS OF PROJECT-BASED LEARNING

Early in the last century, Dewey (1938) and Vygotsky (1962, 1978) encouraged experiential learning, providing the theoretical foundations for project-based learning. More recently, Brown, Collins, and Duguid (1989) and Lave (1990) have proposed that learning is contextualized for individuals. Through interactions with the environment, including people and technologies, individuals create meaning. As suggested by Vygotsky, the most effective learning environments afford learners personal interest and the opportunity to negotiate meaning from others (Brush & Saye, 2000). Thus, pedagogy that fosters personal interests and interactions with peers, experts, resources, and technologies seems to offer promising alternatives to teacher-centered instruction.

The principles of project-based learning are observed in other instructional methods and pedagogy, such as project-based science (Blumenfeld et al., 1991; Marx, Blumenfeld, Krajcik, & Soloway, 1997), disciplined inquiry (Levstik & Barton, 2001), open-ended learning environments (Hannafin, Hall, Land, & Hill, 1994; Hannafin, Land, & Oliver, 1999), WebQuests (Dodge, 1995, 1998) and student-centered learning environments (Land & Hannafin, 2000). Grant (2002) defined the common elements across these models for project-based learning as (a) an introduction, (b) definition of the learning task, (c) procedure for investigation, (d) suggested resources, (e) scaffolding mechanisms, (f) collaborations, and (g) reflections and transfer activities.

RESEARCH SCOPE & QUESTIONS

To more completely examine the interactions between the learner and the learning environment, the role of learner differences *in situ* must be explored. Recent research has examined complementary aspects, such as the teacher's role and learner differences in the environment (e.g., Turner, Meyer, Midgley,

& Patrick, 2003), as well as learner differences and achievement (e.g., Snyder, 2000). Still other authors advocate matching individual differences determined from assessment instruments to specific instructional strategies and pedagogy (e.g., Beck, 2001; Burke & Dunn, 2002). Few reports, however, indicate how individual differences are used by learners particularly in computer-supported learning environments (c.f., Turner et al., 2003), and limited accounts represent the voice of the student.

Attempts at investigating isolated characteristics of individual differences (e.g., Renninger & Snyder, 1983; Vos, 1997) dismiss the other salient elements of the learning environment. By seeking to understand and interpret the interactions among the learners, computer-supported project-based learning, and the learning artifacts, more evidence will be garnered about how individuals represent their learning, as well as how individuals function in environments with less teacher direction and more learner autonomy. Results of previous research suggest that many factors contribute to the success of learning environments (e.g., Brush & Saye, 2000). Segregating these variables provides little evidence for effective designs or implementations and necessitates empirical evidence documenting the successes and challenges associated with student-centered learning environments, such as project-based learning.

In this study, we explored how learners incorporate their individual differences, specifically abilities, into computer-supported project-based learning. In particular, we aimed to represent the learners' voices and points of view. Lowman (1991) defined *abilities* as "what one is able or potentially able to do" (p. 11). We used this more general term in order to distinguish from IQ and general intelligence (*g*) (Spearman, 1904) as well as to reflect other possible taxonomies and classifications of abilities (see e.g., Lowman, 1991). Also of interest was how the computer-mediated artifacts produced in project-based learning reflect the learner and his or her knowledge. So *technology* in this study was operationlized as computer-based technologies—specifically hardware, software, and networks. Moreover, *computer-mediated learning artifacts* was used to describe both analog and digital products the students fashioned with the aid of computers, such as research papers and museum displays.

Specifically, the questions our study examined were:

1. In what ways do learning-artifacts reflect individual differences, such as those abilities delineated in multiple intelligences?
2. In what ways do learning-artifacts reflect a learner's knowledge?
3. In what ways does project-based learning allow learners to tap their individual differences?

METHOD

Context

The setting for this study was a small, private middle school in the southeastern United States. Minorities comprised less than 10% of the student body. The geography course was one of five courses (i.e., language arts, math, science, foreign language) required for all eighth grade students, and each class contained approximately 15 students.

The middle school was implementing a ubiquitous computing initiative, similar to the Microsoft Anytime Anywhere program (see e.g., Rockman et al, 2000). Each student leased a laptop computer and had Internet and school intranet access through wireless connections. The eighth grade teacher had been using a laptop professionally for three years, while the students were in their second year of using laptop computers. The geography teacher used primarily teacher-centered activities but was open to trying more student-centered activities that exploited the ubiquitous computing environment in her classroom. Windschitl and Sahl (2002) have suggested that ubiquitous computing has offered an avenue for teachers to reconcile dissatisfaction with previous teaching practices by moving to more student-centered instruction.

The recent laptop computer initiative was an attempt to use the technology as an agent to change teachers' practices (see e.g., Hill, Reeves, Grant, Wang, & Han, in press). As part of this current research, we attempted to capitalize on this opportunity, specifically for the geography teacher. In the past, the geography teacher had relied on the curriculum structure of the textbook, traversing the globe in regional sections, such as South America, Latin America, and so on. With the textbook badly out of date and access to the laptop computers and Internet, the geography teacher saw ubiquitous computing as an opportunity to break from the traditional curriculum. Instead, she chose themes to structure the curriculum, such as population, famine, conflicts, and human rights. So the laptop computers and network access to digital resources offered an opportunity to use the most current geographical content available, while making substantive changes in her practice and the means by which students could learn.

Description of the Unit

For this study, the cooperating geography teacher and primary researcher collaborated to design an extensive WebQuest that specifically incorporated Grant's (2002) elements of project-based learning and utilized the laptop computers in a more significant manner. In particular, we used the WebQuest site as metacognitive, procedural, and strategic scaffolds (Hill & Hannafin, 2001) to facilitate students' progress through the unit, as well as aid students in managing discrete approaches to tasks. We planned a unit on geography and human rights that lasted ten weeks. During the planning, we selected five countries spread across the globe—in contrast to previous years, where units were organized by geographical regions traversing the globe—where citizens were currently experiencing violations against human rights. These countries were Argentina, Kashmir, Sierra Leone, Sri Lanka, and Sudan. One of the participants remarked the unit "lasted longer than … the Civil War in seventh grade." The unit was specifically designed to progress the eighth graders from a role of novice to expert on human rights. Jonassen, Mayes, and McAleese (1993) have suggested that as students move toward more expert knowledge, they have the ability to take more responsibility for their learning and assert more personal perspectives. The unit on human rights was designed in this manner to become more student-centered as the unit advanced.

The human rights unit was divided into four stages. Stage One included learning the physical and human geographies of all the countries under study.

Students researched using Internet and print resources and collated their facts into a spreadsheet template created by the teacher and researcher. Stage Two asked students to define human and civil rights, rewriting the United Nations Declaration of Human Rights in language appropriate for eighth grade and applying their definitions to a case study of apartheid in South Africa. Stage Three required students to prepare a research paper on the human rights violations in one of the five countries. Students were asked to rank the countries in order of their preference, and the teacher divided out the countries for research equally among the students. Finally, in Stage Four, the students were asked to design a museum exhibit for a Human Rights Fair that offered an in-depth look at current human rights violations in their assigned country. The final exhibit could be digital or analog, but the laptop computers must have been used to mediate the creation of the exhibit. For example, the exhibit may have been a poster, but pictures acquired from the Internet and text generated in a word processor would be integrated.

Throughout the ten-week unit, the students referred to the WebQuest Web site co-created by the teacher and researcher. Resources such as the *CIA World Fact Book* Web site and Internet links to newspapers produced in the countries under study were provided to the students to reduce searches and information seeking. Scaffolds such as a physical and human geographies spreadsheet, electronic note card template, guiding questions, brainstorm sheets, peer evaluation forms, and Internet bibliographic links were developed to support the students in their project-based learning approach. In many instances, the teacher and researcher were resources and scaffolds throughout the WebQuest. On a number of occasions the teacher invited the primary researcher to team teach the unit with her to aid the students in their process of learning and in the production of their computer-mediated learning artifacts.

Participants

Sixty-one students from an eighth grade teacher's four intact geography classes initially participated in the study. A multiple intelligences survey (National Dropout Prevention Center, 1995) was administered to the students to define the students' self-reported levels of expertise (from 0 = "No expertise" to 4 = "Exceptional expertise") in eight abilities: verbal linguistic, mathematical/logical, visual/spatial, bodily/kinesthetic, musical, interpersonal, intrapersonal, and naturalist. Table 1 displays a sample item from each ability's scale, as well as the participants' means and standard deviations for each of these abilities.

From the 61 possible participants, three girls (Allison, Brittney S., & Brittney T.) and two boys (Bob & Brock) were invited to participate further with extended data collection. The five participants were chosen using a criterion strategy (Miles & Huberman, 1994) from the initial survey. These five students were selected based on those with a score of 35 or above (out of a possible 40 points) in at least two of the eight categories of multiple intelligences, as well as a diversity in multiple intelligences, gender, ethnicity, and class period. For example, Brittney S. and Brock were both considered because they rated themselves high in the naturalist intelligence; Brock was also considered an important potential participant because he was an immigrant from South Korea

Table 1: Mean Ability Scores and Sample Items from Multiple Intelligences Inventory (N=61)

Multiple Intelligence Ability	Sample Items (Scored 0="No Expertise" to 4="Exceptional Expertise")	M	SD
Verbal linguistic	Others have recognized that my writing shows…	25.9	4.0
Mathematical/logical	I piece together patters from separate pieces of information with…	25.8	5.4
Visual/spatial	I do jigsaw puzzles, mazes and other visual puzzles with…	27.7	4.5
Bodily/kinesthetic	I play tennis, golf, swim or engage in some similar physical activity with…	28.5	5.3
Musical	I can tell when a musical note is off key with…	19.4	9.1
Interpersonal	I provide advise or counsel to others with…	28.8	5.4
Intrapersonal	I keep a personal diary or journal to record the events of my inner life in a way that displays…	26.2	4.5
Natural	I am able to classify such things as rocks or aquatic life or clouds with…	19.1	8.8

and could provide insights into another culture; and three of the four class periods per day were represented. The participants self-selected pseudonyms at the beginning of the extended data collection, and these were used throughout the data collection and research report. The five participants are described in detail in the "Findings and Interpretations" section.

Design and Data Sources

The case study method (Merriam, 1998) was used in order to study both the process and products of learning over time. The case study was flexible enough to allow for the study of each participant as an individual case and then develop themes across all the cases. A variety of data collection methods were used to inform the results of this study. The use of multiple methods helped to triangulate the data and to confirm the findings and interpretations. The primary researcher collected all the data as part of dissertation research.

Interviews

Four rounds of interviews were conducted with each of the five participants: one at the beginning the human rights unit, two during the unit, and one at the conclusion to the unit. Each of the interviews lasted approximately 30 to 45 minutes. A semi-structured interview protocol was used with all five participants to allow variation in the order and phrasing of the questions, as well as probes to specific individuals (Patton, 1990). We used the multiple intelligences (Gardner, 1983, 1999) model of individual abilities as a framework and origin for the learners to reflect on and discuss their own individual differences. However, we referred to these "intelligences" as *abilities* and allowed the participants to discuss their strengths and weaknesses outside of the multiple intelligences framework as well.

Throughout the interviews, the participants were asked to chronicle and reflect on their project as it developed, considering how their abilities were affecting the project as well as which computer technologies they were using. On a number of occasions, we asked the students to reason how their abilities affected their learning, as well as their choice and use of technology tools. For example, the participants discussed which scaffolds had been most helpful in the construction of their learning artifacts. Moreover, they articulated what they were learning and how this met, exceeded, or challenged their thinking. During the final interview, participants reflected on their completed museum exhibit, how it represented their abilities, what they had learned, and what their decision-making processes had been for choosing specific computer-based tools.

Observations

Throughout the unit, the participants were observed at least three times for approximately 50 minutes each. The researcher was a participant observer, contributing to the instruction at the request of the cooperating teacher. The purpose of the observations was to provide descriptive information to supplement and complement the interview data. In addition, observational data were used as probes and referents in the interviews. The data collected during observations were useful in corroborating data collected during interviews.

An observation protocol was used to aid in the collection and management of the data. The protocol noted class activities that occurred for at least five minutes, observable abilities such as the multiple intelligences and any others, as well as student groupings. Student activities, such as on-task/off-task behaviors, reading, writing, research, information seeking, discussion, and so on were noted every five minutes during a 50-minute class. Field notes were kept, including comments such as student-teacher interactions, student-student interactions, student-computer interactions, and researcher impressions toward the students' processes in developing their learning artifacts.

Artifacts

At the end of the research paper and the museum exhibit stages, these participant-generated artifacts and documents were collected. The museum exhibits were used as referents and reflection aids in the final interview. Photographs or computer screen captures of these exhibits were taken and examined during data analysis. The photographs and screen captures were helpful in corroborating the participants' abilities noted elsewhere, such as on the multiple intelligences survey and during interviews. For example, some participants created first-person accounts for their museum exhibits; these artifacts helped support expertises in verbal-linguistic, interpersonal, and intrapersonal abilities. As the participants described their abilities and the technology tools they used, they were able to point to examples in their exhibits.

Data Analysis

Analysis of the data followed a general qualitative analysis process (Cresswell, 1998; Merriam, 1998), similar to Glaser amd Strauss' (1967) constant comparative method. Iterative rounds of abstraction and data reduction began with open

coding directly from the interview and from observational and artifactual data. Second, *a priori* codes collected from the literature review (e.g., verbal ability, scaffolding) were applied to the data. Next, demographic codes and research management codes (e.g., gender, interview 1) were applied across the data. These coding categories were reviewed, refined, and discarded when necessary as patterns in the codes combined categories. Lastly, with a faculty colleague, peer review and revisions abstracted the patterns into broader themes. In addition to themes and patterns, descriptive accounts (Merriam, 1998) of the participants were developed to profile the participants, their abilities, and their learning. All data organization and analysis was managed through *QSR N6* (formerly NU*DIST).

Participant verification, or member checking (Cresswell, 2003), was conducted with the students to discuss the themes and participant profiles, confirming the accuracy of the students' voices. Results indicated a high level of researcher-participant agreement. Recommendations from each participant were noted and revisions or additions were made as necessary. In addition, the results were discussed with the eighth grade teachers to ensure accuracy in representing the students, their abilities, and how the laptop computers were used.

FINDINGS AND INTERPRETATIONS

Given the intimate relationship between findings and interpretations of qualitative research, both are discussed together. This section focuses on the experiences of the five participants, and these findings are not intended to be generalized beyond the scope of this research context. For each participant, two sections contribute to the descriptive accounts: An abilities profile highlights the strengths, weaknesses, and abilities evidenced from the participant, and a second section examines the human rights museum exhibit from both the perspective of the technologies the student used and the abilities invested in the product. Each of the participant's multiple intelligences survey scores are summarized in Table 2.

Allison

Abilities Profile

Allison, a Caucasian girl, was conscientious, articulate, and reflective. Allison rated herself at 35 or above (out of a possible 40 points) in three of the eight multiple intelligences: verbal/linguistic, visual/spatial, and interpersonal. She

Table 2: Participants' Ability Scores from Multiple Intelligence Inventory

Ability	Allison	Bob	Brittany S.	Brittany T.	Brock
Verbal/linguistic	35	31	31	32	22
Mathematical/logical	31	35	20	27	35
Visual/spatial	35	33	35	30	35
Bodily/kinesthetic	33	35	26	35	24
Musical	31	12	24	31	32
Interpersonal	35	37	32	39	30
Intrapersonal	28	33	29	27	32
Natural	37	24	37	24	36

also rated herself above 30 in three other intelligences: logical/mathematical, bodily/kinesthetic, and musical. All six of these intelligences were addressed by Allison throughout our interviews.

Allison thought she was good at English and math in school. "English is more fun," she said, "because I like to write and I like to read." "Math," as she explained it, "is more like you do this; and you have to know the facts; and you do this; and you don't get to create things on your own. It's just kind of like you do the problems."

Outside of school, she participated in "a lot" of athletics. She played soccer, basketball, volleyball, and she used to "do swim team in the summer." She thought she was the best at volleyball. She did not have to practice as hard at it; it was her "best" sport. Allison participated in fine arts, too. She liked art, especially drawing and painting; but singing was just "okay."

Allison thought she was weakest in drama class. She attributed this to her lack of self-confidence. She particularly felt vulnerable during impromptu improvisations.

Human Rights Exhibit

Allison's analog exhibit for the Human Rights Fair examined the violations in Kashmir, a territory in the northeast section of India. (See Figure 1.) She combined two tri-fold boards, such as the ones many students use in science fair displays, in order to make a "six sided thing that surrounds you."

The right side of Allison's artifact explicated the specific violations in Kashmir. She synthesized parts of her research paper on Kashmir into smaller, readable chunks, printed out from her laptop computer with large headings. She included images she searched out, downloaded, and printed from the Internet. Text and images brought to life the "terrorism," "torture," and "killings" in Kashmir.

Figure 1. Allison's human rights exhibit with articles of clothing (at left) for visitors to become Kashmiri characters.

Allison's exhibit included an expanded in-class writing activity. She word processed additional first-hand accounts of individuals who may live in Kashmir. Allison planned for visitors to choose a number and "become one of the first-hand accounts," and then read the account to others. During one of Allison's peer conferences, a classmate suggested she add clothing so visitors could dress up like the characters. Allison excitedly incorporated this into her exhibit. Allison didn't think this conflicted with her weaknesses in drama, because "I guess this shows that I like hands-on things [pointing to character costumes], like not really acting things out myself, but having something to do instead of just looking at the project."

Bob

Abilities Profile

Bob, a Caucasian boy, was articulate, sometimes comical and sometimes cynical. Bob rated himself at 35 or above in three intelligences: logical/mathematical, bodily/kinesthetic and interpersonal. He also rated himself above 30 in three other intelligences: verbal/linguistic, visual/spatial and intrapersonal.

In school, Bob thought he performed well in science, geography, English and math. He judged his successes based on grades: "I do pretty well in English. I'm getting an A every semester. I think I've gotten an A in everything except math for every semester." Bob enjoyed science the most. "And science, I just like science. I think it's cool." However, physics was a component of science he didn't enjoy: "There's a whole lot of math involved." Our discussion led to why he didn't enjoy math—his worst subject. He was flustered as he told me:

> I do pretty well on the homework. But when it comes to tests, I just—I can usually—well, I think I did pretty well on this last test. I'm pretty sure I missed two, but I think I did well on the other ones. It's just when it comes down to the tests, I don't think [the math teacher] gives me enough time, and I just start to panic and try to get through quicker. So, I make small mistakes. I think that's one of the reasons my test taking skills in math are not great.

Bob thought he was good at a number of other activities. He liked to build things. It was an activity he shared with his father: "I think I'm good at like—I can build things pretty well. Like I know how to weld and stuff. My dad likes to do a lot of woodworking and stuff, so I can do well with that." But often his woodworking projects didn't "come out right."

He was also involved in school athletics. He thought he was "okay" at football and "okay" at baseball. Sports are what he worked hardest at: "I work hard basically at all my sports, but that kind of thing goes with every sport you play. You've got to work hard at it."

Bob was taken aback when asked about his strongest abilities: "I'm not quite sure. I've never really thought about my strongest abilities … Like when I think about what I'm really good at, when I think about that, I think I'm being conceited in a way." Though he struggled with defining his strengths, Bob without hesitation noted he was weak at "doing math" and "spelling."

Human Rights Exhibit

Bob investigated the human rights violation in Sri Lanka. The artifact he produced for the fair hyperlinked a series of separate electronic presentations. (See Figure 2.) Originally, he had begun working on a tri-fold board to accompany his presentations, but stopped. He felt he had to "make a board" but discontinued the effort "because glue got everywhere . . . and it didn't work too well."

Bob's electronic presentations divided the content into different strands, such as the history of Sri Lanka, what was currently happening, solutions to the violations and a gallery of photos. The text on the slides was in a large point size to facilitate reading, and the amount of text per slide had been summarized and abbreviated. Instead of distributing the images throughout the presentations, he consolidated them all into a gallery. Bob's exhibit used a common navigational structure throughout all the presentations. Large "next" and "previous" arrows directed visitors to proceed through the presentations. He indicated that he took into account the audience during the production of the exhibit:

> I think you have got to think what people are going to want to see, if they are going want to have lots of pictures or lots of words … you'll probably not want to have lots of words because you don't want to be reading about Sri Lanka, a country that they've never heard of and if that happens, they don't know where it is.

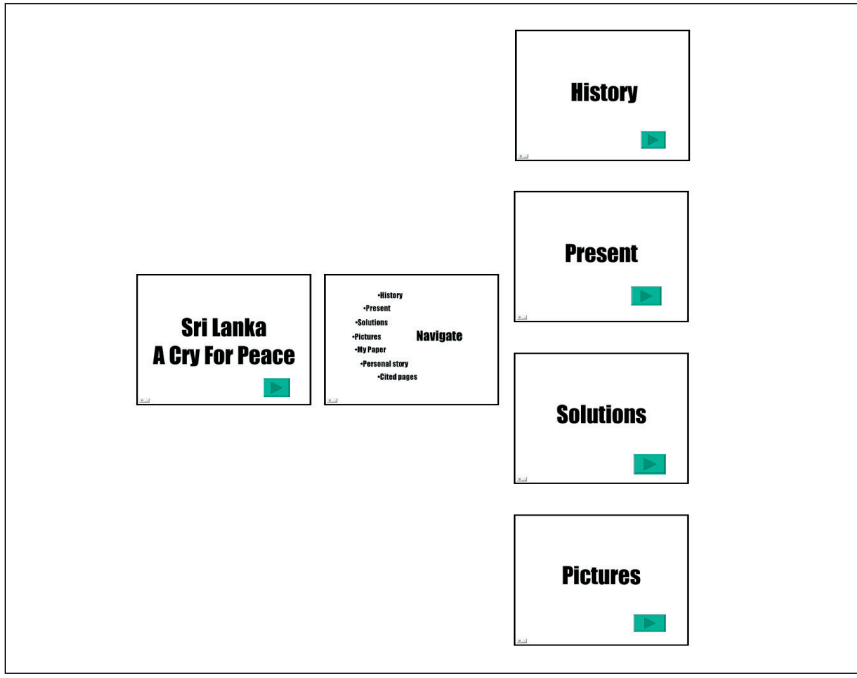

Figure 2. Bob's human rights exhibit with four electronic presentations (at right) hyperlinked to the intro presentation (at left).

Brittany S.

Abilities Profile

What was most striking about Brittney S., a Caucasian girl, was how empathetic she was toward the plight of Sudan. Repeatedly she described how she had become immersed in her project, imagining what it must be like to live in Sudan and how useful it seemed. Brittney S. rated herself above 35 in two of the intelligences: visual/spatial and naturalist. Her exceptionally high score in the naturalist intelligence was one of the reasons she was considered for this study. Brittney S. also rated herself above 30 in two other intelligences: verbal/linguistic and interpersonal.

Brittney S. thought she was good at English, geography, biology and Spanish. She thought she was good at English, because she liked "to write a lot." "I like English. Anything I can relate to, I'll enjoy. Like numbers, I don't relate to them, so I don't like them." Geography gave her to opportunity to "learn about the world where" she lived and because "you don't really know about how other people live in this world." Brittney S. indicated she was interested in biology, and she wanted to be a veterinarian. Spanish was different from the other subjects. Brittney S. thought she was good at Spanish, but she did not enjoy it: "I just think it's a waste of time, maybe."

Outside of school, Brittney S. felt she was good at art, basketball, and riding horses. With art, she thought she had "a good imagination." In basketball, she "really like[d] it" and she thought she was "tall" so that helped. She enjoyed riding and thought she was good at it also. But, it wasn't always pleasant. She explained: "Sometimes I don't like doing tedious work. I would just rather have fun riding them. I don't like training them all the time."

Her weakest ability affected all parts of her life: "Staying organized. I'm sloppy. Getting up in the morning. I'm kind of lazy, too." Organization was what she had to work the hardest at also. She depicted her struggle as: "I have to—really staying organized. I'll lose stuff. I have to really make a point to remember what I need to do and stuff. I'll always forget to do stuff."

Human Rights Exhibit

Her exhibit combined a tri-fold board and an electronic presentation to concentrate on the slavery in Sudan. (See Figure 3.) The center of her display featured two fictional diary entries from individuals. These were word processed and printed out. On each side were images she downloaded from the Internet. Her stories seemed to be the central elements to her exhibit. She described their purpose:

> I spent a lot of time writing a personal story that would be really detailed and give people an understanding of what it would be like to be a slave. 'Cause I think you can relate more to, um, what, you can understand something better if you can relate to it. And kind of get involved and have, like, stronger feelings about it.

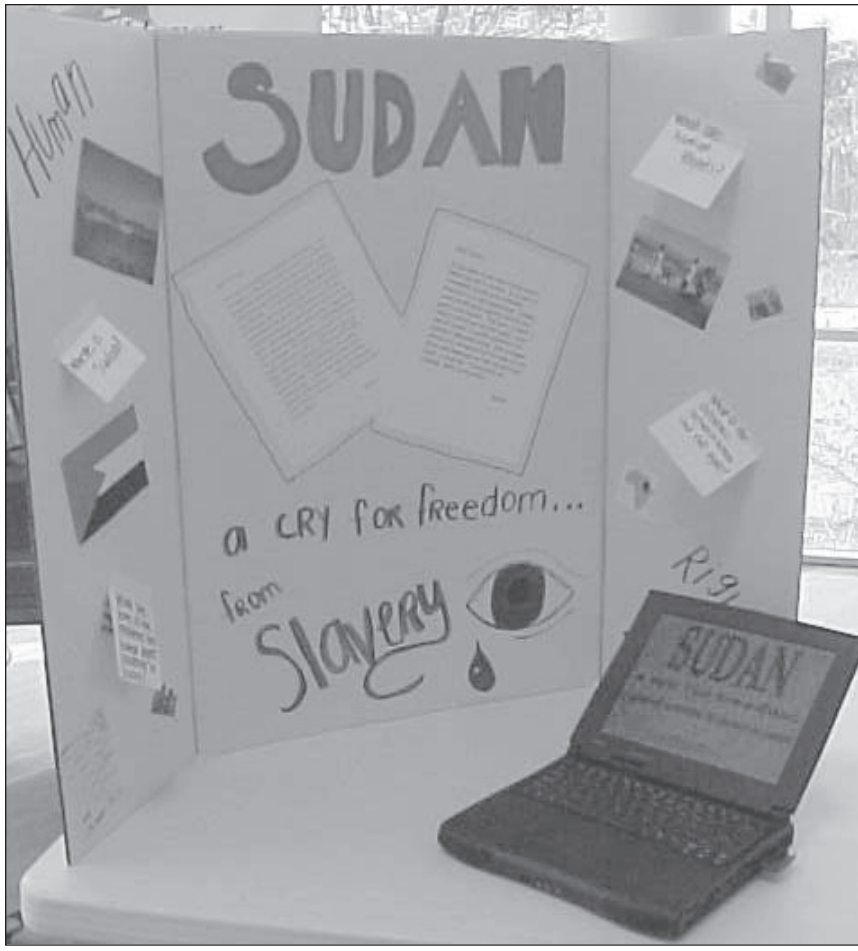

Figure 3. Brittney S.'s human right exhibit with diary entries and an electronic presentation on her laptop.

Alternating with the images were small flaps. On the outside were trivia questions about Sudan she had handwritten, and visitors could lift the flaps to check their guesses with answers she had handwritten. Brittany S. used her own words to provide answers to questions such as "What are human rights?" and "What is the difference between human and civil rights?"

Brittney S. also included an electronic presentation. Visitors could click through the five slides, which gave background information, specifically looking at slavery in Sudan. Brittney S. thought if she had put more effort into her presentation, she could have made it "less plain." Though she had accomplished what she wanted to with the exhibit, she was a little disappointed, because she thought she "could have spent a little more time on it." She admitted she struggled to stay "organized" and to avoid being "sloppy."

Brittany T.

Abilities Profile

Brittney T., a Caucasian girl, was shy; ironically, she wasn't shy about it. Brittney T. rated herself above 35 in two of the intelligences: bodily/kinesthetic and interpersonal. She also rated herself at 30 or above in three other intelligences: verbal/linguistic, visual/spatial, and musical.

In school, Brittney T. thought she was good at English and geography. With English, she said, "I've always kind of understood it." She enjoyed English because "you get to read books and you get to write about stuff." Geography was like English; she enjoyed it, thought she was good at it, and thought it was "fun."

Outside of school, Brittney T. played sports and liked art and drama. She played volleyball, basketball, and tennis, and rode horses. She said she enjoyed volleyball, but was not "that good at basketball and tennis."

Brittney T. thought her strengths lay with her ability to write and her ability to talk. She said she could "just fill up a page really fast." During an observation, her class was writing first-person accounts for individuals who lived in the countries under study. At a half hour into writing, Brittney T. had already begun her second page. All the other students except one were still on the first page.

Brittney T. felt her weakest abilities were math and meeting new people. Math and her shyness were not just sudden weaknesses; they had been traits throughout her life.

Human Rights Exhibit

Brittney T.'s human rights exhibit investigated Argentina, composed of a tri-fold board and Web pages on her laptop. (See Figure 4.) Along the two side panels of the board, she synopsized the major sections of her research paper, noting the weak economy, the government, the Dirty War, and the imprisonment of civilians. She used large text with bullets and graphic headlines printed from her computer to divide the sections. In the center of her board, Brittney T. presented images she downloaded from the Internet, including the Argentine flag.

On her laptop, Brittney T. offered visitors the opportunity to click on images embedded in a Web page she built in Microsoft FrontPage. Each of the images hyperlinked to a first-person account she had written. Brittany T. had not used a Web page editor before this unit. Her geography teacher had suggested she try it and had shown her how to create the Web pages, insert the images, and create the links.

Brock

Abilities Profile

Brock, an Asian boy, was from South Korea. He had only been at the day school for a year and a half at the beginning of this study. Brock rated himself at 35 or above in three intelligences: logical/mathematical, visual/spatial, and naturalist. He also rated himself at 30 or above in three other intelligences: musical, interpersonal, and intrapersonal.

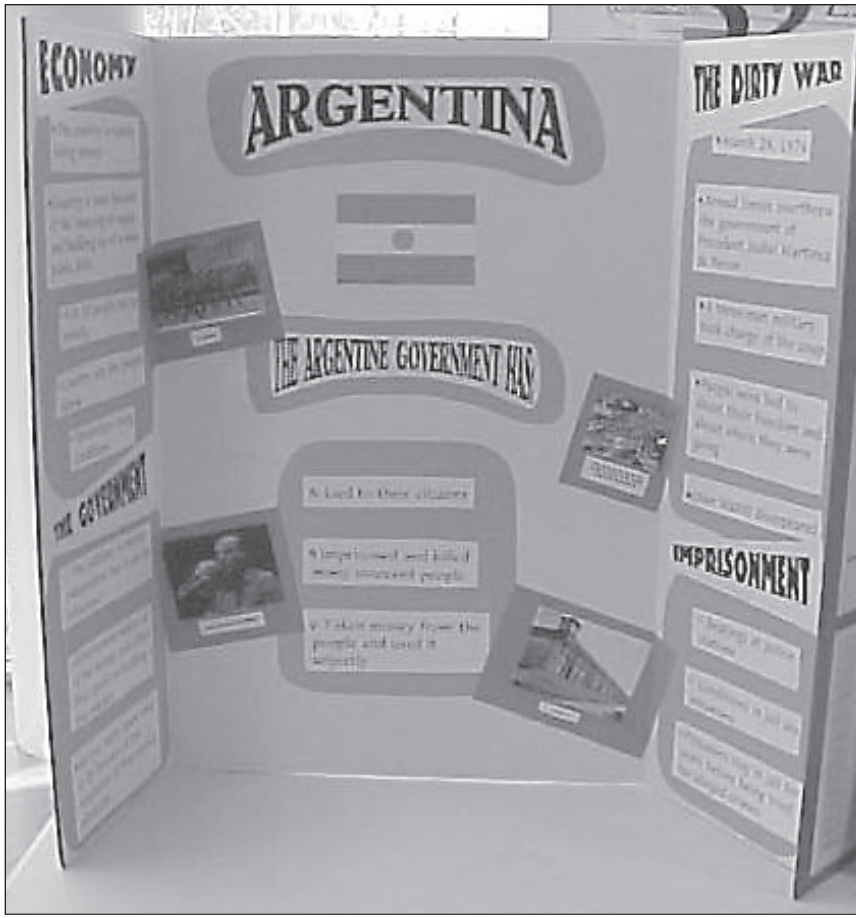

Figure 4. Brittney T.'s human rights exhibit excluding her first-hand accounts Web pages on her laptop.

In school, Brock thought he was only good at math. He felt it came easy to him. He did not think he had to work very hard at all in math. He got the best grades in math, and he liked math the most, too.

In other activities, Brock thought he was good a playing the clarinet, playing soccer, and art, though he had only been clarinet for about two months when the study began. He admitted, "I'm just beginning." But he felt he was pretty good at it. Soccer and art were similar. He just liked them. He could not explain why, though. He said, "I just like it."

When I asked Brock about his strongest abilities, he said, "Thinking." He went on to say "solving, calculating, and math." He believed that "solving" problems and "calculating" was what math was about. He used to have to study and work harder for science class, but when math was involved, he liked it more. He described his struggle as: "I used to work hard in science. I had the

lowest grade. But now I like it. We're into physics now, and it's math." Solving physics problems made the connection that Brock needed to make science easier and more gratifying—more like math.

Brock thought his weakest ability was "[to] concentrate." He described that many times at home he would "just like daydream and lose [his] thoughts." I followed up with him about how he tries to work at concentrating. As he laughed he said, "I don't work. Try to concentrate."

Human Rights Exhibit

Brock's exhibit for the Human Right Fair combined a couple of different technologies. (See Figure 5.) His introductory page was a simple Web page, generated in a Web page editor. It included five bullet points of the major elements from his research paper on Argentina and two hyperlinks, one for an electronic presentation of background information on Argentina and one for an electronic presentation of political cartoons.

One of the hyperlinks launched an electronic presentation that expanded on the five bullet points from his Web page. The slides included images he had searched and downloaded from the Internet. The content came from his research paper and included topics such as anti-semitism, the economy, and solutions.

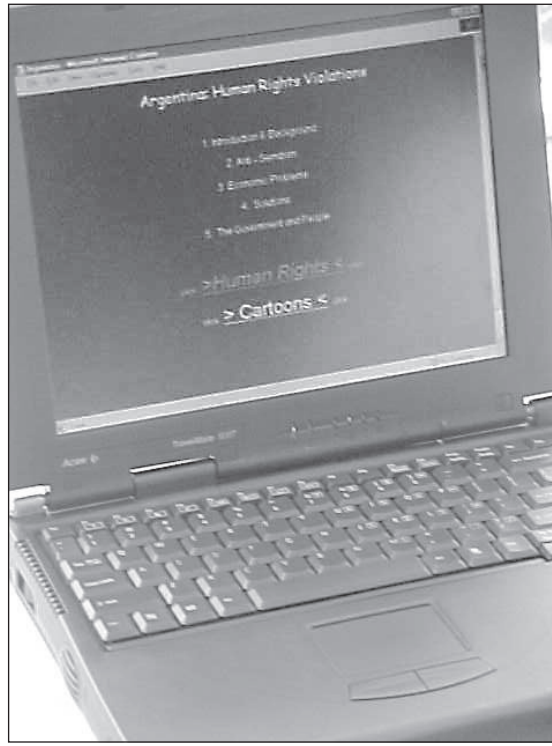

Figure 5. Brock's human rights exhibit with hyperlinks to two electronic presentations at the bottom of the computer screen.

The second hyperlink launched another electronic presentation containing eight political cartoons. Although the political cartoons did not relate directly to Argentina, Brock said he included them "because the cartoons were funny."

RESULTS BY RESEARCH QUESTIONS

The purpose of this research was to explore how the computer-mediated artifacts produced in project-based learning reflect the learner and his or her knowledge. Three overall trends emerged from across the cases:

1. Individual differences were reflected in the learning artifacts as a blend of abilities while some abilities went unused or unrecognized;
2. System knowledge, domain knowledge, and metacognitive knowledge were evident in the learning artifacts; and
3. Resources and scores allowed learners to use their individual differences throughout the project-based learning.

Question One: In what ways do learning artifacts reflect individual differences, such as those abilities delineated in multiple intelligences?

Both abilities identified in a multiple intelligences inventory and those identified by the participants, such as creativity, organization and computer skills, are components of the artifacts the participants produced as part of a unit on human rights. This section examines how abilities were blended into the computer mediated learning artifacts, as well as how abilities went unused or unrecognized.

Blending Abilities

Although the participants' individual abilities were discussed previously, isolation of these expertises was rare. Gardner (1983, 1999) contends that abilities work together to achieve goals. For example, Allison was a good writer, creative, visual, and enjoyed hands-on activities. Her exhibit for the Human Rights Fair integrated all of these abilities. She wrote first-hand accounts to place the visitors in the shoes of victims in Kashmir. Her display was well organized; she used large photographs and headings to gain the attention of visitors and direct their attention. She felt her abilities were a natural extension of herself. She explained how they became part of her exhibit:

> It is just that's who I am. So when I do a project like that, it just naturally, that's my tendency to do something that involves those, 'cause that's what I'm good at. So that's just my personality that goes into what my project is like. And also the part about being good at those, those certain abilities. That's one of the reasons that they got in my project because one of the abilities that I'm not very good at is not gonna be something that I want to put into my exhibit. So, I guess the things that I'm the best at usually show up in my projects.

Coincidentally, Brittney S. and Brittney T. independently chose the same pseudonym. Their abilities were similar, as were their exhibits. Brittney S. and Brittney T. both liked to write and felt sympathetic toward the victims in their

respective countries. They both imagined what it was like to live in countries where basic human rights were violated. They translated these mental images into word processed fictional accounts for visitors to read. They blended their verbal/linguistic skills with their interpersonal skills. Brittney S., for example, described this process as it related to her own life:

> My abilities would relate to people, and understand, if I relate to people I can understand what people in my country are going through. 'Cause, I mean, that's a strong ability for me to, um, like to help my friends and relate to other people. So that helps my understanding of what people in my country are going through.

Bob's sensitivity to others (social ability, Lowman, 1991) was conveyed through how he organized the content and decorated his completely electronic exhibit (logical ability) (c.f., Erickson & Lehrer, 2000). He considered his audience, and he used himself as a guide. In some ways, his high intrapersonal skills (33 out of 40) may have blended with his interpersonal skills (37 out of 40). He put himself in the place of a visitor to the fair and designed his exhibit around this perspective. Bob sought to make his audience understand what he had learned. He explained it as:

> You have to make it more—you have to make it less complicated, since you've been studying it for awhile. You have to make it easy for somebody who doesn't even know what human rights is to, to, uh, figure it out.

Unused or Unrecognized Abilities

Some abilities went unused or were unrecognized by the participants. Allison, Bob, Brittney S., Brittney T., and Brock were all involved in athletics. However, these kinesthetic abilities were not used by any of the participants in their exhibits. As Allison explained: "I guess there wasn't really anything that I could do that involved [athletics]. And athletics aren't usually included in schoolwork, and I guess I could have had a game but … it just didn't seem to fit with my topic."

Other cognitive abilities, like those used in math and science, were also not used. Brock found no connections between solving problems and logical thinking in geography. He failed to recognize where his abilities in one discipline, such as math, could be translated into another discipline, such as geography. Similarly, Bob missed the opportunity to see where math and science knowledge—two subjects in which he did well—could be transferred to geography. "Because they weren't needed," Bob explained. "I don't think I needed math or science in a geography report." Bereiter and Scardamalia (1985) and Brown, Collins, and Duguid (1989) suggest that when learning is decontextualized, knowledge and skills may become inert, or unable to transfer from one context to another. Similarly, the participants' abilities in some cases seemed over-contextualized in that the participants were also unable to transfer these to a new context. School or classroom cultures may exacerbate over-

contextualization by preferring specific representations of knowledge to others, limiting the use of individuals' full ranges of abilities. Interestingly, the laptop computers were used in all the disciplines across all the different courses. So, skills learned in another course were used in the creation of learning artifacts for geography class. The laptop computers seemed to be discipline independent.

It was not possible to identify and correlate every ability the participants noted to a specific attribute or instance within their artifacts. Some abilities were directly connected to evidence in the learning artifacts. For example, Bob's logical expertise was reflected in the organization of his paper and his electronic presentations. However, we struggled to correlate and interpret other abilities. For example, Brittany S. rated herself high in visual/spatial expertise and this evident to some degree in her exhibit. But she said she struggled with being "organized" and she was "sloppy," which was also evident in her exhibit.

Question Two: In what ways do learning artifacts reflect a learner's knowledge?

Question One examined how individual differences were reflected in the artifacts the participants created. Question Two elaborates on this idea to look at how the artifacts represent the knowledge of the learners. Hill and Hannafin (1997) have suggested different forms of knowledge are important to consider during learning with technology-based systems and open learning environments, including system knowledge, subject or domain knowledge, and metacognitive knowledge. Land and Greene (2000) concurred that these types of knowledge were critical in project-based approaches. As patterns emerged with regard to this research question, *a priori* codes from the literature were used to further analyze and interpret the data related to learning.

System Knowledge

System knowledge represents prior knowledge and recognition in information search and retrieval systems (Hill & Hannafin, 1997). The participants worked within a ubiquitous computing environment. Moving from information-searching and retrieval to information-organizing and use was part of their system. For example, all the participants used search engines to perform a search, then copied and pasted this information into a word processing document, and finally, paraphrased this information for use in a research report. System knowledge in this study was operationally defined as the learner's ability to use computer hardware and software to perform project tasks as they moved among software applications, such as Web browsers, word processors, electronic presentations, and Web page editors.

All the participants included images they had searched for and downloaded from the Internet in their exhibits. Allison was especially proud of the images she had found on the Web:

> I'm most proud of these pictures right here because even though I just found them on the Internet, some of them are really good pictures and they went perfectly with the accounts that I had, and I think that added a lot of stuff to my project. I mean, people would

> make comments about, "Where did you get those pictures and stuff?" And I think it drew a lot of people to my board, like with the pictures down the sides.

Allison's knowledge and comfort with Web browsers and search engines, she felt, contributed to the success of her Human Rights Fair exhibit. Her ability to use the software to access and capture the images she needed to complement her exhibit was an important detail. Allison even mentioned how she had to use image editing software to manipulate the size of the images for her display.

Most evident from the participants' system knowledge was their comfort in switching between software applications to complete their work. During the research phase of the written reports, all the participants were observed multitasking. For example, an electronic note cards template, created as a scaffold by the researcher and teacher in a word processor, would remain open while the students conducted Internet searches. As information was collected, it was simultaneously catalogued in the note cards file. For example, Brittney T. commented, "It was easier to just copy and paste different things. It's just easier, because it goes faster on the computer." But they were difficult to manage. Allison's system knowledge tried to overcome this limitation:

> My friend had an idea, and we were trying this. It works really well if you had PowerPoint and you put [the electronic note cards] on PowerPoint slides. Because that way when you open up a PowerPoint presentation, you can just click the arrows to go back and forth and you can move … the slides.

Her comfort with electronic presentations led her to try reconstructing the template as slides, so she could use the slide sorting feature to move the note cards around.

Participant system knowledge about the technology-rich environment was not stagnant. Participants learned new skills as necessary to accomplish their goals. For example, Bob was interested in connecting multiple electronic presentations together. With direction from the geography teacher and a small amount of guidance from the researcher, Bob learned to hyperlink his presentations and use action buttons—two advanced features of electronic presentations.

Domain Knowledge

Domain knowledge represents the existing knowledge related to the subject in which one is searching or learning (Hill & Hannafin, 1997). When the participants began this unit on human rights, they held little prior knowledge of the countries they would be studying or on human rights. Stage 1 of the unit (physical and human geographies) and Stage 2 (defining human rights) were designed by the cooperating teacher and researcher to build the prerequisite knowledge necessary to interpret information about their respective countries. The environment was designed to transition the participants from novices to experts in human rights violations of a specific country, becoming more student-centered as the project progressed (Jonassen, Mayes, & McAleese, 1993).

The acquired expertise of each of the participants is evident in each of their research papers and their exhibits. For example, Allison described the first-hand accounts she produced for her exhibit as a "tool."

> It's kind of like a tool, because if I tell about the person and what they've gone through, let's say their mom was kidnapped and killed, then that is introducing one of the human rights violations on its own. Or let's say they're really scared that, you know the human right to feel safe, and when it's talking about the terrorists, but at the same time it's easier for the audience to get in touch with that, with what's actually happening there specific to the country. … Because it ties in the general human right and what's going on and also the specific, where it's happening and who it's happening to.

She combined the human geographies with the knowledge she had learned about human rights violations in Kashmir to weave a story that describes the plight of Kashmir without explicitly stating the problems Kashmiri individuals face.

Brittney S.'s investigation of Sudan led her to discover religious differences and economic factors contributing to violation of basic human rights. These were not topics she had considered previously. She said, "Talking about human rights and civil rights helped me get a better understanding of what I was going to be looking for and 'cause I really never thought that much about human rights and civil rights and so that helped me, like, know I was supposed to find information-wise [in my paper]." Her discovery of slavery in Sudan led her to focus on slavery in her exhibit for the Human Rights Fair. Brittney S.'s fictional diary entries were powerful devices to convey her knowledge and opinions about slavery in Sudan, particularly the slavery of children.

As domain knowledge with regard to human rights and political influences increased, the participants were able to inject more of their personal understanding. Jonassen, Mayes, and McAleese (1993) assert that as learners approach expertise, stronger personal perspectives develop and can be afforded through learner-centered pedagogy, such as the project-based approach used in this study. The first-person accounts developed by Allison, Brittany S., and Brittany T. illustrate this flexibility to offer their own opinions and interpretations for the violations in their countries.

Metacognitive Knowledge

Metacognitive knowledge reflects the awareness of one's own cognition (Hill & Hannafin, 1997). These processes include "scanning, searching, questioning, chunking, generating hypotheses, and making decisions" (p. 38). This study did not specifically look to explore data on metacognitive knowledge. Moreover, although there is not a preponderance of data to fully explicate this finding, data from interviews suggested that artifacts reflected decisions the participants made about their own thinking and learning.

Bob was the most articulate about his metacognitive knowledge. His learning decisions affected the structure of his writing and his exhibit. For example,

based on how he learned himself, Bob tried to follow this same process in his writing for his research paper. He explained:

> So that's just how I do it. I just do, you know, intro, leading up to present, and conclusion. … I don't know. I just, I figured, it was easier than most other ways, like: Who? What? When? Where? Why? And, most of my note cards were in that order from like past going into present.

This timeline structure continued into his research paper:

> At this time Sri Lanka is in a civil war. The war is basically the minority versus the majority. Both governments involved, picture themselves as the victims. … Although one could say that many factors contributed to the civil war in Sri Lanka one event was the catalyst for it. On July 20th, 1960, Sirimavo Bandaranaike was elected as the prime minister of Sri Lanka. On December 31, 1960, Bandaranaike passed a bill that made the Sinhalese language the official and only language of Sri Lanka. The Sinhalese may have primarily started the conflict but the Tamils reacted strongly to the situation. After the bill was passed the Tamils staged many protests and were later arrested for doing so. … The current situation that this war is in is abysmal. Over 16,000 deaths have occurred in this ongoing 16-year battle. Terrorist acts have become more and more frequent causing more bloodshed.

Bob also constructed decisions based his own thinking for his exhibit. Bob used his own impressions of visiting the Human Rights Fair to determine what his exhibit should include.

In contrast, Allison's awareness of her thinking shows the interaction that metacognitive knowledge has on domain knowledge. Land and Greene (2000) suggest that domain knowledge and metacognitive knowledge function concurrently to influence learning. Allison said when she started researching Kashmir, she assumed there was a "bad guy"—either Pakistan or India. Instead, the longer she worked and thought about the information, she began to think more about how this type of atrocity could happen. In an early interview, she explained her conflict:

> There are a lot of Web sites that some are sided on India's perception of it, like the Indian army has one Web site about that says we're peaceful and we're trying to bring hope to Kashmir. And then I went to this other Web site that was about Indian atrocities committed in Kashmir and all these horrible things that they've done to people there. And then there's some about how Pakistan is bad and living in terrorism, and it was hard to decide which side is committed more of the crimes against the people.

In a later interview, she clarified how her thinking had evolved:

> I just thought about it more because I am so used to…when I think about something like that, like a conflict, one country being right or one country being wrong [pause] and I guess I thought well, it must be the same. But really it wasn't. I mean it was just kind of both countries hated each other so much. I don't know if it was really more time, I just thought about it while I was writing the research paper and while I was doing my project.

The participants in this geography course had completed projects before in other classes and previous grades. This unit, however, attempted to be more learner-centered than prior instruction, employing scaffolds, resources, and tools to support learners and instruction. The teacher desired the students to take more responsibility for their learning. Meyer, Turner, and Spencer (1997) report that manipulating metacognitive skills is necessary for students to self-regulate learning. Bob and Allison seemed to be unaware of the decisions they were making regarding their learning; they accepted these decisions as the way they each worked—a part of their processes. Making students aware of their metacognitive skills may provide stronger instructional support in more open-ended learning environments. Asking students to articulate and document their decision making may also offer audit trails of their learning (Collins, Brown, & Newman, 1990).

Hidden Learning

The previous sections clarified how the learning artifacts produced by the participants reflected system knowledge, domain knowledge, and metacognitive knowledge. It is important to recognize that the learning artifacts may not reflect all the knowledge the learner has acquired. Instruction that solely focuses on final or single products of learning may do an injustice to the learner.

For example, Bob did not receive the grade he felt he should have for his museum exhibit. In his exhibit, Bob chose to reduce the number of facts and amount of text in order to produce a display that appreciated his audience. In comparison to his research paper, many details were omitted for the sake of the authentic context of the fair. Through this project, we did not allow for the students to communicate their processes or thinking about their products. Penuel and Means (1999) have noted that recognition of an external audience is an important goal with project-based learning, emphasizing the authenticity of the task. The artifacts of Bob's learning included system knowledge, domain knowledge, and metacognitive knowledge. By examining only his final museum exhibit, it may be impossible to discern all that he has learned or the efforts and decision making used to produce the artifact. The products of learning, like system knowledge, metacognitive knowledge, and sensitivity to the audience, may be intangible elements as well. The lack of artifacts to document process decisions may do students a disservice and obscure certain aspects of learning from the teacher.

Question Three: In what ways does project-based learning allow learners to tap their individual differences?

The previous two research questions focused on the products created by the participants. This question, conversely, explores the process the participants experienced. The construction of the learning artifacts was a creative, generative process. The decisions made throughout the process were reflective of the participants and their individual differences. Halprin (1970) has suggested resources and project plans, or a score, affect decision making in creative processes. As patterns developed with regard to the resources participants used and the decisions the participants made about their construction process, these data were interpreted within this literature.

Resources and Decision Making

Resources are the materials, knowledge, and abilities available to the individual (Halprin, 1970). In this study, these resources included computer hardware and software applications afforded in the school's ubiquitous computing environment, print and Internet documents, scaffolds provided by the teacher and researcher, in addition to collaborations with others. Hill and Hannafin (2001) organize resources as static and digital, including print, electronic, and human. For example, Allison and Brock's processes of constructing their exhibits were influenced by their decisions about the resources accessible to them.

Allison's decision making was based explicitly on her available resources. Allison's original plan for her exhibit was to create a "room" for visitors to walk into. After a conversation with her dad—one of her human resources—she made alterations to the design because of practical matters:

> Well, when we first got assigned the project, I talked to my dad about it for awhile, just because, in case he needed to help me with any of the building or anything of it. Because the first thing I wanted to do was like a stall and it had a curtain and you walked into it and you're surrounded with pictures and things about it. But then I decided that was a little bit over-scaled and that was going to be really hard to do. So I kind of scaled it down to just having the tri-folds half way around. And I guess the tri-fold board idea was kind of a surrounding thing, but it was easier to do it with a tri-fold board because they fold around easier. And I also used it on a science fair project when I was younger, so I'm used to using those boards.

Allison analyzed her available resources, including her comfort with the materials, the complexity of the project, and the time necessary to complete the project. Based on these parameters and the advice from her dad, she decided to modify the design of her exhibit. After the human rights fair, she explained:

> At first I wanted to have a thing that surrounded you almost like a room but then I realized that—I mean, I could do something like that … was going to be pretty hard to do that surrounded someone

> and was high enough. But once I started thinking about this, it actually turned out exactly like I wanted it to. Because I wanted it to have those three sides just like that, and I told people I was going to have two put together, and they were like, "Is that going to work?" And I guess, it turned out not *exactly* how I wanted it to. I wanted to have a little bit more pop ups and that kind of thing on the actual board you could interact with, but I didn't have time to do that the night before. I didn't start early enough putting it together. But I had all of the resources that I needed to do it.

Allison said she had all the resources she needed except for time. As an intangible and non-renewable resource, time is critical to the success of project-based learning. Stronger metacognitive skills on the part of Allison or a more robust monitoring structure as a scaffold may have aided her with procrastination.

Brock also made explicit decisions about his exhibit based on his available resources. In fact, the resources, namely his laptop computer and the software installed on his computer, were the most noticeable in his exhibit. Brock wanted to use his computer for his exhibit and could not see past creating a Web page and electronic presentations. He said, "I thought it was only way to do on my laptop. Yeah, so I made PowerPoint." Brock made decisions based on the features of the computer and the software. During one of our interviews, he indicated how the computer influenced which abilities he used in his exhibit:

> Researcher: What determined that you were going to use those abilities?
> Brock: The computer.
> Researcher: In what way? How did it determine that you were going to use those abilities?
> Brock: 'Cause it's, it's easy to write. It's easy to decorate and, um, yeah.

For both Brock and Allison, the resources available to them influenced their decision-making during the construction of their learning artifacts. Students may lack metacognitive skills necessary to evaluate the use of resources and make decisions about their learning needs (Hill & Hannafin, 2001). Land and Greene (2000) have suggested that system, domain, and metacognitive knowledge work concurrently and may compensate in some instances for deficiencies in others. So, it may be difficult for a teacher to detect deficits in metacognition.

Scores and Decision Making

A score, or project plan, describes what will be performed or created (Halprin, 1970). Like a conductor's score, it is the plan that evolves over the process of constructing the interpretation of the music. In project-based learning, parts of the score are often embedded in the task as a list of requirements the artifact must contain. In this study, the research paper contained a number of explicit

requirements, such as page length, references format, and deadlines. Therefore, the teacher, researcher, and student together devised a score for the paper.

In contrast, however, the human rights exhibit had very few requirements. The primary objective was to produce an exhibit like in a museum that highlights one or more of the human rights violations in the country under investigation. Because this was a new unit, no examples of the museum exhibits existed for the students to review. Students typically edited the content from their research papers to incorporate into their exhibits. Graphics and images were downloaded from the Internet to include with the exhibit. In some instances, students created original first-person accounts. As mentioned earlier, Bob's past experiences with projects led him to create, but then abandon, implicit requirements for the exhibit. Thus, students were left to determine their own requirements and score.

IMPLICATIONS FOR PRACTICE AND FURTHER RESEARCH

The variety of ways in which the five students in this case study developed their computer-mediated learning artifacts offers significant implications for practitioners and teacher educators, as well as researchers.

Practitioners and Teacher Educators

Sustained project-based learning is a not a simple task for teachers or students (c.f., Brush & Saye, 2000; Scott, 1994). It is essential for teachers to comprehend how students will perform in these learning environments and recognize that students may be ill prepared. Hill and Hannafin (2001) suggest that students with primarily didactic, teacher-directed experiences may not have the skills necessary to work within more open-ended learning environments. Knowledge and skills such as metacognition and self-regulation may be beyond students' reaches. Bob and Allison demonstrated the strongest uses of metacognitive knowledge, but they were limited in recognizing how it assisted them. In addition to recognizing new roles and responsibilities, Grant and Hill (in press) suggest confidence with integrating technologies, such as the ubiquitous hardware, software, and network from this study, is a considerable variable that students and teachers must manage in project-based learning.

A hallmark of project-based learning is the sustained inquiry into a specific topic (Blumenfeld et al., 1991; Grant, 2002). This approach often conflicts with current school accountability measures that emphasize breadth of content over depth (Hill & Hannafin, 2001). The context for this study was a private day school, and the teacher had tremendous autonomy over the scope and pace of the geography curriculum; public school teachers may not perceive this freedom (c.f., Passman, 2001). Teachers may need to balance providing students with opportunities for in-depth studies with attending to the standardized curriculum's scope and sequence (see e.g., Scott, 1994). This would provide students and teachers with prospects toward practicing the "learning to learn" skills (i.e., metacognition, self-regulation, group collaborations) inherent to more open-ended environments. Moreover, scaffolds and job aids targeted at learning management, such as progress charts, may aid students such as Allison and Brittany S., who struggled with managing time.

Second, we realized that through the data collection and interviews, we were privy to details of the students' processes that the teacher was not. Bob's decisions to edit his electronic museum exhibit from his research paper were unseen by the classroom teacher. The project plans, or scores formed by the students, were also not recorded except by the researchers. Where learning artifacts are produced, increased emphasis needs to be placed on chronicling students' development processes. These are necessary to help record for the teacher process decisions that are difficult to detect and recognize (Land & Greene, 2000). In addition, Meyer et al. (1997) suggest providing opportunities for students to describe their mistakes with peers. The unit created by the cooperating teacher and primary researcher failed to make full use of reflection, which could have helped provide these process details. Computer-based intentional learning environments (e.g., Oliver & Hannafin, 2000; Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989) may offer students more directed opportunities toward reflection and documenting students' decision-making and learning processes. Other monitoring methods, such as reflective journaling (Spaulding & Wilson, 2002), double entry journals (Hughes, Kooy, & Kanevsky, 1997) and KWL strategies (Carr & Ogle, 1987; Ogle, 1986), may also offer promise in computer-supported self-regulation and metacognition, as well as documentation for summative assessment.

Next, the adolescents that participated in this study often struggled with identifying and describing their abilities. In addition, they segmented their abilities and domain knowledge based on the classrooms they entered. For example, Bob could not comprehend why math and science knowledge would be transferable to geography, and Brock disconnected solving problems in math from more general problem solving. Simply put, students mentally "turned off" math as they physically walked out of the math classroom, while mentally "turning on" geography as they walked into geography class. This fragmentation of knowledge and skills revisits the value of preventing inert knowledge (Bereiter & Scardamalia, 1985). Like transfer of knowledge, teachers and curriculum developers should emphasize transfer of skills and abilities across domains. It seems from this research that a greater emphasis should be placed on exploring cross-disciplinary units and team teaching, so that students observe use of knowledge and skills in multiple content areas. As mentioned earlier, because computer skills were emphasized in all their classes, the participants had no difficulties in transferring these skills across domains.

Researchers

The preponderance of research and implications for practitioners suggests differentiating pedagogy to match individual abilities (Beck, 2001; Burke & Dunn, 2002). However, little research (c.f., Summerville, 1999) recommends developing students' awareness of their individual differences, such as abilities, and encouraging teachers to provide opportunities to meaningfully demonstrate these abilities in their learning. Project-based learning, such as the human rights unit in this research, afforded students flexibility to use their knowledge, skills, and abilities in a variety of ways, individualizing the instruction and

the learning for themselves, as well as discovering novel means to use the technology tools available to them. Further empirical research should examine the benefits of making students aware of their abilities and providing guidance in how these abilities may be used to achieve learning goals, but not attempting to adapt instruction to meet specific abilities.

Also, we grappled with understanding how personal behaviors such as organization interacted with expertise in abilities. We were also unsure how behaviors and personality traits differed from abilities. Ericsson, Krampe, and Tesch-Romer (1993) contend that expertise has specific developmental characteristics, which may distinguish it from behaviors. More research is needed in this area, as well as to examine how pragmatic factors such as time constraints may cause abilities or behaviors to be used or filtered out.

Student-centered learning approaches, like project-based learning, often use cooperative and collaborative learning (e.g., Blumenfeld et. al, 1991; Marx, Blumenfeld, Krajcik, & Soloway, 1997). The primary researcher and cooperating teacher chose to limit the collaborations in this project-based unit to peer reviews. We were concerned that cooperative grouping may obscure the individual differences of learners displayed in the learning artifacts, where students with stronger interpersonal skills may dominate more intrapersonal individuals. However, further research should examine how cooperative and collaborative learning would mediate the individual differences of the learners, exploring how individual differences result in group products.

This research focused on the voice of the students. Further research should also examine project-based learning from the teacher's perspective (c.f., Brush & Saye, 2000; Scott, 1994). Principally interesting and valuable may be how teachers define project-based learning, what effects these definitions have on the artifacts students produce, and what skills are necessary for teachers to successfully manage project-based learning, such as Grant and Hill's (in press) list of factors influencing student-centered pedagogy.

Moreover, this research capitalized on the ubiquitous computing environment to propel changes in the geography teacher's pedagogy and the ways in which the student could learn. However, continuing research needs to examine factors affecting teachers' implementations of student-centered learning, such as content, pedagogical and technological knowledge (Pierson, 2001), as well as epistemological beliefs (Ertmer, 1999, 2003; Ertmer et al., 2001; Windschitl & Sahl, 2002). For example, other low-student-to-computer-ratio research (e.g., Bickford et al., 2002; Windschitl & Sahl, 2002) has documented teachers' resistance to change practices even over longitudinal cases.

Finally, in this small study, Allison, Bob, Brittany S., Brittany T., and Brock were students at a private day school with ubiquitous access to technology tools and a broad range of high abilities. Although this may limit generalization to other populations, other research should examine how students in public rural and urban schools and with a variety of ages perform within similar open-ended environments and with a variety of computer-based tools. Researchers may discover similar high mathematical/logical and verbal-linguistic abilities, reflective of our educational emphases (Gardner, 1983), but other singular high abilities may be distinct in these

learners. It would also be interesting and worthwhile to study if other populations segmented their abilities like the participants and what other influences affect the use of abilities. Longitudinal studies following younger students may help provide evidence for if and when students begin to filter their abilities for specific domains and tasks. Likewise, further research may examine more closely how technology tools may augment, extend, or compensate for learners' individual abilities.

CONCLUSIONS

Ability identification or measurement and computer-supported project-based learning are not panaceas. Combined, however, they offer students with a variety of individual differences opportunities to learn and represent their learning in myriad accurate and acceptable approaches. Teacher educators should model for students, as well as provide experiences for preservice and inservice teachers to demonstrate instructional strategies, assessment techniques, and classroom management skills that incorporate student-centered learning with multiple representations of learning. Likewise, school administrations and classroom teachers should consider balancing didactic instruction with methods that allow in-depth inquiries to provide students the opportunities to practice the metacognitive skills and self-regulation necessary to monitor and manage their learning. These skills are the hallmarks of life-long learning and are necessary in the Information Age.

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