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Technology Support for Learning Scientific Control as a Whole Class

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ABSTRACT

Third grade students used wireless handhelds and a large shared display in a whole class activity to discover strategies for the control of variables in scientific experiments. The technology suite supported activity requirements including synchronous individual control, face-to-face interaction, and instantaneous display updates. In an empirical study, students demonstrated learning in both task-specific and transfer domains. Analysis of activity discourse yields a representation of "theory salience" that encapsulates student progress toward the task goal.

INTRODUCTION

Elementary school students spend more instructional time in whole class activities than in individual or small group activities; in a recent national survey of kindergarten teachers, almost half of instructional time was structured as whole class activity (NCES, 2001). Given the predominance of the whole class organization, it is somewhat surprising that technology support for whole class activities is so unbalanced. Schools have traditionally been leaders in the adoption of group display technologies, from opaque projectors to video projectors. This supports broadcast communication (including lectures), but leaves interaction with technology solely in the hands of the presenter. With the important exception of the calculator, whole class activities rarely involve individual students directly interacting with technology. The technology imbalance biases utilization toward a transmissive model.

The emergence of wireless communications has had a stimulating effect on the learning technologies research community because of their potential to put control of technologies into the hands of individual learners (Soloway et al., 1999; Colella, 2000; Danesh et al., 2001; Roschelle & Pea, 2002). The limited screen size of handheld devices, however, makes their use problematic in whole class instructional contexts that require a common visual referent. One alternative is to add a shared display to reflect the aggregate work conducted using individual handheld devices (Dufresne, et al., 1996; Rekimoto, 1998; Stewart, et al., 1999; Wilensky & Stroup, 2000).

In this paper we present a case study of an instructional design that combines networked wireless handhelds and a large shared display to help third-grade students gain a better understanding of a fundamental strategy of experimental science: evaluating the impact of one variable in a multivariable system by holding the other variables constant. This *control of variables* (CoV) strategy is not easy to master, particularly across content domains; even college-aged students show unreliable application of the strategy (Kuhn et al., 1998; Schauble, 1996). However, successful instructional strategies have been developed for even young children. Chen and Klahr (1999) demonstrated that children in second through fourth grades could be successful at adopting the CoV strategy given a combination of (1) opportunities to design their own experiments and (2) direct instruction in the design of unconfounded experiments.

Our goal was to extend this work by seeking designs that led to the acquisition of the CoV strategy without the need for direct instruction. We designed a *participatory simulation* (Colella, 2000; Wilensky & Stroup, 2000) activity, *Who's Who?*, in which each student simultaneously controls a single independent variable. In order to promote discovery of the CoV strategy, the activity requires that the manipulation of independent variables be instantaneous, and that all participants can see and discuss the effects of those manipulations. Our hypothesis was that universal involvement, external feedback from a large visual display, and the need to collaborate with peers would combine to lead to acquisition of the strategy without the need for direct instruction.

WHO'S WHO?

In *Who's Who?* the students are seated on the floor in front of a large screen. On the screen, projected from behind the students, is a picture consisting of a grid of large "pixels": discs colored either orange or blue. Each student holds a handheld (Palm-size) PocketPC computer, on which is displayed one large button. Each PocketPC is linked to a specific pixel; pressing on a button causes that pixel to change its color from orange to blue (or vice versa). The projector is driven by a notebook computer, which also serves as the hub for a wireless network to which the PocketPCs also subscribe.

In the *Who's Who?* activity, the students are told simply to "re-color" the grid from its original (random) configuration to a target configuration (also shown on the display) as quickly as possible (with an elapsed time clock displayed prominently on the screen). The students are told nothing about the relationship between the buttons and the screen. In order to complete the task, the class needs to collectively discover (a) the *mechanism* by which pixel colors are changed (i.e., the 1-to-1 linkage between PocketPCs and pixels, and the fact that button presses switch color), (b) a *strategy* for effecting the global state change (i.e., one person at a time), and (c) a *control process* for implementing that strategy (e.g.,

Figure 1. *Who's Who?*: students using PocketPCs to control color of "pixels" in projected display.

centralized control directed by one student).

METHOD AND DATA SOURCES

Seventeen third-grade children, including eight girls and nine boys, completed the following sequence of activities:

- *Pre-tes*t (day 1): a written test to evaluate his or her understanding of the CoV strategy in an alternative domain (articulation of an effective strategy for assessing which of three ingredients in a mixture of dog food caused the dog to refuse to eat).
- *Who's Who? 1* (day 2): students solved *Who's Who?* puzzle.
- *In-test 1* (day 2): interview to evaluate student's understanding of (a) mechanism and (b) strategy associated with this specific activity.
- *Who's Who? 2* (day 3): students solved *Who's Who?* puzzle, with new PocketPC-to-pixel linkages.
- *In-test 2* (day 3): same as In-test 1.
- *Post-test* (3 weeks later): same as Pre-test.

Data collected included handwritten pre- and post-tests, activity logs of PocketPC usage, videotapes and transcriptions of classroom discourse while solving *Who's Who?*, and videotape interviews and field notes (In-tests). The videotape transcript of the first *Who's Who?* activity was analyzed for the purpose of identifying the theories which were raised by the students during the activity, and the class's subsequent treatment of those theories. Over 500 utterances in that discourse were time-stamped and coded along two attribute dimensions: the specific theory (if any) that the utterance addressed, and the nature of the speech act (e.g., raising the theory, providing counter-evidence, testing a hypothesis) relating to that theory.

RESULTS

Task completion

The children reached the goal configuration in both activity sessions. In the first session, 32:47 minutes were required to complete the task. The second session lasted 3:54 minutes.

User activity

The system was instrumented to record the time and source of each button press. Students averaged 490 button presses apiece (range 147 to 939) during the first activity, or about one press, per user, every four seconds for almost 33 minutes. During the second session, students averaged 11.7 button presses (range 1 to 31), or about one press every 20 seconds; four of the students pressed the button the minimum number of times (either once or twice, depending on the initial state of their pixels). Girls averaged 574 presses to the boys' 406 during the first session, but frequency by gender during the second session was virtually identical.

Task-Specific Understanding

Task-specific understanding was assessed through individual interviews conducted with each student following a *Who's Who?* activity. In each case, based on field notes and videotape recording, two independent reviewers used multiple indicators to classify each student as either "understanding" or "not understanding" with respect to the mechanism of the system (how it works) and a strategy for accomplishing the goal (how to work it). Most of the task strategy learning occurred during the first session, with 94% of the students articulating the "one at a time" algorithm in interviews following each activity. Mechanism understanding—as evidenced by an ability to describe how the buttons impact the display—increased from 65% to 88% between the two sessions.

Domain-Independent Learning

Student performance improved significantly from pre- to post-test ($X^2(1)=5.1, p<.03$) on the transfer (dog diet) question, with 53% students articulating an effective strategy prior to the *Who's Who?* activities, and 88% on the delayed post-test.

Discourse analysis

Students explicitly or implicitly identified seven distinct theories relating to the activity, including (besides the actual operation of the system) the theory that pixels had a "default" color which changed only as long as the user's finger remained on the button and the theory that the PocketPCs operated on the pixels like infrared remote controls. About half of the utterances could be classified in this way; the remainder was incidental comments or statements not assignable to any of the theories.

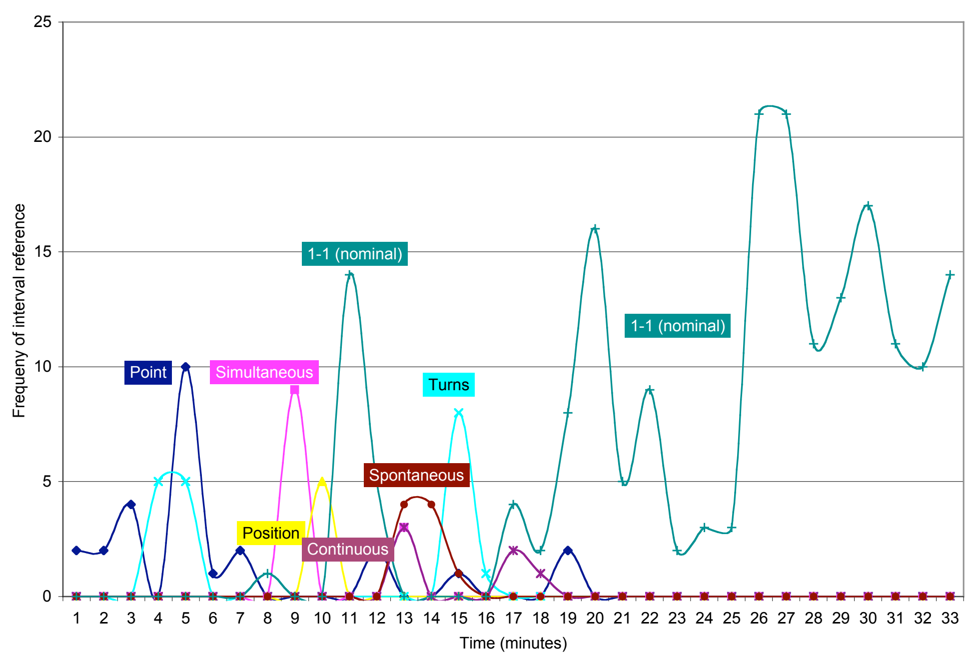

Figure 2. Theory *salience* over time. Each color represents the frequency of reference to a different theory. All theories except the normative theory are abandoned by minute 20.

Among the remaining utterances, students spent about 2/3 of their time working on the normative theory regarding the operation of the system, with the remainder devoted to theories that were raised and either rejected based on empirical tests (2/6) or simply abandoned without refutation (4/6). By counting the frequency of theory references, we were able to generate a trace of *theory salience*: the relative importance of a theory to the collective discourse over time. The graph in Fig. 2 shows the competition among theories for the first 2/3 of the activity, with the final 1/3 of the activity devoted to working out a control scheme to test the theory and implement the solution. About half of the classifiable speech acts related to the implementation of the normative solution; among the remainder, providing verbal support for an active theory was the most common speech act.

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NCES (2001). U.S. Department of Education, National Center for Education Statistics, Early Childhood Longitudinal Study, Kindergarten Class of 1998–99, Public-Use Base-Year File. Table 50.—Percentage distribution of kindergarten teachers' time spent on certain instructional approaches, by program and school type: Fall 1998.