From Handheld Collaborative Tool to Effective Classroom Module: Embedding CSCL in a Broader Design Framework

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Abstract: The TechPALS project expanded a general-purpose handheld CSCL tool (from Chile) to a 3-week classroom module for primary school mathematics (in the United States). To go from tool to module we articulated a framework for an effective CSCL practice—including curricular fit, training materials, pedagogical guidance, formative and summative assessments, and logistical support. In parallel, to meet requirements of the U.S. Department of Education, we conducted classroom experiments to investigate the achievement differences between students who were randomized to use either TechPALS or a non-CSCL product. In this paper, we examine the design changes from initial classroom pilot tests to eventual attainment of statistically significant results, emphasizing the integration of technology, activity designs, and broader educational practices that was required to achieve impacts in ordinary, low-income schools. Based on these results, we recommend a “curricular activity system” framework to support effective CSCL practices.

Introduction

The CSCL conference theme, CSCL Practices, suggests a maturation of the field from CSCL’s traditional focus on design and analysis of collaborative learning with technology to also include more research on successful implementation of CSCL in broader instructional contexts. The Call for Proposals emphasizes the need for CSCL to “design and deliver appropriate technological tools that could be well integrated into educational practices and adopted by the pupils as well as designing associated learning activities, whilst exploring efficient ways to influence appropriately the corresponding contexts, on different scales.” In tandem, we see an increasing emphasis in the field on what might be termed CSCL Effectiveness—comparisons of CSCL approaches to existing, non-CSCL approaches to the same subject matter. Random assignment experiments are a powerful methodology for such experiments, and an increasing number of experiments are being conducted in CSCL, particular in the area of validating CSCL “scripts” (e.g., Schoonenboom, 2008). We see a need for combining the practice and effectiveness perspectives to generate more research-based knowledge about effective CSCL practices.

In the TechPALS project, we aimed to investigate whether an existing CSCL tool from Chile, called “Eduinnova” might serve as the basis of an effective CSCL practice in American primary school classrooms. Eduinnova is a suite of software activities and database of content for wireless, handheld platforms. While these activities were not specifically mathematical, they could be adapted to mathematics tasks. To expand from Eduinnova to a classroom module, we integrated Eduinnova with a portion of the American mathematics curriculum, specified how it fit into American instructional practices, designed training materials and supporting classroom routines, incorporated formative assessment practices, and identified appropriate summative assessments. To evaluate whether the resulting classroom module, called TechPALS, was effective, we conducted randomized experiments in two schools in our pilot year and three more schools in the subsequent experimental year. As we will describe shortly, the pilot year yielded mixed results. This led to significant design iteration. Some of improvements were focused on the tool itself, but many were focused on the supporting framework. After applying this broader framework, we obtained statistical significant effects in our school experiments; students who used TechPALS learned more.

In this paper, we use these experimental results to provide a context for a discussion of the broader design framework that was needed to go from a tool to an effective classroom module. We describe three phases of design:

- From CSCL tool to pilot classroom module
- From pilot classroom module to implemented classroom module
- Beyond the module implemented in our experiments: What is needed next?

We begin by briefly describing the Eduinnova tool and reviewing relevant theory and research.
Chang, 2007), where handhelds’ mobility is naturally required because of the setting. The low-cost and ease of integrating devices into everyday classroom routines makes handhelds also attractive for in-school uses (Rochelle & Pea, 2002). Focusing on these in-school uses, Nussbaum and colleagues designed software that runs on low-cost mobile devices in support of collaborative activities among students working in small groups, targeting typical school subject matter (Cortez, Nussbaum, Rodriguez, Lopez, & Rosas, 2005; Zurita & Nussbaum, 2004). This software and the related activities are called “Eduinnova.” After successful initial trials in Chile, Nussbaum sought collaborators in other countries who could leverage Eduinnova in further research and development. SRI decided to test the approach for the teaching of fractions for fourth grade (age 9) students in American primary schools.

The theoretical approach underlying Eduinnova builds on stable bodies of research-based knowledge in cooperative learning and formative assessment. Two well-known key principles for designing these effective cooperative learning patterns and incentives are:

1. **Positive interdependence**: The task should be designed so that individual contributions are needed for group success; “students need to know that they sink or swim together.” (Johnson, Johnson, & Holubec, 1998, p. 4.7).

2. **Individual accountability**: The task should be designed so that each individual has their own work to do and cannot expect to succeed be freeloaders on the efforts of their partners (Slavin 1996).

Meta-analytic studies of cooperative learning have found a positive effect for cooperative learning interventions that incorporate these factors. In a review of 104 studies, Johnson and Johnson (1987) found an effect size of +0.78 favoring cooperative learning over individual learning. In a review of 52 studies, Slavin (Slavin, 1996) found a +0.32 effect size favoring reward structures in cooperative learning that include the features of positive interdependence and individual accountability.

Formative assessment incorporates the notions of rapid, useful feedback to students and teachers. In a meta-analysis of 58 studies, Bangert-Drowns and colleagues (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991) found a modest overall positive effect (+0.26) for feedback on student achievement. A second meta-analysis by Kluger and deNisi (1996) found higher effects when students were given feedback on the correctness of their solution methods and on their improvement from earlier trials and when they were using computers. Effect sizes for feedback for these interventions ranged from +0.41 to +0.55. Finally, other individual investigators have found that some of the most effective forms of feedback (1) guide improvement on a student product as it is being made or (2) guide teachers to adjust students’ instruction (Butler & Winne, 1995). In fact, researchers (Fuchs & Fuchs, 1986) found large positive effects for achievement when teachers were required to alter their educational program for students if particular patterns in data were found (ES = +0.91).

The Eduinnova software aims to support both cooperative learning and formative assessment principles. By managing the work of assigning roles in collaborative tasks to students, software can make it easier to implement CSCL in the classroom. Further, by providing rapid feedback to students and teachers in a relevant and comprehensible format, software can make it easier to implement formative assessment.

Four activities drew our initial attention as fitting our target domain of 4th grade fractions: Consensus, Exchange, Ordering and Aiming Between. We describe each briefly below, with specific attention to how they support cooperative learning and formative principles. We also discuss the feedback provided to the teacher in the Eduinnova framework.

**Consensus**

In the Consensus activity, each student in the group of three receives the same multiple choice question at the same time (Figure 1). Each student enters an answer independently (individual accountability); however, the system requires that students agree on an answer (positive interdependence) and provides feedback only at the group level. If students do not choose the same answer, the software tells them they must agree, which generates much discussion. Once students agree, the software tells them whether they were all right or all wrong (formative assessment). If wrong, the software makes the previously incorrect choice unavailable so that students individually select a different answer. The group may not go to the next problem until they have answered correctly. After several failed attempts (usually three), the software will only allow them to choose the right answer.

**Exchange**

In the Exchange activity, each student receives two representations of a fraction, such as a numeral representation and a pie representation (Figure 2). Each student’s goal is to match the representations on his or her screen. A match is achieved if the representations depict equivalent fractions. To achieve a match, students exchange representations within their group (positive interdependence). When all three students think they have a match, they check their answer. Similar to Consensus, the software tells the students only that all the matches are correct or that at least one student does not have a match. It is up to the students to determine who has the mismatched representations. Because of the need to both exchange representations and find mismatches,
students have to interact with each other cooperatively. Further, because one student may have the numeral 1/2 and another student a pie showing 2 of 4 shaded sections, the students are encouraged to explain to each other why particular representations are or are not equivalent. After several failed attempts (usually three), the software indicates the correct answer.

Ordering
In the Ordering activity, each student in the group of three receives a unique fraction between 0 and 1. As a group, the students must input the fractions in a sequence of ascending order. Each student must submit her fraction at the right point in the sequence. Once all group members have submitted their fractions, the system will evaluate the submitted sequence. If the group has submitted an incorrect sequence, the system will give them another try.

Aiming Between
In the Aiming Between activity, consists of two parts: generating a unique fraction and evaluating fractions on a number line. Each student in the group of three receives the same representation of a number line with a target interval highlighted as shown in Figure 3. The number line always starts at 0 and ends at 1. The target interval and tick mark divisions vary from item to item. Each student tries to construct a fraction that would fall in the interval of the number line that is targeted. For example, if the target extended from 24/100ths to 51/100ths, a correct response would be any fraction greater than or equal to 24/100 and less than or equal to 51/100. Each student enters her answer independently (individual accountability). After all group members answer, the system checks to make sure that each group member has submitted a unique fraction (equivalent fractions are accepted). If a group member has submitted an answer that had already been given, the system instructs her to submit a unique answer. Once the group has submitted unique answers, the system allows the group to proceed to an answer evaluation screen. Each group member evaluates each of the three answers as either correct or incorrect. If the group members do not agree on the correctness of a response, the system instructs the group to come to a consensus. Once all group members evaluate the three answers in the same way, the system evaluates whether the consensus evaluation is correct. If the group has evaluated correctly, but did not submit at least one correct answer, the group must start over. If the group has evaluated the answer choices incorrectly, they must
evaluate the answers again. After three incorrect evaluations, the system displays color-coded arrows on the item’s number line representation showing the location of the students’ answer choices along with a list of the submitted answers. Again, feedback occurs only at the group level, and students must agree (positive interdependence). Once students agree, the software tells them whether they were all right or all wrong (formative assessment).

Figure 3: Handheld showing the fractions construction screen for the Aiming Between activity

Feedback to the Teacher
Across all activities, the teacher receives feedback on how the students were doing. The feedback was organized as a simple grid of groups (rows) by problems (columns) as displayed in Figure 4. A cell in the grid is colored green if the group gets that problem right on the first try, yellow if the group gets the problem right on a later try, and red if the group exceeds the number of allowed trials. By scanning the grid, a teacher can identify groups that are having trouble (many red cells in the row) and provide assistance. Alternatively, the teacher can focus on a particular problem (many red cells in a column) that requires additional explicit teaching. Thus the teacher can enact formative assessment by adapting their instruction to fit emerging student needs.

Figure 4: Handheld showing the teacher feedback screen

Year 1: Design and Pilot
The TechPALS design process involved both development work and pilot testing, both of which took place in the first year of the project, the 2006-2007 school year. The development work involved adapting Eduinnova activity structures to 4th grade fractions content and designing training materials for students and teachers. The pilot testing work involved identifying or designing measurement instruments and conducting preliminary field tests in classrooms. We describe our process for both the development and pilot testing work below.

Initial Design of Classroom Modules
Our first big decision in fitting the CSCL activity into a larger instructional framework was to target collaborative learning to a specific phase of instruction. In broad terms, we saw instruction as composed of three phases of instruction: 1) teacher-led presentations and discussion, 2) student-centered practice, and 3) homework. We decided that TechPALS would deploy collaborative learning as an alternative to individual student practice.

To support development of suitable activities, we organized the content of 4th grade fractions into two categories, concepts and procedures, each with three subtopics. We decided to focus on three important concepts of rational number: number, part-whole, and measurement. We organized our thinking about rational number procedures into three categories: operations (adding and subtracting), equivalence, and ordering (including comparison). The design team then proposed four activities, each based on prior Eduinnova activities, which would collectively cover the concepts and procedures, as shown in Table 1. (Please note that we understood that
the concepts and procedures interconnect and did not propose teaching them in isolation; rather multiple activities allowed us to vary the emphasis and ensure coverage.)

The Consensus activity, because it is based on multiple-choice questions, can address all concepts and procedures. However, we did not want to use only this activity because of the potential for students to lose motivation. We conjectured that the Exchange activity would be particularly appropriate for the concepts and procedures relating to equivalent fractions. This activity format focuses students on matching different representations of the same quantity. For example, the students may be challenged to match the fraction 1/4 to a pie divided into 8 equal slices, two of which are shaded. In each group of three students, students would have three equivalent fractions to match, expressed in either the same or two different representations. The Aiming Between activity was intended to focus on the concept of a fraction as a number on a number line and to require students to construct fractions (rather than choosing among numbers already expressed as fractions). Finally, the Ordering activity introduced a new form of engagement because it required students to press a button at the right time to correspond to the place of their fraction in an ordering from smallest to largest. After the activities were determined, we developed databases of content for the individual items in each activity based upon a detailed analysis of the content in the curriculum and research suggesting the kinds of problems that students would find to be difficult.

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<thead>
<tr>
<th>Activity Type</th>
<th>Concept</th>
<th>Procedure</th>
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<tbody>
<tr>
<td></td>
<td>Number</td>
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<tr>
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<td>Ordering</td>
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Table 1: Four Activity Types to Cover Mathematical Concepts and Procedures

Based on prior research (e.g. Webb, 1991), we realized it would be necessary to provide training to students and teachers about the desired cooperative learning behaviors. To encourage TechPALS students to engage in appropriate collaborative behaviors, we developed “The Cooperagent,” a short multimedia presentation and storybook about an agent who models collaborative learning behaviors and training. Teachers received parallel training on their role in supporting cooperative learning. Consistent with the recommendations of Webb (1991), students were guided to explain their answers and procedures and to ask for explanations, not just “the answer.”

**Pilot Testing**

We tested our initial materials in three schools, each with different standings according to the California Academic Performance Index (API, used to rank California schools’ academic achievement from low to high):

1. A bilingual school in a major urban center, middle API.
2. A school in an affluent suburban location, high API.
3. A school in a relatively poor suburban location, low API.

In each case, the school used TechPALS for 2-3 weeks, however only schools 2 and 3 were teaching fractions while TechPALS was being implemented. We collected observational and test score data during the pilots. Five key findings emerged:

1. The approach did not seem to work well in the school with low API due to severe behavioral problems.
2. It also did not work well in the school with high API; the students had already mastered the material. It did work well in the bilingual school with middle API.
3. The assessment we used, the Iowa Test of Basic Skills (ITBS), did not have enough fractions items on it to measure the learning we were seeing through observations. Further, the items that did exist on this test were mostly procedural; the test did not pick up conceptual gains.
4. The ordering activity did not work well as a cooperative learning activity. In many cases, we observed one student directing other students to press buttons in sequence. The other two students were therefore passive. We were discouraged by the level of training it might take for students to do this activity more collaboratively.
5. Technical problems reduced time on task.
5. Although collaborative behaviors were observed, we felt they could be more strongly encouraged.

Discussion
Our first step in going from the Eduinnova tool and activities to a classroom module was to determine a place for CSCL in instruction; mainly as a replacement for time typically allocated to individual practice. Although this may seem somewhat trivial, time is a major problem in American classrooms—if teachers are required to find additional time for technology use, teachers tend to use technology less and less. Also, because American classrooms are highly accountable to curriculum standards, it was important to direct technology use to a critically important and difficult topic, such as rational number. In addition to curricular fit, we produced training materials to introduce desirable collaborative behaviors to students and teachers. While our initial research focused more on the technology and student use of the technology, we quickly came to realize that the context of practice needed additional attention if we hoped to realize and measure the potential benefits of a CSCL approach.

Year 2: Design Refinement and Randomized Experiment
In Year 2, we refined the design considerably. The design refinements offer a look at the broader issues that must be tackled to integrate CSCL into ordinary classroom instruction. In addition, we conducted an experiment across three schools, which demonstrated statistically significant results. Observations, however, suggested another phase of design would still be needed.

Design
We discuss our refinements in order from the broadly contextual to the narrowly technical.

First, we decided that TechPALS could not be expected to produce results in schools with severe behavioral difficulties (collaboration was an unlikely when students were frequently misbehaving). Further, although we could have made TechPALS appropriate for advanced students with more time to produce adaptive databases of content, in the short run we decided the content was not appropriate for affluent suburban students who were more than one year ahead of their lower-income peers. Hence, we determined to target TechPALS towards schools that were in the middle of the API distribution, not at the tails.

Second, in order to measure both procedural and conceptual gains, we switched from the commercial ITBS test to an established research-based test for primary school fractions content. Because the test was targeted to students who were one year older, we supplemented the test with some additional items.

Third, we further specified the fit of the TechPALS module to overall instruction – we analyzed the textbooks teachers would be using and specified an interleaving of teacher-centered presentations (without TechPALS) to student-centered practice (with TechPALS), so that teachers would present the appropriate concepts and skills shortly before students would practice them in TechPALS. Further, whereas in the pilot a specially-trained “teacher aide” introduced TechPALS, we provided more support to teachers so that they could be in charge of the activity. We did this because we observed that students were less inclined to take the activities seriously when their ordinary classroom teacher was less involved.

Fourth, we sharpened the training materials (Cooperagents). To help students concentrate on the conceptual and procedural aspects of the math, we simplified and focused the Cooperagents training on the core cooperative learning skills of asking and answering two kinds questions, “how?” and “why?” With this focus, we were able to provide more examples to students of what they should do. Further, we added a group challenge, which emphasized the need for students to help each other. In the group challenge, each student in the group answered a test question, working quietly and individually. Each student, however, received a score that was the sum of the number of correct answers in their group and these were publicly posted. Students quickly surmised that to get a high score, they would have to support learning for all members in their group during the practice sessions.

Finally, we dropped the Ordering activity (because it was susceptible to non-collaborative behaviors) and focused on only the remaining three activity types. In addition, we refined the technical design to reduce the network and login problems that had reduced time-on-task.

Experiment
We describe the experiment in brief here; a longer manuscript has been submitted to a journal, where we will have the longer space required to fully describe our experimental design, procedures, and results.

Our hypothesis was: “Students assigned to the TechPALS intervention will outperform students assigned to work individually in a computer lab.” We tested this hypothesis by randomly assigning individual students to solve fractions problems during practice sessions using either TechPALS or a commercial software program. We selected iSucceed Math (formerly Larson Intermediate Math) for the counterfactual condition. This widely used commercial software provides students a bank of practice items organized by topic.
We recruited two classrooms of fourth-grade students in each of three elementary schools that were in middle of the distribution of schools on California’s Academic Performance Index. The school populations were approximately half Hispanic, 59% from families in poverty, and 45% English language learners. In the first half of each mathematics period, classroom teachers provided their usual instruction to students. We arranged for half the students from one teacher to exchange classrooms with half the students from a neighboring mathematics teacher for the portion of the class period devoted to student-centered practice. In one of the two newly mixed classrooms, students used TechPALS for practice and in the other they used iSucceed Math. This design counterbalanced the effects of the different teachers across the two conditions. Further, the design ensured that students in both conditions spent the same amount of time practicing fractions with technology. Because we used random assignment to form the mixed classrooms, we have no reason to suspect any systematic bias due to the classroom of origin. Students were given a pretest on the first day of the experiment and an identical posttest on the last day of the experiment, spanning approximately 12 days of instruction and practice.

To examine group differences, we used a two-experimental-condition X three-school ANOVA with students’ gain score on the assessment as the outcome variable. We found a significant main effect of experimental condition (Figure 5), with TechPALS students learning more \[F(1,155) = 4.08, p < .05\]. In each school, the effect favored the TechPALS condition, but the effect size (Cohen’s d) ranged from 0.14 in School 2 and 0.17 in School 3 to 0.44 in School 1. Our observational data were consistent with our design premise – TechPALS would work by increasing student collaboration and improving feedback. Behaviors compatible with collaborative learning occurred significantly more frequently in the TechPALS condition. These include reading a problem aloud, asking a mathematical question, giving an explanation, making a collaborative move, directing a peer, and disagreeing with another student. Although our initial research with TechPALS produced promising findings, additional work is needed to increase the quality of the technology, provide better curriculum materials for teachers and students, and train teachers so they can enact instruction that integrates concepts and procedures.

![Figure 5](https://isls.401)  
**Figure 5.** Main effect of experimental condition on students’ scores for fraction knowledge between the pre-test and post-test, in each of three schools.

Although the experiment found an effect, our observations also revealed some disappointments. In particular, we found that the textbooks used by the schools presented concepts very poorly. Further, the textbook presented conflicting procedures for slightly different types of problems. We also observed that teachers’ presentations of fractions topics tended to focus only on procedures. We observed students becoming confused while giving explanations to each other during the collaborative activities and inferred that students could not be highly successful in collaborative learning if neither their textbook nor their teacher provided them with a conceptual basis for the mathematics. Further, we still felt the technology was too expensive and fragile for large-scale use; the handheld devices we were using cost about $300 each and frequently broke or malfunctioned. For the same money, we felt small laptops would be a better value or that custom hardware (ala the “LeapFrog” commercial product) might be more robust. We have proposed additional design phases that would continue to focus on packaging of CSCL in a broader context – we plan to develop all the textbook materials, teacher training, and technology for use during the teaching of rational number in two consecutive school years – and would further refine the technology for greater scalability.
Discussion
Our second step required extensive re-design. Most of the changes we made were broadly contextual, not tightly
to the collaborative activity. For example, we refined our specification of target schools, adopted a more
appropriate assessment measure, and specified in more detail how the CSCL activity would fit into a larger unit
of curriculum, instruction and assessment. We also added training material so ordinary classroom teachers could
take more ownership of the CSCL portion of instruction. In particular, we tightened the Cooperagents training
materials and spent more time with teachers describing how their presentations should interleave with CSCL-
based practice sessions. Some additional time was spent refining the Eduinnova tool and activities. It is
important to note that the majority of our effort was contextual and not specific to the technology.

Whereas in the first year results had been mixed across schools, in the second year we now measured
learning gains in favor of TechPALS in each of the three schools. Further, our observational measured showed
that desirable collaborative behaviors were present in the TechPALS classrooms and not in the computer lab
classrooms. This supports the conclusion that this iteration of TechPALS was an “effective CSCL practice.” Nonetheless, our results also suggested that further improvements would be possible by including more
contextual elements in the classroom module; in the future we plan to focus on rewriting the textbook, providing
more teacher professional development and further refining the cost and reliability of the hardware.

Conclusion
At the beginning of the TechPALS study, we envisioned our design space to be focused on building and testing
a CSCL tool. Our pilot year of work dissuaded us from this naive notion and we quickly re-envisioned the
design space to encompass a broader practice of implementing CSCL. Only by attending to non-technological
aspects of our classroom module, such as the school context with its expectations of student behavior and
teachers’ specific curricular sequence plans, were we able to address factors with significant effects on student
learning. The TechPALS experience provides evidence that to develop effective CSCL practices, we must
expand our design focus beyond CSCL tools and activities.

In particular, we have come to conceive of designing effective CSCL practices in terms of a “curricular
activity system.” At the heart of this phrase, we focus on the design of good collaborative activities. We found
that Consensus, Exchange and Aiming Between each had good qualities for encouraging students to work
collaboratively on mathematics problems. In our broader view, activities are contextualized by two adjacent
phrases. Integrating CSCL activities with curriculum is important, because curriculum is at the heart of how
schools allocate time to activities. Unless a new activity targets important and difficult curriculum content, it is
unlikely for teachers to use it often. Further, deeply considering curricular goals (in our case, how to support
student learning across a matrix of concepts and procedures) influences the choice and design of particular
CSCL activities. Further, we believe it is important to think of CSCL activities in the context of a larger
instructional system. In the case of TechPALS, this system included paper-based training materials to introduce
teachers and students to desired collaborative behaviors, formative and summative assessments, paper-based
group challenges that encouraged students to see the value in helping each other to learn, and teacher
professional development. To go from CSCL tools to effective CSCL practices, we recommend that innovators
focus on the complete curricular activity system, and not just the collaborative activities.

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