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Implementing Mathematics Learning Software Successfully in Urban Schools: Lessons for Research and Practice

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Objectives

This paper presents findings and lessons learned from implementing and scaling up a research-based mathematics learning technology intervention in several dozen classrooms in urban schools serving predominantly low-income students. We address issues essential to improving educational equity, diversity, and student achievement by examining the circumstances and resource configurations that enabled or impeded implementation of the innovative learning software. The context for this analysis is a federally funded efficacy and replication study testing 4 web-based Perceptual Learning Modules (PLMs) focusing on key concepts related to fractions and measurement that were developed through an extensive research process [1, 2]. The PLMs were implemented in successive years with two cohorts of sixth-graders. Participating schools were under unprecedented budget pressure during the implementation years, but resources provided through the project ensured that certain kinds of support (e.g., professional development, supplementary computers, on-site technology and classroom support) were readily available. Implementation has now been completed with both cohorts, and this analysis summarizes quantitative and qualitative data examining challenges and factors associated with the quality of implementation across participating teachers and schools.[1]

Our objective here is to inform policy and to provide practical advice as schools attempt to adopt and scale-up promising technology-based learning interventions. Lessons learned from this project also contribute to the knowledge base about the kinds of issues that must be addressed to successfully conduct randomized controlled trials in real-world classrooms.

Theoretical Framework for the PLM Mathematics Software

The four software modules that comprise the intervention integrate (1) well-established principles of *perceptual learning* that accelerate learners' abilities recognize and discriminate key structures and relations in complex domains [1, 2, 4, 5]; and (2) *adaptive learning* algorithms that use a constant stream of performance data, combined with principles of learning and memory, to improve the effectiveness and efficiency of learning by adapting the learning process to each individual [6]. *Perceptual learning (PL)* emphasizes the importance of learning to fluently and meaningfully extract and process relevant structures, patterns, and relationships in a given task or environment [7; see 4,8, 9 for recent reviews]. In contrast to instruction that focuses on the acquisition of declarative and procedural knowledge, studies of expertise consistently implicate the fundamental importance of learning to recognize and discriminate key structural and relational information in varying contexts. Mechanisms of perceptual learning are particularly suited to addressing this kind of learning.

As an illustration of this approach, consider difficulties many students encounter with fractions. Understanding a fraction as a quantity involves understanding a relation between the denominator, which specifies a partitioning unit, and the numerator, which specifies multiplicative iterations of that unit (e.g., 11/8 is 1/8 multiplied by 11) [10]. Structural relationships such as the inverse relationship between the value of the denominator and the size of the partitioning unit, or the constant proportional relationship between equivalent fractions with different denominators, elude many students, even as they gain proficiency with procedures for operating on fractions (such as "flip and multiply" to divide by a fraction) [10, 11]. Figure 1 illustrates a problem from one of two fraction PLMs designed to make these structural relationships more evident and intuitive. The other two PLMs similarly apply principles

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[1] Analyses of student learning outcomes comparing experimental and control conditions for Cohort 2, controlling for a number of student-level co-variates, are currently being conducted and will be reported separately. Significant effects of the learning intervention on student learning measures have already been reported separately for Cohort 1 [3].

of perceptual and adaptive learning to help students understand the structure of linear and area measurement units.

Method and Data

Sample and Participants

This study involved 41 teachers in 34 schools serving predominantly low-income and minority students in a large city in the Northeast US. Seven additional schools (11 teachers) began participation but withdrew before contributing data. For the analytic sample, Cohort 1 included 708 students in 29 classrooms in 28 schools, and Cohort 2 included 744 students in 30 classes in 27 schools.

PLM Software

Classrooms implemented four PLMs as a partial replacement for standard curriculum on topics related to fractions and measurement. Each module is subdivided into categories, which the student can master independently by correctly responding to 4 out of the last 5 presentations of each problem type. Mastered categories drop out, allowing learners to concentrate on less well-learned material until all categories are mastered.

As students used the web-based software, time-stamped data were automatically collected on a problem-by-problem basis. Teachers could use their teacher dashboard to monitor the complete learning history and real-time progress of each student, as well as a variety of class-level views of activity and progress. The teacher dashboard also had linked and downloadable teaching resources to support students' use of the PLMs.

Data Sources

The analyses presented here focus only on experimental classrooms that used the PLM software (n=29 for Cohort 1 and n=30 for Cohort 2). Data sources include detailed usage and mastery data automatically collected by the software; demographic and standardized test data at the student-level; qualitative observations from classroom visits; and records of communication and participation history. There are several ways to evaluate the quality and completeness of the implementation of the intervention, but in this report we focus on the percentage of mastery achieved in each class averaged across students and modules. While this is in part a measure of student performance, it is also a measure of the degree to which the software was implemented because of the adaptive nature of the software. Data from Cohort 1 indicated that students who were in the lowest quartile in terms of initial performance were able to use the software successfully and even achieve full mastery of all components; however, they needed additional time with the module to accomplish this [12].

Procedure

Teachers were trained and supported in using the PLMs in summer and school year professional development workshops. The project contracted with school technology specialists to update and repair school-owned computers and also provided LCD projectors and supplemental laptops on loan in many schools so that each teacher would be able to get at least half of their students on computers at the same time. The project's implementation team was available by e-mail, text, or phone and made many school visits to assist teachers; most classrooms were visited at least once and some were supported more regularly.

Teachers in Cohort 2 were given guidelines derived from Cohort 1 data for typical numbers of problems they should expect students at different levels to attempt in order to reach mastery with the software.

They were shown how to track this in their teacher dashboards, and the team also gave them periodic progress reports and suggestions for pacing students' use of the software during the year.

Results

Implementation Levels

Table 1 indicates the average percentage of mastery that students achieved across all modules in each classroom for each cohort. Overall, the learning software was implemented to a reasonable degree in most of the classrooms, especially in Cohort 2, where the overall average was 72%, but the range was distributed from very weak to very robust implementations.

Several factors are likely related to improvements from Cohorts 1 to 2. Cohort 1 averages were lower in part because some classes did not get through all four modules by the end of the school year and so had very low or 0 averages for one or more PLM. With one exception, all Cohort 2 classes implemented all four modules at least to some degree. It also was clear in the Cohort 1 data [12] that low-performing students in a number of classrooms were not given sufficient time with the software, and, in fact, often had less access than the averages for students in higher-performing classrooms. When these data were shared with teachers in professional development sessions in the summer between cohorts, several teachers recognized that they may have inadvertently limited their students' learning opportunities by giving them less time with the software, in the belief that they would not be capable of making progress. Being given more explicit targets for student usage in Cohort 2 assisted them in planning and pacing instruction better. The project also provided more laptops, improved resources for introducing the PLMs, more on-site support visits, and detailed individual planning documents in Cohort 2.

We examined the degree to which the mastery levels achieved in each class were predicted by common demographic and student factors, including minority status, eligibility for free school meals,[2] Disability and Limited English Proficiency status, and state standardized test scores in reading and math from the previous year. Spearman's correlations were performed using student-level data for Cohort 1 and Cohort 2. For Cohort 1, significant correlations were found for minority (non-white) status (-.536, $p = .005$), 5^{th} Grade Math scores (.383, $p = .053$), and 5^{th} Grade Reading scores (.429, $p = .029$). For Cohort 2, significant correlations were found for minority (non-white) status (-.389, $p = .052$), CEP (-.500, $p = .010$) and 5^{th} Grade Reading scores (-.389, $p = .040$).

Retention and Attrition

Seven out of 41 schools and 11 out of 52 teachers withdrew from the study across the two cohorts. Table 2 summarizes factors associated with attrition or with a significant delay or compromise during implementation. The most common disrupting factors were related to instability in roster schedules and teachers' positions—what some have termed "churn" or positional instability [13]. An ongoing budget crisis, a large number of school closures and reorganizations, and turnover of principals all contributed to uncertainty and instability related to school leadership, staffing, enrollments, and roster schedules. These factors tended to have the greatest impact at the start of the school year until schools "leveled" classes toward the end of October, though we had instances of classes being re-rostered as late as the end of May, usually as a response to disruptive student behavior. Notably, every Cohort 1 teacher whose position and eligibility did not change, was retained for Cohort 2.

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[2] CEP refers to the Community Eligibility Provision for qualifying for free meals through the USDA National School Lunch and Breakfast Programs. FRPL is Free and Reduced Price lunch. The participating district shifted from FRPL to CEP between cohorts.

We also encountered both planned and unplanned medical leaves that delayed or reduced implementation, but these typically did not result in complete attrition from the study. Access to technology—potentially a large barrier in many of the schools—was generally ameliorated by providing professional on-site technical support and 145 additional laptops. At least 8 schools would not have been able to engage in software-based learning had the project not provided computers. In many other schools, we also helped get school-owned computers back in service and reduced demands on teachers' time by updating browsers and trouble-shooting wireless networks.

As Figure 2 shows, stability is associated with stronger implementations. Students in classes that did not experience changes in teacher assignments, roster schedules, school leadership, or teacher leaves achieved higher levels of mastery with the software. From Cohort 1 to 2, implementation improved considerably in the less stable schools, suggesting that enhanced project support may have had an ameliorating effect.

Significance of Study

The many challenges encountered in under-resourced urban schools affect both the capacity for schools to innovate and improve and for researchers to conduct rigorous, reliable, replicable studies. This paper describes a partnership with a group of schools that successfully negotiated most of these challenges by strategically combining the resources of a funded research study with those of the teacher and school partners. While the project experienced attrition and turnover, these remained manageable, and the intended power of the study was preserved. Teachers and researchers together worked to improve implementation as they gained experience from the first to the second cohort. Lessons learned can inform similar initiatives by others.

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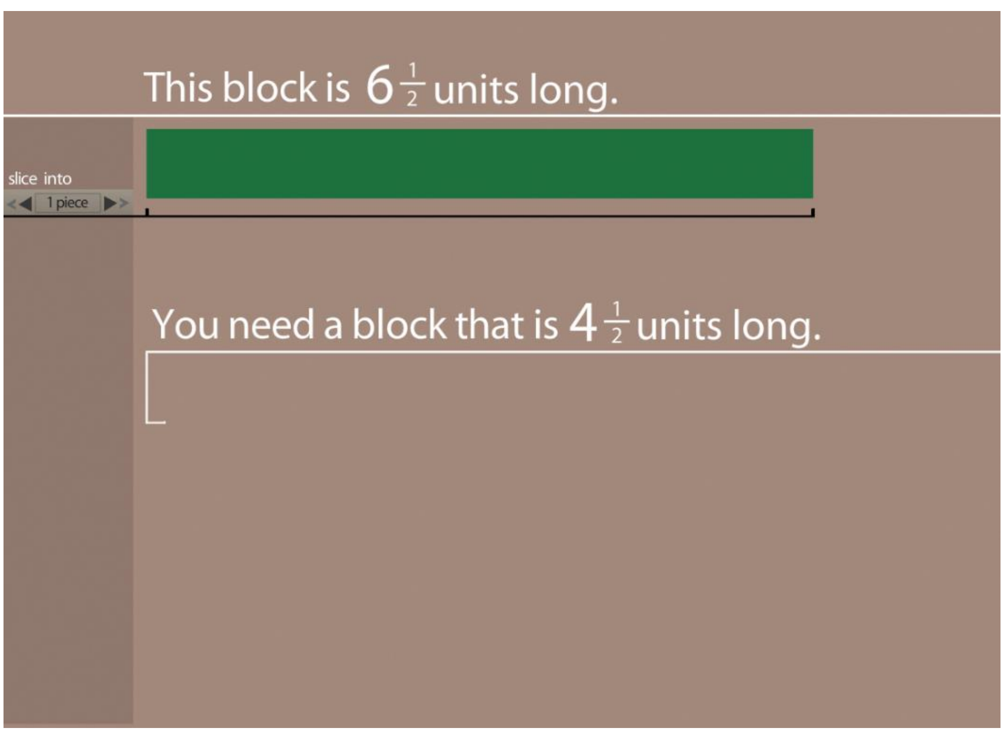
Figure 1: The Slice and Clone 1 PLM environment makes the structure and relations underlying fraction concepts tangible to learners by providing them with interactive on-screen tools that they can manipulate. The students' task is to start with a given quantity and use the slicing and cloning tools to create a new quantity. As shown in the top panel, students operate a "slicer" tool (in the upper left) to cut a continuous extent into a desired number of pieces, thus creating a unit fraction. As shown in the bottom panel, when they have created a successful unit, it drops down into a "cloner" tool (bottom left) that will iterate that unit a desired number of times and output the result. While these screenshots are static, the actual PLM is fully interactive with customized animated feedback at every step.



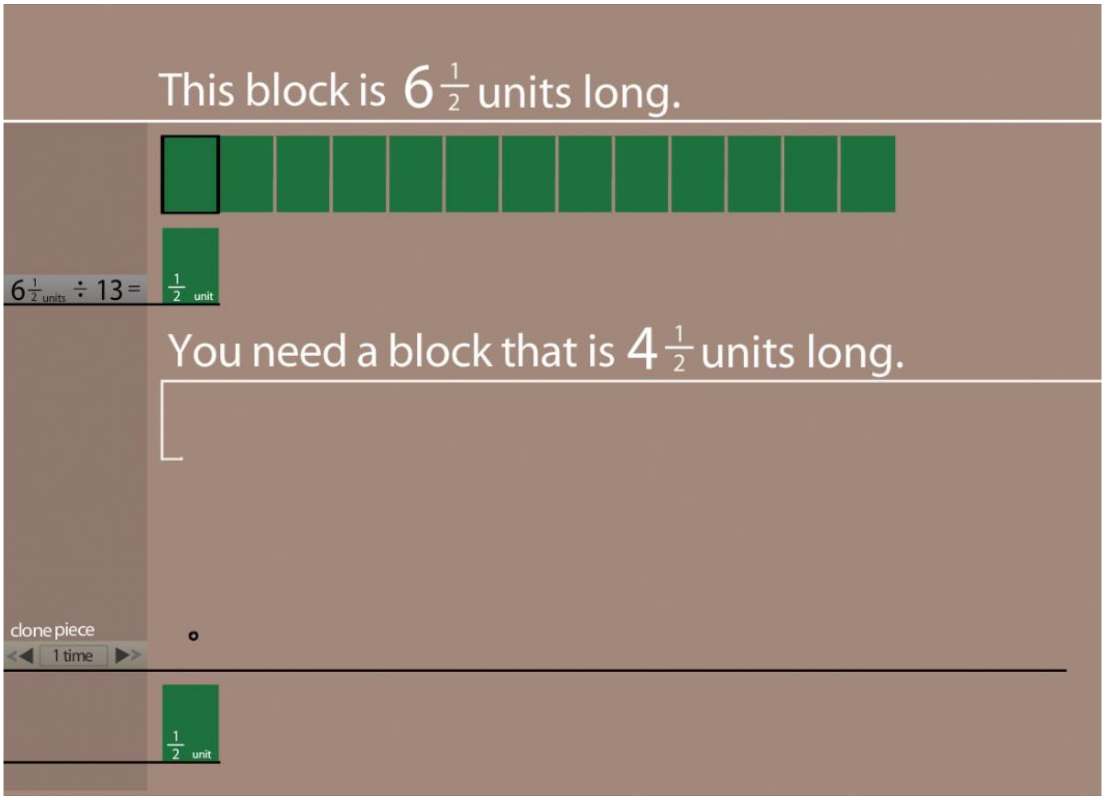


Table 1: Percentage mastery averaged across students and modules for schools in Cohort 1 and 2.

School/ Teacher	Cohort 1 Average % Student Mastery	Cohort 2 Average % Student Mastery
Lilac School	99	98
Beech School	96	95
Olive School	93	75
Buckeye School	91	90
Hazel School	87	91
Aspen School	86	89
Balsam School	85	98
Hickory School, Teacher 2	77	77
Hickory School, Teacher 1	67	54
Dogwood School	65	74
Willow School	62	69
Walnut School	57	NA
Sumac School	55	76
Spruce School	52	69
Ash School	51	53

Poplar School	48	47
Mulberry School	48	NA
Magnolia School, Teacher 1	48	NA
Magnolia School, Teacher 2	NA	76
Elm School	47	66
Sycamore School	47	NA
Cypress School Teacher 1	41	NA
Cypress School, Teacher 2	NA	28
Redwood School	41	48
Palm School	40	NA
Pine School	39	NA
Cherry School	36	NA
Chestnut School, Teacher 1	24	NA
Chestnut School, Teacher 2	NA	68
Maple School, Teacher 1	21	NA
Maple School, Teacher 2	NA	45
Maple School, Teacher 3	NA	74
Birch School	18	NA
Apple School	13	NA
Elderberry School	NA	99
Juniper School, Teacher 2	NA	89
Juniper School, Teacher 1	NA	63
Pecan School	NA	81
Linden School	NA	73
Peach School	NA	69
Plum School	NA	61
Cohort Means	**56**	**72**

Table 2: Factors associated with attrition or compromised implementation. (Note that more than one factor might play a role in a single school or teacher attriting from the study.)

	Early Attrition within Cohort	Late Attrition within Cohort	Attrition between Cohorts	Partial or Delayed Implemen-tation	Total
Rostering and re-rostering issues (shortened periods, classes combined or crossed disrupting conditions)	10	1	2	2	**15**
Change to teacher's position (laid off, quit, changed grade level, changed job)	4	1	4	0	**9**
Medical and maternity leaves or absences	0	0	0	6	**6**
Technology infrastructure or access	4	1	0	1	**5**
Competing priorities and demands, weak or mixed support from school leadership	3	2	0	1	**6**

Figure 2: Average level of mastery achieved by students in Stable vs. Not Stable classrooms.