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An Interdisciplinary Approach to Professional Development for Math, Science, and Technology Teachers

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This article describes findings and evolution of a teacher-training program based on a partnership of knowledge domains (technology, content, and pedagogy), teaching staff (college faculty and school teachers), educational institutions (colleges and K-12), and local communities (urban and suburban). Within 5 years, more than 180 teachers from 15 secondary schools attended a 3-tier summer institute and follow-up activities. Summer trainees were offered stipends, laptop computers, advanced graphing calculators, smart boards, LCD projectors, mentorship, and technical support during the academic year. While teachers were initially frustrated to learn outside their subject areas, they all completed the initial workshop and more than half returned in subsequent years for advance and expert level training. External evaluators collected data and conducted longitudinal analysis of performance indicators for teaching quality and student learning. Teachers reported increased level of student engagement in and comprehension of mathematics and science topics. Graduation rates and student achievement scores in partnering school districts increased noticeably during the initiative. Comparison of target and control groups showed that treatment students consistently outperformed non-treatment students.

INTRODUCTION

Content knowledge (CK) and pedagogical knowledge (PK) were treated as distinct until the mid 1980s when the concept of pedagogical content knowledge (PCK) emerged (Shulman, 1986) to suggest the importance of their intersection and union. Despite such early attention to the question of *how to teach what*, technology knowledge (TK) has been treated separate from pedagogy and content until recent years. In a classroom, they are all intersected and tied together. Not all technologies can be pedagogically suitable to teach all subjects and not all content can be taught with all technologies and pedagogies. The knowledge of 'what goes with what and how' has given rise to a new framework beyond Shulman's original work to describe how all three bodies of knowledge (technology, pedagogy, and content) interact with each other in the classroom. Therefore, contemporary professional development (PD) opportunities need not only follow principles of effective PD (Loucks-Horsley et al., 2010) but also focus on 'how technology can be used' to improve teachers' pedagogical content knowledge (Koehler & Mishra, 2008; Niess, 2011).

An interesting way of using technology to improve teaching and learning is through 'computational modeling and simulation' as a method of scientific inquiry to complement experiment and theory (CSTA, 2013; NSTA, 2008). National laboratories and industry have already been employing it in R&D for more than four decades. Universities and colleges have deployed undergraduate degree programs based on a computational approach to math, science, and technology (C-MST) (Swanson Survey, 2010; Landau, 2006; Yasar et al., 2000-2006). While benefits are promising, challenges are also equally great. The interdisciplinary aspect of C-MST education requires learners to acquire knowledge in multiple domains. Also, due to frequent changes in technology tools and their increasing capabilities, course contents, training materials, and curriculum inventories often need to be updated.

In 2003, with support from the National Science Foundation's Math and Science Partnership (MSP) program, the Authors founded a C-MST Institute in partnership with two local school districts and several national organizations, Rochester City School District (RCSD) and Brighton Central School District (BCSD). In this partnership, the higher-education partners demanded better students from K-12 partners and they in turn demanded better teachers from higher-education partners. This article reports a C-MST approach that carries with it necessary elements of effective PD and innovative pedagogy to enhance both teaching and learning. It is also very timely with the recent recommendations of national math and science standards to teach computational thinking skills. As with any reform, we need to train teachers to reach out to students.

DESIGN & IMPLEMENTATION OF THE C-MST PD PROGRAM

An intensive summer PD was designed for in-service math, science and technology teachers from the two partnering school districts (RCSD and BCSD). The instructional team consisted of about a dozen faculties from various departments, including two from the Education and Human Development Department, four visiting scientists from national partners, and four veteran RCSD/BCSD teachers. Two external evaluators were hired to conduct the evaluation efforts. Driven mostly by the needs of attendees (in-service teachers) and the lessons that the designers had learned about interdisciplinary training, the PD program underwent several modifications. What follows below includes not just the results of the PD, but also its evolution, starting with a brief description of the setting.

CONTEXT: RCSD is an urban school district surrounded by wealthier suburbs, including BCSD that consistently enjoys strong national ratings, and one of the highest 4-yr college matriculation rates (73%) and the lowest dropout rates (0.9%) in the State. By contrast, RCSD has been among the districts with high dropout rate (13.3%), high suspension rates (short term: 49%, long-term: 18%), and lowest 4-yr college matriculation rates (37%) in the State. Poverty is widespread among students in the city district; 88% of the students in the district receive free lunch. Table 1 shows profiles of the urban (RCSD) and suburban (BCSD) partner school districts. They both had much to offer and gain from the partnership.

Table 1

Profiles and subgroup graduation rates in RCSD and BCSD.

Student Subgroup	Graduation Rate (2004-2005)			
	RCSD		BCSD	
	Cohort-2000	Completed	Cohort-2000	Completed
American Indian/Alaskan Native	4	NA	0	0%
Black	1182	52%	15	93%
Hispanic	335	41%	8	88%
Asian or Pacific Islander	48	NA	49	86%
White	287	64%	221	94%
Total	1856	52%	293	92%
Results by Gender				
Female	943	59%	142	94%
Male	913	44%	151	91%
Total	1856	52%	293	92%

ORIGINAL DESIGN: The design of the PD, a four-week (Mon-Thu, 12 noon – 4 pm; 64 hours) summer institute with opportunities for single-year or multi-year training, commenced in 2003. The goal was to introduce in-service teachers to the latest computational technologies and investigative techniques, so that they may use them in classrooms and stimulate student interest in science and math. More specifically, the PD was to include modules for developing/improving (a) the general computer and Internet research skills, b) knowledge for collecting and analyzing data using software (such as LabView), c) abilities to use math modeling software (such as MATLAB), d) knowledge of computer programming (such as FORTRAN 90) and visualization (such as AVS) skills, and e) experience with scientific inquiry using model simulations. Participants were to receive incentives, including summer stipends, laptops, advanced graphing calculators, and coaching support for one year after the summer institute. In return, they were expected to develop lesson plans and implement them, incorporate modeling examples in their teaching, prepare a student team for the annual Challenge, and offer turnkey training to a colleague in the school district who could not attend the PD.

FIRST REVISION: External reviewers raised two major concerns about the design. First, they wondered about the efficacy of teaching programming languages such as FORTRAN to secondary school teachers and expecting teachers to teach it to their students. Second, they wondered whether teachers and students would be able to understand the nitty-gritty of scientific simulations, let alone generating such simulations on their own. In response, designers turned to their colleagues in the ACM/IEEE Supercomputing community to learn about software tools more appropriate for the K-12 level. Encouraged by a post-grant requirement by the MSP program at NSF to develop a 5-year Strategic Plan, the designers shifted their approach from forcing a dress onto the customer to an approach of rather fitting the dress to the customer. Pedagogy and assessment experts were brought to the design team. Informational meetings held to recruit in-service teachers for the summer institute afforded the opportunity to seek input from would-be institute attendees. All of this, especially input from in-service teachers, provided valuable information to calibrate the content, length, location, and dates of the summer institute. In preparation of the institute, designers of the PD held weekly, then bi-weekly, and later monthly meetings. The culmination of this sequence was the creation of a revised PD that addressed the concerns of the external reviewers, needs of the in-service teachers and the objective of the institute to introduce new pedagogies to K-12. Changes made to the original design included:

- Use of more friendly modeling and simulation tools such as those in Table 2.
- Training of Texas Instruments (TI) graphing calculators that are required in State Math exams.
- Adding a module on State/National student learning outcomes & teaching preparation standards.
- Develop an inventory of C-MST lesson plan database to support training & classroom instruction.
- Reach out to all teachers in both districts to increase participation and to maximize the impact.

Table 2

Brief descriptions of software tools used by participants of the PD program.

Interactive Physics (IP) is a visual tool to investigate and experiment with concepts in physics. Graphing tools allow monitoring location, speed, energy, and elapsed time for a system.
AgentSheets (AS) is agent-based modeling tool to create interactive games, virtual worlds, training simulations, and other interactive content by using agents and the rules of engagement.
STELLA is used to model a dynamic system by creating a pictorial diagram to link components and assigning the appropriate initial values and functions (rate of change equations) to the components.
The Geometer's Sketchpad (GSP) is used to model and explore concepts from mathematics and geometry. It computes distances, angles, and areas on images pasted from other tools such as IP.
Project Interactivate (PI) is a set of free online computational science courseware from the Shodor Education Foundation (www.shodor.org) for exploring scientific and mathematical concepts.

Table 3

Two-stage PD strategy to maintain continuity and deepen gained knowledge.

C-MST Summer Training	Number of Teachers targeted with grant support					
	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Introductory	50	25	40	30	0	145
Advance		25	10	20	15	70

The initial plan was to train 50 teachers (Cohort I) for two years and another 50 teachers (Cohort II) for the next two years. Teacher-feedback convinced the developers of PD that self-initiative would be more effective than mandates. Accordingly, instead of compelling participants to attend multi-year summer training, the PD plan was modified to give teachers the option of opting for single-year or multi-year training. An immediate benefit was that more teachers could be trained in the same time period, while also allowing both introductory and advanced trainees to come (Table 3).

MIDCOURSE CORRECTION: In-service teachers attending the institute maintained a professional development activity (PDA) log, which they updated daily. The College's classroom management software (ANGEL) was used for this purpose, and the Project Director, external evaluators and participating faculty monitored and reviewed the logs. Notwithstanding all of the aforementioned deliberations and planning, the first summer institute encountered headwinds as soon as it started. Some in-service teachers were ready to drop out at the end of the first week, in part because they expected that the institute will provide them with turnkey lesson plans, and, in part, because they found the process of learning to use new technologies difficult, a difficulty that got compounded when examples used to introduce software packages (Table 2) fell outside their subject areas. Subjecting a diverse group of in-service teachers (see Table 4), including Special Education teachers, to the same training regiment proved to be a much bigger challenge than what the designers of the PD had anticipated, not the least because some of the institute participants had never used a spreadsheet program like Excel, presentation program like PowerPoint or graphing calculator like TI-83.

Table 4

Distribution of in-service participants according to subject areas and districts.

District	Math	Special Education/Math	Technology/CS	Science
Urban – RCSD	62%	9%	5%	24%
Suburban – BCSD	40%	4%	6%	50%

Several designers of the PD, especially those who are schooled in C-MST approach, were convinced that if only the teachers knew what students in their classes might be able to do with software packages, the teachers will persevere and they and their students will be rewarded in the end. To illustrate the power of software packages, the project director introduced a middle-school student to one of the software packages, the Interactive Physics, and asked him to demonstrate what he was able to build in about an hour. The student built a pool table in 45 minutes and demonstrated how it worked. His demonstration made it clear to in-service teachers that they better be ready for a technologically literate student population. What the middle-school student did also challenged them. If a middle-school student can use the software to create simulations, so should teachers. In addition, institute instructors altered their pace and started providing after-class support and one-on-one coaching. By the end of the third week, the comfort-level of the participants with technology in general and software packages in particular improved. The designers also encouraged interaction and teamwork to develop modeling examples and lesson plans applicable to multiple content areas.

RATIONALE FOR SUBSEQUENT REVISIONS: About 95% of 62 beginner-level attendees completed the summer institute in its first offering (2003). Those who dropped out indicated either an unexpected personal/family problem or stated that the Institute was more demanding than they had expected and that they did not want to commit most of their summer to the institute. Exit interviews of those who completed the summer institute in 2003 indicated 100% satisfaction, with 57% rating the outcome from the institute 'very beneficial' and 43% rating it 'beneficial.' With respect to teachers from different disciplines, 70% of the math and 45% of science and technology teachers rated the outcome from the institute to be 'very beneficial.' Examined from a different perspective, the PD designers learned that 76% of teachers found the materials to be 'extremely useful,' whereas 24% stated that the materials were 'somewhat helpful.' Many science teachers from the urban school district were in the latter group.

As stated in the NSTA report (2008), some science teachers are in the forefront of technology infusion, whereas others are waiting for best practices to emerge to do so. These innovators and early adopters readily integrate microcomputer-based probes into their laboratories, employ digital videos and imagery to illustrate concepts in class discussions, and use administrative programs and electronic grade books to organize their classes. The C-MST institute had its share of such innovators. The suburban partner district (BCSD) had a dedicated physics teacher (S. Whitman) who not only promoted participation of his colleagues in the institute but also developed an inventory of science modeling examples and helped the college STEM faculty train teachers from the urban schools. By and large, science teachers from the city district were more cautious in their approach in introducing technology to classrooms. It appears that limited access to computer labs, skepticism about use of technology, and lack of lesson plans and curricular modules were among the contributing factors.

From the post-institute survey, it became apparent to external evaluators that though the teachers felt that they have acquired enough knowledge about the C-MST approach and the tools needed to implement it, they were much less confident about their ability to deploy it in the classrooms. For example, only 35% felt fully prepared to implement modeling-based lesson in the classroom during the following year, 40% felt 'probably prepared', 15% felt unsure, and 10% did not feel prepared at all. A great majority of urban teachers also anticipated some barriers against fully implementing the C-MST approach in their classrooms. Teachers recognized that software tools made it easier for them to construct a simulation, but they doubted their ability to create one on their own or use the ones that others have developed, ostensibly because the training they received was insufficient.

With the consent of all attendees and instructors, the length of the summer institute was extended from 4 to 5 weeks. This was to enable better preparation and readiness of teachers for the following school year. It also allowed PD designers to better manage unforeseeable difficulties, and more importantly, it also allowed enough time for institute participants to develop team projects encompassing lesson plans and for the teams to share their projects. This modification became part of the subsequent introductory training for later years. Another challenge was that most teachers did not have adequate math (calculus, algebra, discrete math, and differential equations) and computing background to fully understand the mechanics of modeling to develop authentic simulations. As a result, they could not feel ownership of the acquired knowledge to go beyond what they were exposed to by the end of first year training to implement C-MST approach. This challenge led to additional modification to the PD program, which is discussed in the next section below.

YEARLONG PROFESSIONAL DEVELOPMENT: Each beginner-level participant was required to develop at least 2 lesson plans by the end of the summer training and implement them during the following school-year. As explained above, designers of the PD became convinced that summer training and two lesson plans that teachers developed during the summer training were woefully inadequate for them to implement C-MST approach in their classrooms. A two-pronged approach was put in place to improve this situation. First, teachers were requested to update their PDAs on a weekly basis, which were then monitored by external reviewers, the Project Director, and instructors of the summer institute. Second, summer institute participants were offered Saturday trainings during the school year to further improve their technological and pedagogical skills with the software packages.

A full 62% of urban teachers who attended introductory-level summer training participated in the Saturday trainings during the following school year. Half of these came back for the advanced-level training in a subsequent year. Of all beginner-level teachers who did (or could) not attend Saturday trainings during the academic year, 15% (both urban and suburban) came back for their second year of summer training. Overall, 76% of urban teachers pursued additional training after attending the first summer institute, while only 36% of suburban teachers did the same. Partnering districts quickly integrated C-MST training into their own PD offerings as well. Consequently, almost all beginner-level teachers pursued additional training in one way or another.

At the conclusion of the first two years of summer institute, the developers of the PD had a pleasant surprise waiting for them. While two years of training and support helped teachers feel confident in their computational pedagogy skills, some participants, most of whom were very active during their introductory and advanced level trainings, expressed a desire to return for one more year of training. This requested a challenge and an opportunity. When the summer institute concluded during the second year, we had a cadre of teachers who had received beginning and advanced level training. They were distributed among the many schools of the city school district. Beginner-level teachers at the same school building can now be put in small groups (2-3 individuals) under a teacher (coach) who had advanced training and a college faculty advisor to mentor them during the school year. Coaches were given incentives — stipends, smart boards and LCD projectors — and group members could borrow smart boards and LCD projectors for their classroom use. School principals and district officials were so impressed by the use of these tools that they started to acquire them. Table 5 and 6 show the final structure of the three-level C-MST summer PD program as it was implemented in five consecutive years with the support of federal funds from the National Science Foundation.

Table 5

Three-stage PD strategy implemented in the Summer Institute.

Number of Teachers Receiving Summer Training (with grant support – stipend, technology, mentoring)						
Training Level	2003	2004	2005	2006	2007	Total
Introductory	59	47	45	37	0	188
Advance	0	21	21	22	14	78
Expert	0	0	13	15	15	43
Total	59	68	79	74	29	309

Table 6

Profiles of Teachers Receiving Summer Training from 2003 to 2007.

	1st Year Teachers			2nd Year Teachers			3rd Year Teachers			Total
Subject	Urban	Suburb	Total	Urban	Suburb	Total	Urban	Suburb	Total	
Math	96	14	110	42	2	44	22	0	22	176
Science	38	15	53	17	9	26	12	5	17	96
Tech	7	3	10	5	1	6	2	1	3	19
Spec. Ed	14	1	15	2	0	2	1	0	1	18
Subtotal	155	33	188	66	12	78	37	6	43	309

Table 7

Enrollments (Teacher Candidates) at C-MST Courses (from 2003 to 2011).

Number of Teacher Candidates Receiving C-MST Training (without grant support)										
Course	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
NAS 501 (Intro)	3	9	10	41	39	23	29	15	11	180
NAS 601 (Adv)	0	0	0	0	11	11	5	0	0	27
TOTAL	3	9	10	41	50	34	34	15	11	207

In retrospect, adding a third-year of training to marry tool usage and mathematical foundations with content knowledge should not have been a surprise. A national report commissioned by the GE Foundation and published by the Urban Institute (2005) indicates that effective PD programs need a minimum of 160 hours of training to include enough focus on one's content knowledge and its use in the curriculum. Since C-MST has a multidisciplinary nature, the amount of training to actually change teachers' instructional behavior would be more than what is needed in just one content area.

SUSTAINING C-MST APPROACH: In order to sustain the C-MST training after the expiration of the MSP grant, the designers of the PD created credit-bearing graduate courses (NAS 501 and 601 C-MST Tools for Teachers I-II) for teacher candidates. Faculty advisors in both secondary-level math and science teacher education programs and the Master's of Liberal Arts program promoted these courses. To this date, more than 200 teacher candidates have taken the NAS courses without incentives (laptops and stipends). The introductory-level course is still being offered, though the enrollments in them have gone down lately (See Table 7) due to a general declining trend in enrollments in teacher preparation programs in the state.

Partnering school districts (RCSD and BCSD) also institutionalized the C-MST training through district-run professional development efforts. Both districts acquired software licenses for all C-MST tools used in the training. 160 RCSD teachers received 20 hours of technology training during the Superintendent Days. Overall, almost all 200 RCSD math teachers participated in this PD study; whereas only a fraction (30%) of 130 RCSD science teachers participated.

RESULTS

At the conclusion of each year's summer institute, the instructional team was evaluated by external evaluators through surveys and interviews. Teachers ranked 80% of the instructional faculty as excellent to very good with respect to their content knowledge. As far as the opportunity for interaction is concerned, 71% said they had 'very good access' to instructional faculty during summer, while 29% said that access was 'good'. Interestingly, participants with less experience in teaching ranked the institute instructors higher. The general profile of teacher participants in the summer program and subsequent activities is shown in Table 8.

Table 8
C-MST Teacher Profiles.

Years of Experience	Percentage of Teachers		
	Mathematics	Science	Technology/CS
1-2 years experience	18%	16%	20%
3-10 years experience	70%	69%	40%
11+ years experience	12%	15%	40%

Two external evaluators conducted both formative and summative evaluations to assess the impact of the PD program based on the C-MST approach on teacher quality, teacher retention, and student engagement and achievement. They were given access to report cards of students and results of local and state exams of students taught by PD participants. Among other things, external evaluators assessed correlation between student achievement and the amount of training received by each C-MST teacher as well as between school-wide achievement and the number of teachers in each middle and high school who completed the PD program. Collaboration with other NSF MSP projects, such as The Council of Chief State Schools Officers, Horizon Research, and Wisconsin Center for Education Research, enabled collection of pre- and post- activity data from both target and control groups.

GENERAL OBSERVATIONS: Notwithstanding the frustration of some of the participants with new software tools and the compounding of this frustration because of the use of examples from fields other than their own, 95% of the in-service teachers who signed up for the institute completed the training. According to the urban district's own professional development staff and the Director of Mathematics at the RCSD, the PD program based on the CMST-approach had the highest attendance and retention rate of any such voluntary program in the district's history. That the summer institute was held at a college campus that is not close to where the teachers worked and lived and that their daily commute to attend the institute would be about half an hour did not dissuade teachers from signing up or actively participating in the program. Even the unexpected increase in gas price did not cause attrition.

Approximately, one third of the teachers attending the institute also taught summer school at their district in the morning and then drove to the College to attend the institute. This yielded an unforeseen benefit. Several participants reported that they used in the summer school what they had learned the week before from the institute. Not only did these teachers get a chance to apply skills they learned before such skills degenerated but the designers of the PD realized that the C-MST tools have a quick turnaround time vis-à-vis field implementation and that there is genuine excitement among participants.

At the beginner-level, participants received 80 contact hours of training. Those who opted for advanced training received no less than 140 hours of training. Some requested for and were granted permission to return for a third year. They received no less than 200 contact hours of training. Attendees also received additional PD training through a certification program for the use of TI graphing calculators (~60 hours), Saturday sessions (~8 hours) and one-on-one training (~8 hours) via a Coach and/or Team Leader. Data collected through self-reporting surveys, interviews conducted by external reviewers, and online weekly logs maintained by institute participants all support the national findings of the Urban Institute report; which claims that a minimum of 80 contact hours of training is needed to affect changes in teachers' instructional behaviors and a minimum of 160 contact hours is needed to affect changes in the classroom environment.

TEACHER RECEPTION AND RETENTION: After the beginner-level training, about half of the participants reported feeling ‘confident’ to teach with the C-MST tools, and the other half reported that they are ‘somewhat confident’. Apparently, 80 contact hours of training allowed teachers to gain knowledgeable about the C-MST approach and associated tools, but the duration of the training was not sufficient enough to put that knowledge into practice. In fact, not until the trainees actually deployed software tools and modeling methods in their own classrooms did the confidence-level of some of attendees start to improve. Many, however, felt that even after a year of practice, they had much more to learn and master. An average teacher felt confident and comfortable using C-MST approach in his/her classroom only after three years of training and practice.

The upshot is that a significant amount of authentic classroom practice between training sessions is critical to changing a typical teacher’s classroom behavior and the environment in his/her classroom. As reported by others (Haring et al., 1978), a learner typically advances through a predictable series of learning stages: acquisition, practice, implementation, and assimilation. At the start, the learner is uncertain as he or she tries to use the target skill, but with much practice and proper feedback, the learner becomes more fluent, accurate, and confident in using it. In the final stage, the teacher is accurate and fluent in using the newly acquired skills, integrates them regularly in learning situations and is able to modify or adapt the skill to fit novel task-demands or situations. Furthermore, more recent reviews identified the following beliefs common to successful comprehensive PD programs: the program should be sustained and intensive, informed by what we know about how people learn best, centered around the critical activities of teaching and learning; and it should foster collaboration and include a diverse yet coherent set of experiences (NAP Report, 2000; Borko, 2004; Darling-Hammond et al, 2005; Weiss & Pasley, 2009; Loucks-Horsley et al., 2010).

A reassuring aspect of the PD described above is that it had a lasting impact on participants. In 2010 (7 years after the first summer institute and 3 years after the expiration of financial incentives) a survey of 40 active teachers indicated the following: 94% agreed that C-MST pedagogy made them more effective in the classroom; 87% agreed that it strengthened their pedagogical skills; 73% agreed that it strengthened their content knowledge; 100% agreed or strongly agreed that C-MST training strengthened their skills related to modeling and simulation; 100% indicated that the stipend and laptop provided to each participant were a significant motivation to get them started with the Initiative; 80% reported that they are enhancing their computational skills through available means (district and college offerings and other grant programs); 100% reported that they continue to use their CMST skills in the classroom; 86% indicated that they continue to access the enhanced collegial network created through CMST participation; 86% reported that they continue to use the hardware, software and other materials made available through CMST in their classrooms; and 80% believe that their participation in CMST served to build their school leadership skills. In examining the impact of C-MST professional development on teacher retention rate, the following facts emerged:

- Of the 152 RCSD teachers trained via summer sessions, at the end of 5 years, 93% was still employed by the RCSD: 83% were classroom teachers and 10% took administrative positions. At the end of the 6th year, the retention rate was 86%, and at the end of 7 years it went down to 73%. Of the remaining, 65% were math and 35% were science teachers.

- Of the 14 BCSD teachers trained via summer sessions, at the end of 5 years, three individuals left: 79% retention rate. Two of these individuals accepted administrative positions in other districts and one individual retired but continues to maintain a relationship with C-MST Institute as an instructor. At the end of 6 years, 8 individuals remained in the District with the retention rate going down to 57%, whereas at the end of 7 years, only seven (4 math and 3 science) teachers remained in the District (50%). All of those remaining were at the high school level.

Retention rates observed in both districts, during the 5 years of C-MST participation, were significantly above the national rate (50%). The mobility of teachers from school to school and grade to grade is common in the city and this has both strengthened and diluted the cultural impact. All in all, C-MST has been credited by partnering districts with recruitment of new teachers and delay retirements of veteran teachers. C-MST teachers have also moved up quickly to hold key positions, including the posts of Mathematics and Science Directors for the districts.

STUDENT ENGAGEMENT: Funds from the project and school districts provided teachers with necessary laptops, smart boards, graphing calculators, and software licenses. In a 2005 survey conducted by external evaluators, most teachers agreed that using the C-MST tools in their classrooms significantly increased student engagement and evaluators verified these through classroom observations. Students in higher grade levels found modeling more engaging in both math classes (grades 7-8: 77% vs. grades 9-12: 90%) and science classes (grades 7-8: 75% vs. grades 9-12:

85%). Modeling was even found helpful to non-traditional (special education) learners; again the higher the grade level the higher the engagement: math classes (grades 7-8: %76 vs. grades 9-12: 100%) and science classes (grades 7-8: 75% vs. grades 9-12: 85%). Student reaction to modeling (versus traditional techniques) was found to be 97% favorable in math and 77% in science classes. Teachers observed an increase in student interest in STEM studies math (88 %) and science (67%) classes; but again more in math classes. Ninety percent of teachers agreed that C-MST initiative made math and science concepts more comprehensible to students. 72% of math and 31% of science teachers reported observed improvement in problem solving skills. While science classes utilized technology less due to limited access and lack of science-related modeling examples, in instances where it was utilized, it led to a deeper understanding of science topics than it did for math topics (83% vs. 76%). Majority of teachers agreed that different genders responded differently to technology. While male students showed more interest in playing with technology and plowing through the details with less regard to the big picture, female students initially seemed reluctant and timid but excelled when details (curriculum) were put into context of real-world problems, projects, and applications.

STUDENT ACHIEVEMENT: To measure student achievement, we have used mixed-method evaluation, including (a) quantitative data such as standardized tests, school reports, and unit tests, (b) qualitative data such as surveys of students, teachers, school administrators, and faculty, and c) classroom observations by experienced teachers and college faculty. Comparisons were made between students taught by trained teachers (the treatment group) and students taught by other teachers (the control group). Since the control group got smaller every year due to the increased number of trained teachers, the treatment-control comparison was eventually dropped after a few years into the initiative. Longitudinal data for courses taught by the same teacher could not be consistently collected because of the frequent changes in teacher assignments to different courses (and even different schools within RCSD). However, multiple treatment effects were measured by collecting achievement data for students who were taught by one C-MST teacher versus those taught by multiple C-MST teachers in a given year. Also, the impact of C-MST team size at a school was followed for schools that housed more C-MST teachers than others. Finally, a few case studies were conducted to compare the impact of C-MST pedagogy on the learning of a topic by comparing student performance in unit tests for a treatment and control classrooms.

Improved performance in Regents graduation rate and mathematics achievement clearly emerged as a consistent measure in the urban setting (RCSD) since the start of the C-MST initiative (see Table 9). The district-level scores in mathematics and sciences match the level of participation by teachers and administrators in those areas (Table 4). The Math Director was actively involved from the outset. She capitalized on the early buzz the initiative raised to build support for and integrate the work of this initiative into the school district efforts at improving math performance in general. She further drew upon the skills of the trained teachers to disseminate C-MST skills and strategies through turnkey training. This momentum was felt by the school principals who demonstrated their engagement by committing resources to strengthening the technological foundation laid by the initiative. The Science Director, however, did not engage the initiative but rather let it evolve independently. There were no concerted efforts to link what was happening within the initiative with district science efforts at large. Limited access to computer labs, skepticism about use of technology, and lack of lesson plans and curricular modules may have also discouraged science teachers at the early stages of the initiative to invest in trainings that lacked significant science content and representative lesson plans. Improvements in physics and chemistry can be linked to availability of CMST-based content in these fields and the work initiated by suburban C-MST teachers such as Steve Whitman to educate their urban counterparts through the initiative.

About thirteen secondary schools (grades 7-12) within RCSD participated in the study during the initiative from 2003 to 2008. RCSD middle and high schools were undergoing a metamorphosis throughout the study with middle schools growing up to 7-12 sites and high schools growing down to 7-12 sites. This evolution necessitated the reassignment of teachers. It is not unusual for RCSD teachers to be assigned to teach different course content each school year. Each of these 13 schools had a varying degree of participation in the initiative, which led us to make comparisons among them to correlate impact versus collective participation (see Table 10). Two categories were considered: schools with 30% of its MST workforce actively participating in C-MST and those below 30%.

At the end of the 6th year of the study, 10 RCSD schools had reached the 30% threshold. Schools with a higher proportion of C-MST teachers consistently outperformed their counterparts. This trend continued throughout the initiative and is a strong indication of the collective impact on teacher quality, retention and student achievement. In order to consider the impact of project size within individual schools and the effect size has on project collegiality, administrative consciousness/direct support and ultimately student performance, a study was conducted sorting schools by current rate of acceptable grade performance into high and low performance categories. The data indicated that among schools in the high performance rate category (greater than 45% acceptable grade rate), the average number of C-MST teachers per site was 6.1. In the schools with an acceptable grade rate of less than 45%, the average number of participating teachers was 3.56.

Table 9

Achievement Rate (Score > 65) according to data from State School Report Cards.

District		2002	2007	2008	2009
RCSD	Regents Diploma Rate	21%	56%	54%	59%
	Mathematics A	13%	67%	54%	42%
	Living Environment	77%	52%	56%	62%
	Earth Sciences	66%	44%	41%	39%
	Chemistry	9%	27%	28%	29%
	Physics	3%	28%	34%	27%
	Grade 8 Mathematics	10%	18%	33%	58%
	Grade 8 Science	46%	26%	39%	34%
BCSD	Regent Diploma	84%	94%	96%	95%
	Mathematics A	51%	99%	96%	98%
	Living Environment	98%	96%	95%	99%
	Earth Sciences	97%	96%	93%	94%
	Chemistry	91%	96%	95%	94%
	Physics	52%	78%	83%	86%
	Grade 8 Mathematics	89%	86%	89%	91%
	Grade 8 Science	96%	90%	90%	90%

Table 10
Comparison between RCSD schools over and below 30% threshold (2008-09 data).

Courses	Schools Over 30%		Schools Falling Below 30%	
	# Enrolled	% Passing	# Enrolled	% Passing
Math VIII	588	54%	903	53%
Intermediate Algebra	498	62%	897	53%
Algebra II H	249	74%	248	48%
Science VIII	445	65%	864	62%
Living Environment	971	64%	1752	55%
Chemistry	271	83%	509	52%
Physics	14	79%	71	73%

School-wide C-MST participation gradually declined in the later years. As incentives diminished and school administrators and teacher assignments changed in many of these schools, the C-MST profiles of these schools changed, which ultimately eroded the collective momentum gained earlier in mathematics. By year 7, considerable changes occurred in district teacher assignments; teachers advanced to administrative and other non-teaching assignments; retirements occurred; and some teachers left the district for other pursuits. Seventeen principal and school-within-school principal assignments changed in 36 months. As a result, among the 10 schools that had originally crossed the 30% threshold for CMST teacher participation, in year 7 only 5 were still able to maintain that level. However, despite such a significant turnover in both central and individual school administration positions, individual teachers with CMST training continued to make differences in school performance in some areas.

While frequent changes to teaching assignments make it difficult to sustain the same trained workforce at urban RCSD (unless incentives and training continue), the sub-urban districts are small enough to institutionalize curricular reforms more easily and maintain the same workforce. In BCSD, although the two participating schools never exceeded the 30% threshold for teacher participation, the culture of these schools was such that CMST concepts and methodologies were quickly integrated across all classes. C-MST trained teachers emerged as instructional leaders and were responsible for leading demonstration and training of computer simulation in science classes. BCSD's math curriculum (Core Plus) used an inquiry-based approach that was amenable to use of technology and modeling. Its Physics curriculum fully incorporated Interactive Physics modules into its labs. As a result, contrary to RCSD, the gains at BCSD were sustained and even increased further beyond 2008. As noted by the national findings (NSTA, 2008) on role of technology in science classrooms, some teachers, such as Steve Whitman at BCSD, have been in the forefront of the technological transition. These innovators and early adopters have integrated microcomputer-based probes into their laboratories, employed digital videos and imagery to illustrate concepts in class discussions, and are using administrative programs and electronic grade books to organize their classes. Other teachers are waiting until best practices emerge to justify use of technology in the classroom.

Several C-MST teachers participated in mini treatment-control studies using their own classes and classes of colleagues in their building who have never participated in C-MST but were teaching the same courses. The mini studies revealed that the treatment students significantly outperformed their control counterparts in areas examined. One study showed considerable improvement in a geometry class unit test average (82.5 vs. 49.5) as a result of using Geometer's Sketchpad (GSP) software for two weeks. A few other studies showed students taught by project's math teachers outperforming other students in Regents State Exams. These studies, conducted during 2007-2008 school year, are described below.

Case #1: Teacher X and Y taught the same unit (Properties of Quadrilaterals) in HS math for 2 weeks. Teacher X used GSP in a class of 24 pupils while Teacher Y used conventional methods in a class of 14. Both teachers conducted the same unit test. Even though, Teacher X taught a more crowded class and his students received less of attention from the teacher, his classroom average was 82.5 versus 49.5 for the other class.

Case #2: We conducted a Triathlon, similar to Math A & B Regents tests involving use of TI graphing calculators. Conducted by a number of judges, including teachers and college faculty, this study revealed that students taught by C-MST teachers outperformed students taught by non-CMST teachers in all categories: Math-A: 60.26 vs 49.54; Math-B: 71.9 vs 55.6; and 7-8 Grades Math: 64.0 vs 58.6.

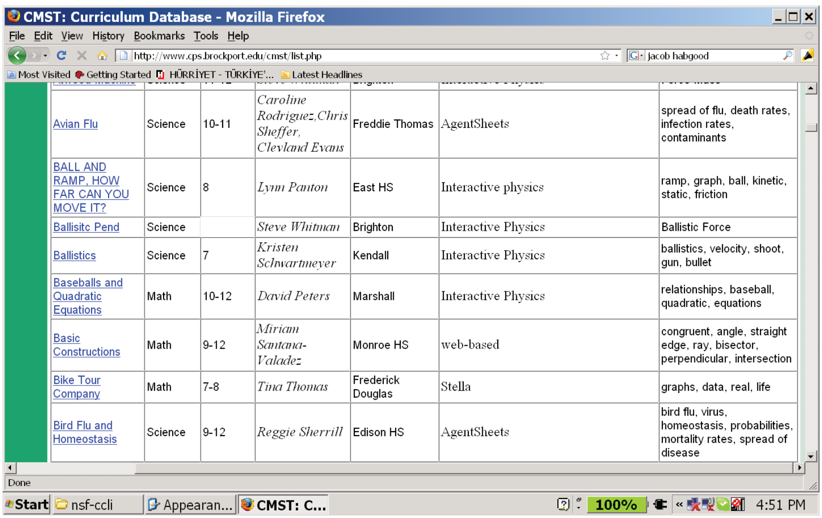
CURRICULUM INVENTORY TO SUPPORT C-MST EDUCATION: More than 500 curriculum modules and lesson plans have been developed to this date collaboratively by IHE faculty and K-12 teachers who participated in the C-MST initiative. They are posted on the web with open access (See snapshot in Fig. 1). Each entry in this database is a zip file that includes several files, including files needed to execute the model, a text file describing the outline of the lesson plan that uses the model, and another text file proposing how to assess student learning and performance at the end the unit taught. The lessons are designated as Level I and Level II. The Level I focused on lower-level tools such as the TI 83+ calculator, Excel, Powerpoint and Project Interactivate. The most popular models are statistical applications because these are a part of the state educational standards and tools such as the graphing and Excel calculator make these complex calculations reasonably transparent. Applications include population growth, geometric series, solution of linear equations and inequalities, cumulative and independent probabilities. The Level II lesson plans focus on using the more sophisticated tools (AgentSheets, Stella, GSP, and Interactive Physics). It is important to note that the teachers were not aiming to have the students develop the models, but rather, use a pre-generated software model to further emphasize fundamental principles. The science teachers were able to easily obtain a number of applications for these tools. While in earlier years the math teachers had difficulties generating ideas, the collaboration in teams greatly improved the math teachers' ability in creating lesson plans.

Interactive Physics (IP) has been the choice of tool for General Science and Physics classes. An example of is illustrated in Fig. 2 to simulate the (harmonic) motion of an object driven by a spring. IP is an easy program to learn and it can display time-dependent profiles of velocity and position. A user does not need to know the underlying mathematics and physics, but there is much to learn for curious minds. IP simulations allow a general simplistic framework from which instructors can introduce a topic and then move deeper with more mathematical tools only after students gain a level of interest to help them endure the hardships. AgentSheets (AS) is mainly used for Biology and Environmental topics, particularly spread of disease, water cycle, and blood flow. Agent-based modeling involves use of agents, a description of how they interact with each other (mostly given in the form of statistical probabilities). An example of an AS model, Fig. 2, involves the study of water cycle from a lake to clouds and rain, and finally back into the lake.

Teachers kept activity logs to document the student response to the C-MST approach via the Lesson Plan. C-MST staff and evaluators regularly reviewed these logs. Along with the lesson plans the teachers also provided helpful tips and advice for implementation of the plans based upon their own experience. New participants found these lessons plans to be especially helpful and stated they were excited to have such a varied range of Lesson Plans to access for the new school year.

DISCUSSION

Content knowledge (CK) and pedagogical knowledge (PK) in and of themselves are not sufficient to make a person an effective teacher. Most in-service teachers have already acquired and perhaps mastered these. With programs focusing on enabling teachers to frequently update and leverage their CK and PK to develop and implement lesson plans that are responsive to and supportive of the abilities and backgrounds of students, much more gains could be realized. We were hoping to accomplish this. The reliance on fast-changing technology enabled many mid-course corrections.



Avian Flu	Science	10-11	*Caroline Rodriguez,Chris Sheffer, Clevland Evans*	Freddie Thomas	AgentSheets	spread of flu, death rates, infection rates, contaminants
BALL AND RAMP, HOW FAR CAN YOU MOVE IT?	Science	8	*Lynn Panton*	East HS	Interactive physics	ramp, graph, ball, kinetic, static, friction
Ballisitc Pend	Science		*Steve Whitman*	Brighton	Interactive Physics	Ballistic Force
Ballistics	Science	7	*Kristen Schwartmeyer*	Kendall	Interactive Physics	ballistics, velocity, shoot, gun, bullet
Baseballs and Quadratic Equations	Math	10-12	*David Peters*	Marshall	Interactive Physics	relationships, baseball, quadratic, equations
Basic Constructions	Math	9-12	*Miriam Santana-Valadez*	Monroe HS	web-based	congruent, angle, straight edge, ray, bisector, perpendicular, intersection
Bike Tour Company	Math	7-8	*Tina Thomas*	Frederick Douglas	Stella	graphs, data, real, life
Bird Flu and Homeostasis	Science	9-12	*Reggie Sherrill*	Edison HS	AgentSheets	bird flu, virus, homeostasis, probabilities, mortality rates, spread of disease

Figure 1. A Snapshot of the C-MST Database. The 1st column shows application; the 2nd subject area; the 3rd grade level; the 4th teacher developers; the 5th school; the 6th name of the C-MST tool; and the 7th curricular concepts covered.

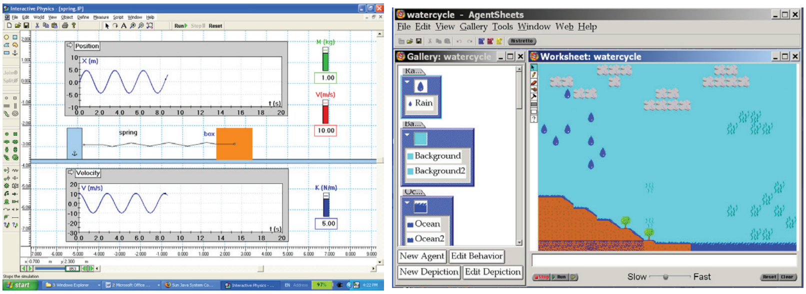


Figure 2. Snapshots of Interactive Physics (left) and AgentSheets (right) simulations.

Our PD program had multiple layers and domains that were well integrated. So integrated, in fact, were the multiple layers and other aspects of the PD that its outcome was more than the sum of its parts. This aspect of our program matches well with a recently developed conceptual framework, namely *Technological* PCK (Koehler & Mishra, 2008). To start with, not all in-service teachers who participated in the summer institute were technology savvy. Nor did many of them know about how technology could facilitate teaching and learning. Because teachers possessed CK, it was possible to introduce technology tools using examples and illustrations from mathematics and science content areas, which allowed them to appreciate how technology may be used to change how they teach content: teachers had an opportunity to acquire *Technological* CK (TCK).

After a general TCK training, participants were introduced to simple simulations and were guided to create their own simulations. For the very first time in their career, many summer institute participants gained a better understanding of the range of technology tools available to them, and in the process, they learned how simulation might be used as a pedagogical strategy. All this allowed them to see technology both as an enabler of instruction and an agent for transforming teaching and learning. Collectively, the knowledge they acquired may be described as the *Technological* PK (TPK).

In describing the conceptual framework of PCK, Shulman (1986) observed that the “[t]he key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students.” When we developed the PD program, we were guided by the premises that computer simulation is an important tool in the arsenal of the practitioners of computational science, that national laboratories and research universities have been employing this approach to solve problems and to generate knowledge, and that this approach holds promise to transform K-12 teaching and learning, if only a critical mass of school teachers can be trained to adopt the C-MST approach in their classrooms. All the software tools that the PD program used are adaptive. Like digital computers themselves, simulation is becoming a mainstream tool. Having created an undergraduate program using the C-MST approach, we had no doubt that this approach is a viable pedagogical strategy. In short, the PD we designed included all the components of *Technological* PCK (TPCK).

Some see technology-assisted PCK as the knowledge base that teachers need to integrate technology in instruction, and yet others, taking a transformative view, posit it as a distinct body of knowledge ((Niess, 2005; Mishra & Koehler 2008; Angeli and Valanides, 2009). Perhaps there are other conceptualizations as well. But what's central to these different conceptualizations is that when a teacher has a firm knowledge of the content, is well-versed with pedagogical strategies, and knows that the use of appropriate technology can both enable and transform teaching and learning, this combination is so potent that the teacher can achieve results not attainable with a subset of tools. The C-MST PD strived to inculcate such a mindset, being a means to achieve the TPCK end.

In order for any PD to have a lasting impact on teaching and learning, those who participate in it must realize that the specific examples used during the training are applicable to a much broader set of situations than they encounter in classrooms. As summarized by Tenenbaum et al (2011), when it comes to learning, human mind makes generalizations through abstractions even with limited data. During this process, the mind hones in on a general concept rather than on specific events. The *integrated aspect* of the C-MST puts mathematics, science, and technology together to view the world holistically, thereby providing a path for the learner to grasp the whole picture and enable conceptual change and override misconceptions and preconceptions. *Modeling*, a critical component of the C-MST approach involves both simplification and generalization; two aspects that enable a learner to grasp important facts and processes surrounding the topic under study. *Simulation,* another critical component of the C-MST approach, provides a medium for the learner to conduct scientific experiments in a friendly, playful, eventful, and interactive way to ask and solve "what if" questions, without having to initially know the full panoply of science concepts. Together, modeling and simulation form a deductive and inductive pedagogy, allowing for the introduction of a topic from a simple framework. Once learners gain a certain level of interest, simulation and modeling allow them to delve deeper into details, including the exploration of underlying principles. This approach helps learners to endure the hardships and frustration of deep learning; and it is consistent with the pedagogical framework *Flow* (Csikszentmihalyi, 1990) and scaffolding strategy to balance skills with challenges. The iterative process and deductive/inductive dynamics of the C-MST approach matches well with another recently introduced conceptual framework, namely computational thinking — a habit of mind concerned with formulating problems, obtaining solutions iteratively, and implementing them with the help of an information-processing agent (Wing, 2006). It appears that solutions arrived in disparate disciplines for solving complex problems have commonalities.

CONCLUSION

We found that C-MST approach has the potential to promote effective PD (Loucks-Horsley, 2010); in part, due to its high dependency on technology and, in part, due to its iterative nature, which affords mid-course corrections. Data analyzed by independent evaluators point out that this approach is scalable in the way described by (Dede, 2005). Interest for PD was overwhelming and long-lasting. Retention was high. The IHE-K12 partnership served to build the confidence of teachers, introduced technology into classrooms, and inspired teachers to share their expertise with others. Experienced teachers partnered with college faculty in the delivery of instruction - adding a rich classroom perspective to the summer institutes. Participation of multiple teachers from individual schools provided the opportunity to build teams and to elevate some institute participants to instructional leaders, which piqued the interest of non-participating teachers. School principals supported technology purchases, release times, and turnkey training. Students who received instruction from multiple C-MST teachers outperformed their peers. District-wide graduation and achievement rates were up.

The partnership motivated urban and suburban teachers to learn from each other and to make progress by embracing best practices and collegial interaction. Initially, urban teachers were more eager than their suburban counterparts to learn (and acquire) new technologies (software and hardware). Suburban teachers were more interested in technological and pedagogical content training than acquiring technology. But the stance of urban teachers changed over the span of five years to a point of resembling to that of the suburban teachers. The project eventually touched more than 500 teachers and thousands of students. The site visit by NSF and testimonies before the U.S. Congress have now provided some national exposure that can be amplified by this article to present the C-MST approach as having a potential to add momentum to the STEM education reform.

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