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Professional development to enhance teachers' practices in using information and communication technologies (ICTs) as cognitive tools: Lessons learned from a design-based research study

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ABSTRACT

Technology integration in K-12 classrooms is usually overly teacher-centered and has insufficient impact on students' learning, especially in enhancing students' higher-order cognitive skills. The purpose of this project is to facilitate science teachers' use of information and communication technologies (ICTs) as cognitive tools to shift their practices from traditional teacher-centered methods to constructivist, student-centered ones. This paper describes the outcomes and lessons learned from an application of design-based research (DBR) in the implementation and refinement of a teacher professional development (PD) program that is a key component of the overall project. This DBR study involved 25 middle-school science teachers from 24 schools whose implementation of cognitive tools with their students in science classrooms and virtually through a social networking site were observed over four years. A mixed-methodology was utilized to examine the impact of the cognitive tools intervention on teachers' classroom practices and students' development of new literacy skills. Identifying reusable design principles related to technology integration was another focus of the DBR study. The results revealed teachers' positive changes in their classroom practices by gradually allowing students to take control over the use of technology, and positive impact on students' ICT skills and science learning. Design principles for future professional development programs aimed at preparing teachers to adopt a cognitive tools approach are described.

1. Introduction

Teachers' classroom technology integration is usually passive, teacher-centered, and treats technology as a “learn from” tool similar to the way students learn from classroom teachers. This approach has yielded low or no significant impact on students' learning outcomes (Kim & Reeves, 2007). Researchers have been advocating a more constructivist, student-centered technology approach, encouraging students to use technology as a “learn with” tool (Jonassen & Reeves, 1996; Lajoie & Azevedo, 2000). This approach has also been referred to as the “mindtool” or “cognitive tool” model (Jonassen, 2000).

Classroom technology resources have increased and improved in the past decade, giving teachers increased flexibility to allow students to use technology as tools to extend their cognitive skills. However, there is a lack of empirical evidence of the impact of cognitive tools on teachers' classroom practices and students' learning. In this study, we developed an innovative professional development (PD) program for 25 middle-school science teachers, aiming to enhance their knowledge and skills in using technology as cognitive tools to support students' learning. A design-based research approach (DBR) employing mixed methods was utilized over the four years of this study. The purpose of this study is threefold (1) to describe how the PD program changed teachers' practices of using technology as cognitive tools in science

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classrooms, (2) to explore barriers that impede teachers' changes in their technology integration paradigm, and (3) to delineate design principles that guide teachers to use technology as cognitive tools wherein students “learn with” rather than “from” technology.

2. Literature review

2.1. The need to adopt technology as cognitive tools

Traditionally, teachers have taken the “learn from” technology approach and used computers primarily as a different type of media for delivering content to students, in a passive manner similar to how students might learn from textbooks or TV programs. Although technology is widely accessible for teachers and students in schools today (Greenhow, Robelia & Hughes, 2009; Purcell, Heaps, Buchanan, & Friedrich, 2013), research indicates that the majority of teachers still adopt technology passively as a learn-from medium. This approach yields insufficient results in student achievement (Cuban, 2001; Kim & Reeves, 2007; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). Such disappointing results force educators to reexamine the applications of computers in science classrooms. If learning passively “from” computers (e.g., reviewing information on a web site, or viewing a YouTube video clip about a scientific concept), has failed to enhance student learning, such practices must be changed.

The calls for reformed instructional practices in science teaching to address students' inquiry experience also shed light on implications for technology integration in science teaching (Park, Jang, Chen, & Jung, 2010). Technology integration driven by the cognitive tools approach emphasizes creating a student-centered learning environment that allows students to solve relevant, realistic problems and develop higher-order cognitive skills (Jonassen & Reeves, 1996; Lajoie & Azevedo, 2000).

Cognitive tools refer to “technologies that enhance the cognitive powers of human beings during thinking, problem solving, and learning (Jonassen & Reeves, 1996, p. 693).” The human cognitive system has weaknesses and limited capacity, but can be enhanced through the use of cognitive tools (Jensen, 2011). Using a “cognitive tools” approach is distinctly different from the traditional approach of using technology, in which information is designed by subject experts or instructional designers and then transferred to the students. By using cognitive tools in a constructive framework, learners engage in a variety of critical, creative, and complex thinking opportunities (Campbell, Wang, Hsu, Duffy, & Wolf, 2010; Hsu, Wang, & Runco, 2013; Wang, Hsu, & Campbell, 2009). The reformed technology integration approach extends students' cognitive skills by encouraging them to access multi-modal resources, organize and analyze data, interpret and evaluate information, and communicate the knowledge they have constructed to others (Lajoie & Azevedo, 2000). For example, Inspiration, a popular concept-mapping software, can be used as a cognitive tool to extends student's cognitive capacities in the learning process as they articulate, share, and refine their understandings in science (Martínez, Pérez, Suero & Pardo, 2013). Another example is when students research information about the moons of planets in the Solar System, and then use spreadsheets to visualize and document their research results (Finson & Pederson, 2011). The spreadsheets extend students' ability to visualize complex relationships, think critically, and solve problems, for example, organize and compare multi-modal information to retrieve the answers, or figure out questions such as “how factor X correlates to factor Y?”

It is difficult to develop a universal integration framework because the adoption of cognitive tools is situational (Kim & Reeves, 2007). Assessing students' learning outcomes is also a challenge since the use of cognitive tools involves not only grasping content knowledge, but also critical thinking and problem solving skills. Multifaceted and alternative assessment tools must be in place, requiring more teachers' time (Robertson, Elliot & Washington, 2007). In light of these complexities, advocates of the cognitive tools approach are still searching for strong empirical evidence of the impact of these tools on learning (Herrington & Parker, 2013; Kim & Reeves, 2007).

As the availability of technology in schools has become almost ubiquitous in many countries, Ross, Morrison, and Lowther (2010), among others, have urged educational researchers to focus their studies less on comparing the impact on learning with and without technology, because technology should be deemed as a vehicle for instantiating pedagogical methods. The adoption of a new tool will not have any impact on teaching and learning unless the tool is used to implement pedagogical strategies that help students deploy meaningful cognitive strategies. Previous studies also suggested that the impact of students using technologies is greater when they are used as cognitive tools, compared with technologies being used as simply alternate presentation sources (Schmid et al., 2009; Tamim et al., 2011; White & Frederiksen, 2005). Technology applications that support learners to perform cognitive tasks just out of their reach without them can be categorized as cognitive tools. They have the following characteristics: (1) support students' decision making, (2) support students' metacognitive processes, (3) enable students to organize, evaluate and analyze information, (4) facilitate students' problem solving, and (5) allow them to collaborate and communicate ideas in multi-modal formats (Azevedo, 2005a; Hsu, Wang, & Runco, 2013; Jonassen & Reeves, 1996; Lajoie & Azevedo, 2000).

2.2. Cognitive tools support scientific practices: new literacy framework

We focus on science learning because it promotes learners' multiple cognitive skills, such as inquire, analyze, infer, or evaluate scientific concepts and theories and fosters constructing new knowledge (Kuhn, Black, Keselman, & Kaplan, 2000). Science is a conceptually rich domain that requires students to deploy various metacognitive strategies (Azevedo, 2005b), and technology as a cognitive tool can facilitate students' metacognitive processes in problem solving. In 2013, the National Research Council released the Next Generation Science Standards (2013), encouraging teachers to provide students with the opportunities to practice inquiry using cross-curriculum knowledge such as engineering, math, and technology. The avocation of these core ideas is based on the need to promote inquiry in the classroom and to prepare students' new literacy skills (also known as 21st century skills, digital literacy, or ICT literacy). Technology integration is an important element in the science classroom because it supports the development of students' cognitive skills and nurtures their new literacy skills.

To help teachers envision the value of using technology to support cognitive processes, a framework to align the features of cognitive tools and scientific literacy skills is needed. In this project, we provided professional development opportunities to teachers focused on adopting information and communication technologies (ICTs) as cognitive tools. ICTs refer to hardware and applications that help people to access, retrieve, process, and exchange information. ICTs also enable social networking functions, and thus can be adopted by educators to prepare students' new literacies skills such as collaboration and communication. Most young generation learners are highly motivated when they have ICT-based experiences in the classroom (McFarlane & Sakellariou, 2002). ICTs enable teachers and students to retrieve information beyond textbooks, to collaborate with people at a distant, and to access real audiences outside of the classroom. Many useful ICTs are free and accessible to students, and ICTs can be deployed to make scientific information more accessible, make thinking more visible, make idea exchanges more frequent and immediate, and enable the representation of knowledge in different forms of media (Linn, 2004). In this project, we employed the new literacy framework to guide the use of ICTs as cognitive tools in science education (Hsu, Wang, & Runco, 2013). New literacy is a situational concept describing a set of skills and knowledge of 21st-century skills that students should possess. The traditional definition of literacy refers to the ability to read, write, comprehend and communicate through languages. With new forms of literacy made possible by computer and networking technologies, the definition of literacy has evolved to include the ability to use digital technologies (ICTs) to "identify questions, locate information, evaluate the information, synthesize information to answer questions, and communicate the answers to others" (Leu, Kinzer, Coiro, & Cammack, 2004, p. 1572).

New literacy research originates from literacy studies that investigate how technology affects students' language and literacy acquisition, as well as communication in a tech-driven world (Coiro, 2003; Hagood, 2003; Hsu & Wang, 2010a; Teale, Leu, Labbo, & Kinzer, 2002). The concept of new literacy is situated within science because technology integration strategies vary across curriculum domains (Hsu, Wang, & Runco, 2013). We chose the term new literacy over others such as "digital literacy (Eshet, 2004)" or "ICT literacy (Markauskaite, 2007)" because the new literacy fluency requires more than just the ICTs skills. Students must be proficient in ICTs skills, literacy and cognitive skills in order to be considered as fluent in new literacy (Fig. 1).

In this project, the ultimate goal is to prepare teachers to create opportunities for students to use domain-free ICTs in their inquiry activities. These tools support different cognitive skills, including information retrieving (cyber databases, web search engines, and Google forms), information analysis and evaluation (spreadsheets and charts, images and video editing tools), and information construction and communication word processing, mapping tools and social networking site (Edmodo is the tool adopted in this project). Students practice their new literacy skills through the inquiry process: Identifying scientifically oriented questions, researching information to form a hypothesis, locating multimodal information (texts, images, graphs, diagrams, charts, videos, hyperlinks, and maps), evaluating the usefulness of the information and citing credible sources, and synthesizing multimodal formats of information to communicate their research findings on the social networking sites. Most importantly, students can apply the transferrable skills learned from one project across subjects, topics, and grades. These transferable new literacy skills can support not only students' school learning, but also important skills to succeed in the future workforce.

Here is one example of using ICTs as cognitive tools to support students' scientific practices:

When studying a unit about human impact on living environments; first, students use web search engines to look for news articles about this topic in their neighborhoods, specifically to figure out what factors might affect local water quality. Teachers then guide the students to form a scientifically oriented question, and collect data of possible factors (e.g., pH level, water temperature) using credible cyber databases (e.g., USGS, local water system websites). Next, students use spreadsheets to log and organize data (such as the locations of the data

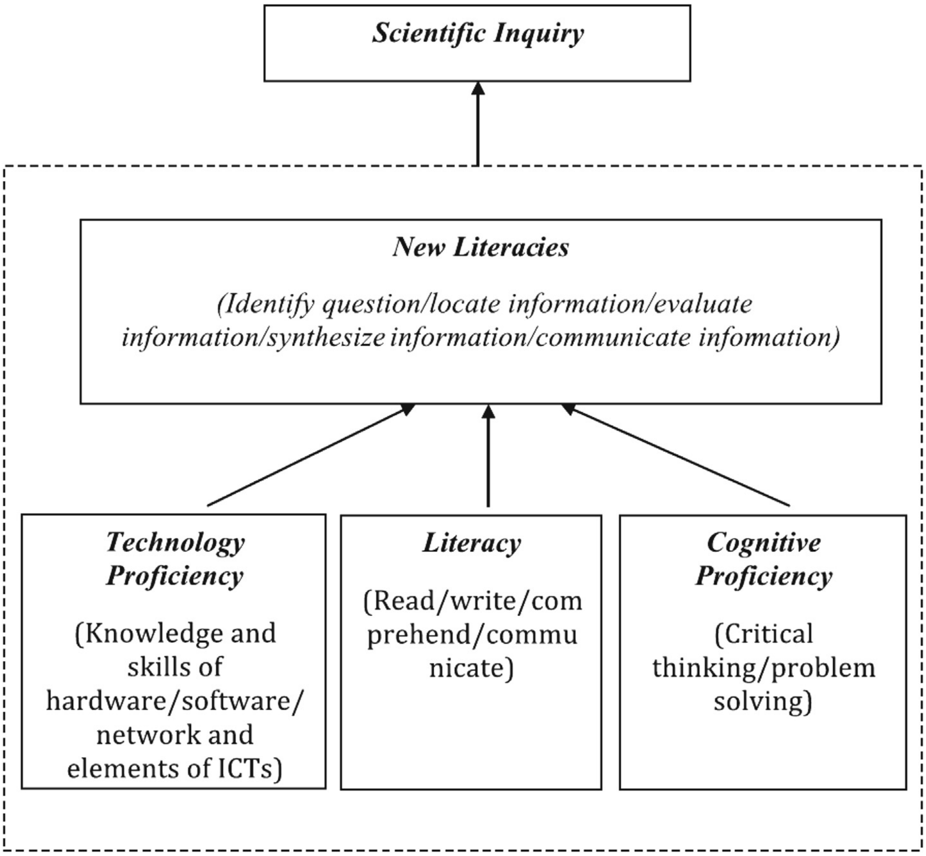


Fig. 1. The new literacy framework (Hsu, Wang, & Runco, 2013).

collected, time of data collected, pH levels, depending on the research questions that students are interested in investigating), and create charts to analyze the relationships among various factors. Students can use mapping tools to mark the locations of the data collected for further comparisons and analyses (e.g., the relationship between elevation and water quality). They might use GeoPhotos found in Google Earth to examine geographical environments or pictures of the body of waters they are investigating. Students then use Google Docs to organize their research results and collaboratively present their work using charts, tables, pictures and maps. The teacher can ask students to share their work to social networking sites (e.g., Edmodo) and have them critique each other's projects. This example demonstrates the seamless integration of ICTs to support scientific practices and cognitive skills. The new literacy skills students develop from this process can be transferred to other topics (e.g., evolution theory, biodiversity, earthquakes…), other academic contexts, and even to solving real-world problems (Hsu & Wang, 2013; Wang, Hsu, & Green, 2013; Wang, Hsu, & Posada, 2014).

The above-mentioned cognitive tools practices are rarely observed in the current science classroom (Hsu, Wang, & Runco, 2013). The majority of the teachers still use technology for personal communications and/or classroom administrative work (Bebell, Russell, & O'Dwyer, 2004) or use content-specific digital versions of learning resources (Hsu, Wang, & Runco, 2013; Tamim et al., 2011), as opposed to creating an environment to facilitate students' use of technology to support their cognitive processes in problem solving. The idea of using technology as cognitive tools presents a challenge to both teachers and students due to the lack of pedagogical support (Iiyoshi, Hannafin, & Wang, 2005), and because the functions of cognitive tools vary depending on the learning tasks (Kim & Reeves, 2007). There is no uniform approach to guide teachers to integrate cognitive tools, but these tools require students to handle huge amount of information and deploy a variety of cognitive skills. In order to meaningfully integrate cognitive tools, teachers must master the features of various technologies, manage the learning environment to enable students' access to these technology, help students master the skills of using the tools, and help students make informed decisions on using appropriate tools to enhance their learning processes and communicate their learning outcomes. These challenges intimidate and impede many teachers from shifting the technology integration paradigm from control (teacher-centered) to empowerment (student-centered). What's more is that the cognitive skills or higher order thinking skills are often neglected in standardized testing (Volante, 2004). To overcome these barriers, we designed professional development (PD) that focuses on developing teachers' knowledge and skills in using ICTs, preparing their knowledge in strategically negotiating and using ICTs as cognitive tools into science classrooms, and building their confidence to allow students taking control of technology usage in the classroom.

3. Methods

3.1. Design-based research

The purpose of DBR is to increase the impact and transfer of educational research, and generate pragmatic and generalizable design principles (Wang & Hannafin, 2005). Anderson and Shattuck (2012) defined DBR as having the following characteristics: (1) it is situated in a real educational context, (2) it focuses on the design and testing of a significant intervention, (3) it adopts mixed-methods to provide better guidance for educational refinement, (4) it involves multiple iterations to reach the best design of intervention, and (5) it promotes collaboration between researchers and practitioners. The goal of this study is to enhance middle school science teachers' new literacy (or technology integration) practices in the classroom, and the significant intervention is an innovative PD program. Mixed methods have been used to investigate the effectiveness of PD's intervention on teachers' science teaching practices.

Major aspects of this study include: (1) researchers worked closely with practitioners in a real large-scale educational context to investigate the implementation of technology integration using a cognitive tools approach; (2) we designed PD to facilitate teachers' use of technology as cognitive tools; (3) we examined teachers' assignments and students' artifacts to track the implementation results and to improve the PD design; (4) we monitored teachers' continuing adoption of cognitive tools approach to increase the usability, sustainability and scalability of this program; and (5) we identified general design principles for future PD. We also applied the DBR framework described by Reeves (2006) to guide our discussion in these iterations. Fig. 2

The following research questions were developed to guide this study:

1. What is the impact of this PD's intervention on teachers' practices of using technology as cognitive tools?
2. What is the effect of teachers' changes in teaching practices on students' uses of technology as cognitive tools and their learning achievement?
3. What factors affect teachers' enactment and sustainability of using technology as cognitive tools?
4. What implications do the results have for the refinement of the PD to prepare teachers to use technology as cognitive tools?

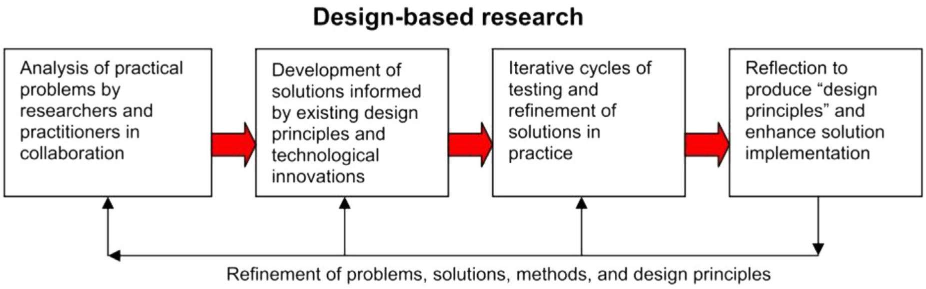


Fig. 2. Design-based research cycle (Reeves, 2006).

3.2. Description of context

To investigate these questions, the team worked with three New York City middle school science teacher leaders, to design four PD modules and piloted these lessons in their classrooms. The revised modules were implemented with 25 NYC middle school science teachers and their students. We followed teachers' implementation of the PD concepts for two years in their regular classrooms. Teachers weren't forced or obligated to implement the cognitive tools approach because we sought to observe the impact and the sustainability of this PD intervention under naturalistic conditions.

New York City is described as one of the most diverse metropolitan areas in terms of ethnicities (Hsu & Wang, 2010b), with 40% Hispanics, 28% African American, 15% Caucasian students, and with15% English Language Learners (NYC IBO, 2013). The challenges for New York City public school teachers are multifaceted: large number of ELLs, students come from poor communities, the demands of standardized testing, and the test score-based teacher evaluations.

3.3. Participants

The 25 participant teachers came from 24 different schools in NYC. They attended two nine-day summer workshops and two three-day winter workshops over two years. The first cohort has 9 teachers; and the second cohort has 16. Of the 25 teachers, eight were African American, seven were Asian, six were Caucasian, and four were Hispanic. The teachers' teaching experience ranged from one year to 16 years. Profile data for each school was collected, including the schools' progress reports and the percentage of free lunches and English Language Learners (ELLs).

3.4. Data collection and analysis

The study adopted a mixed-methodology approach (Tashakkori & Teddlie, 2006) to collect and analyze the following data: Classroom observations, teacher focus groups, students' learning achievement data, and documentation of teacher assignments. In order to triangulate the data collected from classroom observations and focus group interviews with teachers; we collected the teachers' assignments to investigate their enactment of cognitive tools approach.

3.4.1. Classroom observation

In terms of PD's impact on teachers' classroom practices, two external evaluators who were not aware of the PD or the research project were asked to conduct classroom observations, using the Technology Observation Checklist (Appendix A) to help us investigate teachers' cognitive tools practices in the classrooms. The checklist indicated the classroom technology available for teachers and students, classroom organization, teacher's role, ICTs adopted in this class session, ICT-related activities conducted in this session, and how each activity supports the scientific practices components. The inter-rater reliability was calculated to ensure the evaluators' observation scorings were similar. There was an excellent inter-rater reliability ($=0.9$, $p < .01$). The Technology Observation Checklist was conducted three times for each cohort, before the PD, first year after the PD, and second year after the PD.

3.4.2. Teacher focus group

The research team met with teachers each month through Skype to elicit and probe their technology implementation status, success stories, and challenges, using semi-structured interview protocols. Teachers who could not attend the Skype sessions were required to complete open-ended questionnaires that aligned with the interview protocols. The focus group and the open-ended questionnaire responses were recorded for analysis. The team followed Miles and Huberman's (2014) analysis recommendations to identify themes from the teacher responses. Two researchers examined and generated the themes independently and compared the findings to develop the final themes.

3.4.3. Teacher assignments and student sample artifacts

Interview and focus group data are highly subjective, and classroom observations also have limitations (Desimone, 2009). Therefore, we triangulated the data by analyzing teachers' assignments and students' sample artifacts to investigate their enactment of the cognitive tools approach. Using teacher classroom assignments as an indicator to measure their practices is reported in the literature (Clare, 2000; Greenleaf et al., 2010.) In Greenleaf's study, teachers were asked to submit sample lesson materials and student work. The study supports the validity and reliability of using assignment ratings as a proxy for classroom observation to indicate teachers' classroom practice quality (Greenleaf et al., 2010). In this study, we observed teachers' and students' use of the social networking site throughout the academic year and collected all assignments and each assignment's descriptions and/or directions provided on the site. Teachers who did not use the social networking site were asked to submit their assignments that required students to use technology to complete. Then we used spreadsheets to record the types of ICTs that students used and the purpose of using ICTs, aligning with the five components of new literacy skills. This set of data analyses was used to guide our investigation of teachers' technology integration status, fidelity of module implementation, teachers' and students' transferrable uses of ICTs, students' uses of ICTs as cognitive tools, and changes in teachers' practices.

3.4.4. Measures of student learning outcomes

The PD covers several learning objectives in the NYC middle school Living Environment Core Curriculum, and so we adopted 45 test items from the New York State Living Environment Regents exam review test bank. We assessed only 8th grade students in the second year of project implementation (2013 Spring). The standardized test data was difficult to collect across multiple schools. Thus, only teachers who were retained in this study and taught 8th grade administered the test. We collected data from students for whom we had obtained parental consent. We successfully collected 212 students of cohort 1 teachers (who participated in the project for two years), and 245 students of cohort 2 teachers (who participated in this project for one year). We also assessed 398 students from grade 6 to 8 whose teachers were not in the cohorts, to serve as the control group. Teachers in the control group were colleagues who worked with project participant teachers in the same schools and participated in the research study on a voluntarily basis. Therefore, students in the control group shared similar characteristics with students in the experimental group.

3.4.5. *Measure of students' ICT skills*

To measure students' ICT skills, we adopted the ICT literacy survey developed by Markauskaite (2007), as it measures learners' technical and cognitive capabilities. The survey includes 35 items and measures learners' confidence in the following five components of ICTs and cognitive skills: problem solving, communication and metacognition, basic ICT capabilities, analysis and production with ICTs, and information and internet-related skills. The survey was developed based on pre-service teachers' data; therefore, we made minor modifications to ensure the language was appropriate for 8th grade students. The Cronbach's alpha coefficient in the original paper of the five constructs are reported as 0.90, 0.82, 0.91, 0.92 and 0.92, respectively; while the Cronbach's alpha coefficient in this study are 0.89, 0.75, 0.86, 0.85, and 0.92. All items showed α levels above the 0.70 threshold recommended by Nunnally (1967), Nunnally and Bernstein (1994). 642 students whose teachers were in the control group and 332 students whose teachers were not in the control group completed the ICT skills survey. One way ANOVA was used to analyze the differences of students' ICT skills between groups.

Table 1 provides our design-based research timeline, including PD, implementation and data collection.

4. Design narrative: description of iterations

4.1. *Phase one: analysis and design of the modules and PD interventions*

Reeves's DBR model (2006) describes several design research phases. First it starts with the analysis of a significant problem via intense collaboration between researchers and practitioners. In this project, two researchers (one instructional technology and one new literacy expert) worked closely with three teacher leaders who currently teach science in NYC middle schools, to clarify major problems in science education, to define the rationale for using technology as cognitive tools approach, and to reach consensus in defining cognitive tools. We then identified the scope and sequence of the science curriculum, explored the current technology integration status and barriers, selected the technology, and chose the most appropriate topics to pilot the cognitive tools approach.

During the subsequent developing solutions step, we incorporated the already known principles of effective PD design. Our literature review indicated a consensus on the common characteristics of successful science PD as (1) Active learning: provide teachers opportunities to engage in meaningful and relevant activities for their individual contexts (2) Longer duration: PD engagement should be sufficient enough to make significant impact on teachers' attitudes and practices, (3) Connection: connect PD to classroom work, (4) Support: provide teachers continuous support, (5) Alignment: align PD with state or national learning standards, (6) Content: focus on enhancing teachers' knowledge and skills, (7) Access to resources: provide teachers access to new technologies for teaching and ensure students also have access to the technologies; and (8) Collaboration: facilitate teachers' group discourse and reflection process (Akerson, Morrison, & Roth McDuffie, 2006; Desimone, 2009; Gerard, Varma, Corliss, & Linn, 2011; Heller, Daehler, Wong, Shinohara, & Miratrix, 2011; Jeanpierre, Lawless & Pellegrino, 2007; Jeanpierre, Oberhauser & Freeman, 2005; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Supovitz & Turner, 2000). In order to incorporate the recommended PD characteristics, and meet the needs to prepare teachers' scientific inquiry and technology integration skills, our PD (Cyber-Enabled Learning) is designed to achieve the following goals: (1) engage teachers in scientific inquiry activities that can be facilitated through ICTs, (2) guide teachers to enact different levels of inquiry practices

Table 1
Data collection timeline.

	2010	2011				2012				2013				2014
	FA	SP	SU	FA	WI	SP	SU	FA	WI	SP	SU	FA	WI	SP
PD modules														
T-L	M1	M2		M3	M4									
C1-T			M1			M2	M3	M4						
C2-T							M1			M2	M3	M4		
Implementation														
T-L	X	X		X	X									
C1-T				X	X	X		X	X	X				
C2-T								X	X	X		X	X	X
Observation														
T-L	X	X		X	X									
C1-T		X				X				X				
C2-T						X				X				X
Focus Group														
T-L	X	X		X	X									
C1-T				X	X	X	X	X	X	X				
C2-T								X	X	X	X	X	X	X
Assignment Collection														
C1-T				X	X	X		X	X	X				
C2-T								X	X	X		X	X	X
Students Test and Survey of ICT skills														
C1-S-Y2												X		
C2-S-Y1												X		
S-control												X		

T-L: Teacher Leaders, C=Cohort, T = Teacher, S=Student, Y=Year, M = Modules.

and see the value of using ICTs to support cognitive skills, (3) enhance teachers' skills and confidence in using ICTs as cognitive tools, (4) discuss the transferrable ICT skills, (5) deepen teachers' conceptual understanding of cognitive tools, (6) model the use of a social networking tool to create a virtual learning community, and (7) familiarize teachers with the concept of new literacy and its practices in the science classroom. The last goal is especially important in order to change teachers' practices in the classroom. Teachers need to perceive the rationale and feasibility of integrating technology in order to replicate their experience of using ICTs to support scientific inquiry in the classroom.

The Cyber-Enabled Learning project was designed for teachers to receive a total of 240 h of professional development focused on improving their skills in using ICTs as cognitive tools through the new literacy framework, and enhancing their strategies for supporting students' science content learning. The PD consisted of four workshops, including one 9-day workshop during the summer, and one 3-day workshop in the winter, two years in a row. The PD provide teachers multiple opportunities to engage in inquiry activities as learners, practice various ICTs and learn their features, discuss how domain-free ICTs can be transferred to different science topics, understand the concept of cognitive tools, and facilitate their use of technology as cognitive tools to complete inquiry projects related to their curriculum and state science learning standards. The PD provided teachers opportunities to complete three levels of inquiry activities structured inquiry, guided inquiry, and open inquiry (Windschitl, 2003), and afforded them with authentic experiences in conducting scientific investigations and using technology as cognitive tools.

4.2. Phase two (iteration one): providing PD to teacher leaders and piloting modules

Teacher leaders received the compressed version of the PD, because they were already familiar with some of the concepts and skills from when the modules were designed; subsequently the teacher leaders piloted the modules in their classrooms. The team observed and documented the implementations, and refined the modules based on the teachers' reflection and students' artifacts. The following four key findings emerged from the pilot testing and guided our response to the challenge of refining the next iteration.

1. Students' technology skills were not as high as we expected when we designed the modules. The ICTs they are most familiar with are word processing, web search engines and presentation tools. However, once they were introduced to new tools, they were able to master the necessary skills easily.
2. Schools or teachers could not afford (time and resources) to install software in addition to the regular tools they use. Therefore, we adopted ICTs that are free, have low technology demands, not domain specific, and provide reliable service. Making ICT access as easy as possible is essential to sustain teachers' and students' use of technology.
3. Teachers do not have extra time to squeeze in the modules into their already busy schedules. Therefore, we had to make sure these modules were seamlessly integrated in the existing curriculum and could be counted toward teachers' evaluations.
4. Some schools did not have a 1 to 1 computer environment; moreover, some ICTs with educational values could not be used in the schools. Therefore, we adopted the flipped classroom concept (Davies, Dean, & Ball, 2013), to have students learn how to use technology as cognitive tools through tutorial video clips, use their computers at home to work on projects, and discuss their projects in school.

4.3. Phase three (iteration two): providing PD for cohort 1 teachers

The two iterative cycles of testing started from phase three. After we refined the PD modules based on the key findings from the pilot test with the teacher leaders, we provided the PD for the first cohort of teachers. We started with 12 teachers, and 10 teachers were retained at the end. The first year implementation revealed the major challenges that the team had to address in the next iteration: We discussed too many technology skills during the PD. Some teachers were overwhelmed and could not replicate all technology uses in the classroom. During this academic year after the summer PD, we followed these teachers to track their classroom implementation through observation, focus group interviews and students' projects. We did observe the replication of modules in their classroom, but not enough transferrable use of cognitive tools approach in other topics.

4.4. Phase four (iteration three): refining PD and providing PD for cohort 2 teachers

To respond to the challenges revealed by the first iteration of testing with Cohort 1, we again refined the modules to reduce the types of technology, strengthened the discussion of the cognitive tools approach, especially how ICTs as cognitive tools can be transferred to topics beyond the modules, and addressed the alignment of the new literacy framework with the current adopted Common Core Learning Standards. Fig. 3 summarizes the final content and structure of the PD workshops, and indicates how the PD prepares teachers' new literacy and ICTs skills and knowledge.

The third iteration provided a much more successful implementation result compared with the second iteration. We provided the PD to cohort 2 teachers in this phase, starting with 16 teachers, and retained 15. We continued to conduct classroom observations, focus group interviews, and collected students' assignments throughout the ensuing academic year. At the end of phase four, teachers administered a test to assess students' learning outcomes, as supplementary information to help us estimate the impact of cognitive tools approach on students' learning. This test consists of 45 items selected from the New York City Living Environment Regent Exam test bank collected by our teacher leaders.

4.5. Phase five: generalizing the design principles

The last phase in the DBR involved reflection to generate the design principles for researchers and practitioners who are pursuing similar topic of interests. The design principles yielded from this study are reported in the results section.

Year one			
	Module 1 topic: Water Quality **Central technology: Web engines, Google Doc, spreadsheet, chart, social networking sites, cyber databases**		
Day	**Topics**	**ICTs practices**	**New literacy skills (cognitive skills): a) Identify questions, b) locate information, c.) evaluate information, d.) synthesize information, e.) communicate results.**
1	(1) Project overview and objectives. (2) Practice how to collect water quality data using cyber databases. (3) Discuss the new literacy framework and cognitive tools approach.	Cyber databases, spreadsheet	
2	(1) Discuss the sample scientific topic and the aligned state standards. (2) Discuss the research question and hypothesis of the structured inquiry activity. (3) Practice how to search information using web search engines. (4) Practice how to use spreadsheet to log and analyze data.	Web search engines, spreadsheet, chart, cyber databases	b, c, d
3	(1) Discuss the structure of the lab report template and how it facilitates students' development of new literacy skills. (2) PD trainers model how to use ICTs to complete and present the structured inquiry activity. (3) Teachers complete research and share research findings on social networking sites. (4) Discuss other credible cyber databases that can support inquiry activities. (5) Discus the transferrable skills.	Word processing tools, spreadsheet, web search engines, cyber databases, social networking site	b, c, d, e
4	(1) Discuss reflection of the structured inquiry activity. (2) Practice the use of social networking site.	Social networking site	e
5	(1) Teachers practice developing the research question and hypothesis of the guided inquiry activity. (2) Teachers practice using ICTs to complete the inquiry activity.	Word processing tools, spreadsheet, chart, web search engines, cyber databases, social networking site	a, b, c, d
6	(1) Discuss reflection of the guided inquiry activity. (2) Discuss how cyber databases can be applied to other scientific topics. (3) Practice how to use cyber databases to conduct individual research.	Word processing tools, spreadsheet, chart, cyber databases	a, b, e
7	(1) Practice how to use scientific equipment to collect data and use spreadsheet to log and analyze data. (2) Teachers develop their own research question and hypothesis for the open inquiry activity.	Spreadsheet, chart, e-mail	a, b, c
8	(1) Teachers use scientific equipment (Probeware + iPad) to collect water quality data from several spots during a field trip. (2) Teachers use ICTs to complete the inquiry activity.	Word processing tools, spreadsheet, chart, web search engines, cyber databases, social networking site	b, c, d, e
9	(1) Discuss the technology integration strategies as a group. (2) Discuss teacher's sample lesson plans. (3) Discuss the flipped classroom concept. (4) Share resources with teachers through social networking site and model the flipped classroom approach.	Social networking site	e
	Module 2 Topic: Photosynthesis **Central Technology: Image and video tools**		
Day	**Topics**	**ICTs practices**	**New literacy skills (cognitive skills)**
1	(1) Project overview and objectives. (2) Reinforce teachers' understanding of the new literacy framework and cognitive tools approach. (3) Discuss the lab report template structure. (4) PD trainers model how to use image and video to facilitate structured and guided inquiry activities, and use spreadsheet/chart to analyze the data collected. (5) Discuss the research question and hypothesis of the open inquiry activity.	Spreadsheet, chart, image editing tools	a, b, c, d, e
2	(1) Discuss the exemplar projects that used image and video to collect supporting evidences. (2) Develop research questions and hypothesis, and practice how to use image and video to collect supporting evidences as a group. (3) Practice how to use spreadsheet to log and analyze data. (4) Present their group projects.	Spreadsheet, chart, image/video editing tools, word processing tools, social networking site	b, c, d, e
3	(1) Teachers present their open inquiry projects. (2) Discus the transferrable skills. (3) Share resources with teachers through social networking site and model the flipped classroom approach.	Spreadsheet, chart, image/video, word processing tools, social networking site	d, e
Year Two			
	Module 3 Topic: Evolution Theory **Central Technology: Map tools**		
Day	**Topics**	**ICTs practices**	**New literacy skills (cognitive skills)**
1	(1) Reinforce teachers' understanding of the new literacy framework and cognitive tools approach. (2) Discuss the alignment of new literacy framework and the learning standards (Common Core and NGSS).		
2	(1) Discuss the structure of the lab report template and how it facilitates students' development of new literacy skills. (2) Discuss the research question and hypothesis of the structured inquiry activity. (3) Practice how to use mapping tools to collect evidences and create artifacts to present the research findings. (4) Practice how to use spreadsheet to organize data.	Word processing tools, web search engines, map tools, spreadsheet	a, b, c, d, e

Fig. 3. PD design of the four modules.

3	(1) PD trainers model how to use ICTs to complete and present the structured inquiry activity. (2) Teachers present their research and share research findings through social networking site.	Map tools, spreadsheet, social networking site	e
4	(1) Teachers practice developing the research question and hypothesis of the guided inquiry activity. (2) Teachers practice using ICTs to complete the inquiry activity.	Word processing tools, web search engines, map tools, spreadsheet	a, b, c, d, e
5	(1) Teachers presented their research findings through the social networking site. (2) Discuss reflections of the guided inquiry activity.	Map tools, spreadsheet, social networking site	e
6	(1) Teachers develop the research question and hypothesis of the open inquiry activity. (2) Teachers practice using ICTs to complete the inquiry activity.	Word processing tools, web search engines, map tools, spreadsheet	a, b, c, d, e
7	(1) Teachers present their research findings through social networking site. (2) Reflection on the open inquiry activity.	Map tools, spreadsheet, social networking site	e
8	(1) Revisit all ICTs discussed during the past three modules, and discuss the transferrable skills. (2) Discuss and model the use of social networking site in the classroom. (3) Discuss the sample lesson plan.	Social networking site	
9	(1) Discuss the barriers of technology integration, and share the strategies to overcome challenges. (2) Discuss and practice the flipped classroom concept. (3) Share resources with teachers through social networking site and model the flipped classroom approach.	Social networking site, video editing tool	d, e
	Module 4 Topic: Human Body **Central Technology: Google Form and pivot table**		
Day	**Topics**	**ICTs practices**	**New literacy skills (cognitive skills)**
1	(1) PD trainers model how to use pivot table to analyze data in the structured inquiry activity. (2) Discuss the structure of the lab report template. (3) Teachers complete the structured inquiry activity as a group and present the findings through social networking site.	Word processing tool, search engines, spreadsheet, chart, pivot table, social networking site	b, c, d, e
2	(1) Discuss how to use Google form to collect data. (2) Discuss the research question and hypothesis of the guided inquiry activity as a group. (3) Teachers create Google form and collect data from the peers, and use pivot table to analyze data. (4) Teachers present research findings through social networking site.	Word processing tool, search engines, Google form, spreadsheet, chart, pivot table, social networking site	a, b, c, d, e
3	(1) Discus ideas to facilitate students to use Google Form to collect data. (2) Revisit the ICTs, new literacy framework, cognitive tools approach, and the alignment of the PD with learning standards. (3) Share resources with teachers through social networking site and model the flipped classroom approach.	Social networking site	e

Fig. 3. (*continued*).

5. Results

5.1. Classroom observation

The Technology Observation Checklist documented teachers' change in technology integration before the PD and a year after attending the PD. The observers documented students' use of the ICTs in the classroom using a 3-point scale (1 = never happened, 2 = occurred once or twice, and 3 = major activity). Fig. 4 demonstrated the shift in utilizing ICTs in the classroom after teachers attended the PD. Each bar shows the percentage of technology integration frequency observed in the 25 teachers' classrooms. Before the PD, the most adopted ICTs were word processing tools and presentation tools. After the PD, the observation results indicated a gradual change in the technology integration paradigm, from teacher-centered to student-centered practices; and the shift to student-centered practices has significantly increased after their second year of implementation. Teachers began to design activities that incorporate ICTs to enhance students' practices of new literacy as opposed to themselves using technology to present information. Students had more opportunities to practice the following ICTs after the intervention: word processing tools (especially Google Docs, cloud-based word processing tool), spreadsheets, mapping tools (Google Earth or Google Map), web search engines, social networking tools, emails, video and imaging tools. These technologies were the major ones included in the four PD modules. The observed change in teachers' teaching practice and students' utilization of ICTs reflected the PD's efficacy and its ultimate transfer to classroom practices (see Fig. 4).

5.2. Teachers' assignments analysis

Teachers' assignments were analyzed to examine the alignment of the five new literacy constructs that the students practiced. The data was also used to triangulate the classroom observations because they were conducted only twice after the PD. During the observation, each individual new literacy construct (identify, locate, evaluate, synthesize, communicate) practiced was assigned with number 1, if the assignment requires students to use ICTs to practice the component. At the end of the semester, teachers' assignments ratings were totaled and averaged. The results are illustrated in Fig. 5.

The results also indicate that teachers need time to master the pedagogical practices of developing students' new literacy skills. In their first year of implementation, many teachers managed to change their assignment requirements and started asking students to use ICTs to work on their projects. The second year of implementation shows considerable improvement on teachers' effort to develop students' new literacy skills. Students received more opportunities to practice how to use ICTs to evaluate, synthesize, and communicate information through these assignments.

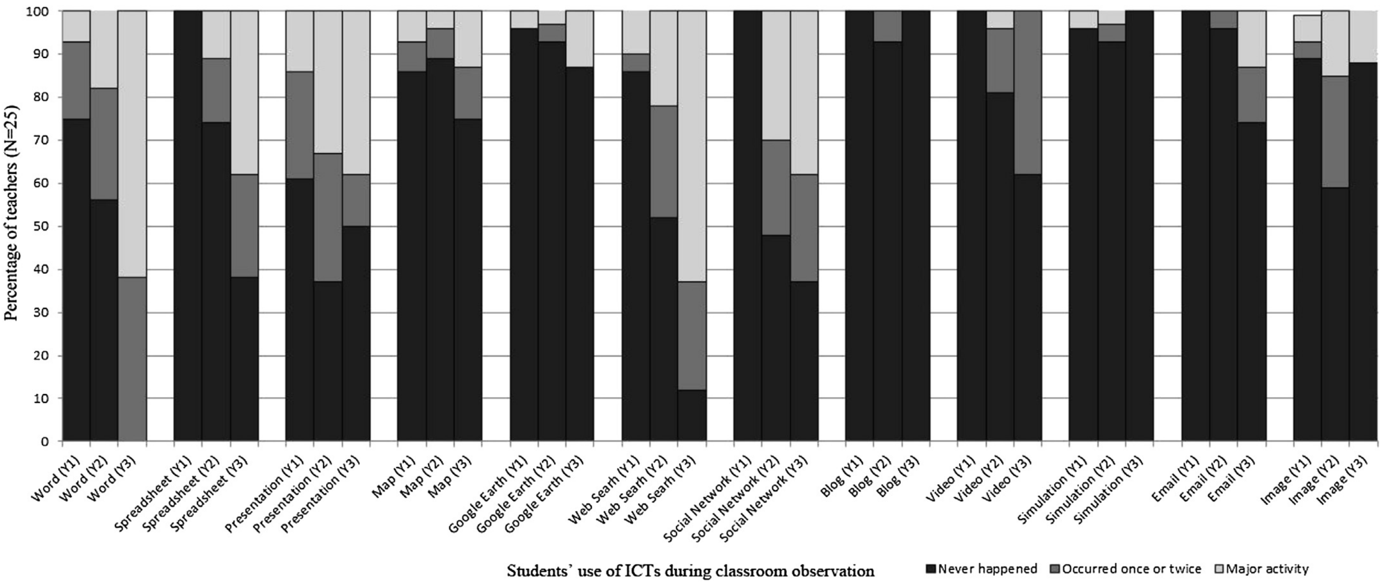
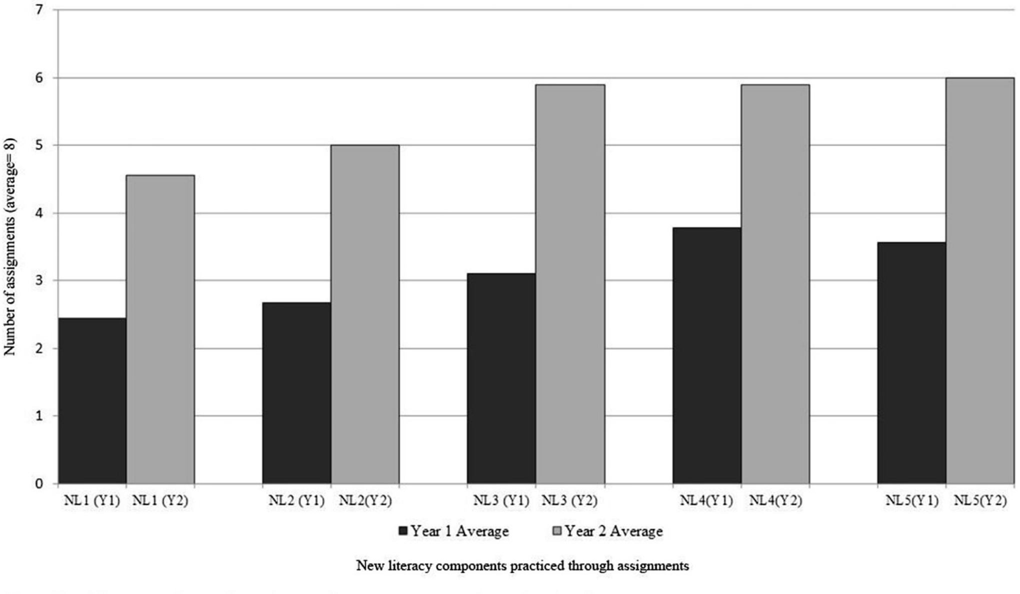


Fig. 4. The differences of teachers' technology integration before the PD, a year after the PD, and two years after the PD.

5.3. Teachers' focus group

Each year, the team conducted seven focus group interviews with teachers throughout their participation in this program, two years in a row. The interview questions were used to investigate the fidelity of the modules, barriers to their technology integration, and success or failure stories of the implementation.



Note: Checklist we used to evaluate the new literacy components in teachers' assignments.

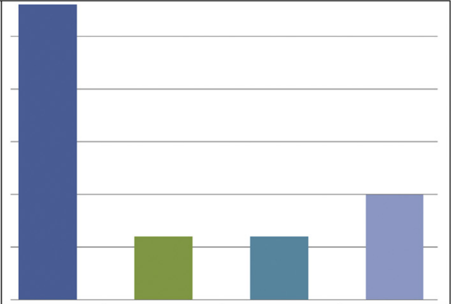
- NL1=Identify question: Students use internet search tools to effectively determine a clear topic and focus for questions to guide the search for information.
- NL2=Locate information: Students locate and organize multimedia format of information relevant to research questions, such as numerical data, texts, video clips, and images.
- NL3=Evaluate information: Students determine the relevance of the information/data to answer the research questions through the use of ICTs.
- NL4=Synthesize information: Students use productivity tools to present their research findings using multimodal texts, including charts, images, video, or interactive content. They use ICTs to manage and organize relevant information through the use of multimodal texts, and demonstrated accurate understanding of the scientific concept.
- NL5=Communicate information: Student uses ICTs to facilitate team collaboration, share their research results to authentic readers.They use a wide array of ICTs to communicate and disseminate research findings, such as social networking tools, blogs, and Google Docs.

Fig. 5. Average frequency of teachers' assignments that require students to practice new literacy components.

We examined the common factors that prevent teachers' technology integration. The literature suggested that factors influencing the success of technology integration in schools lie in the classroom, teacher, and school levels (Hew & Brush, 2006; Hsu & Kuan, 2012; Keengwe, Onchwari, & Wachira, 2008; Snoeyink & Ertmer, 2001). The focus group interviews helped us define the barriers to their technology integration; categorize these barriers according to their enactment of cognitive tools; and rate the challenge level of these factors to each teacher based on the focus group interviews, classroom observations, and assignments analyses (Table 2). The classroom-level factors include the students' technology skills, students' characteristics (e.g., number of students who have special needs or ratio of diverse students population), and availability of technology resources and technical support. The teacher-level factors include teachers' beliefs in technology integration, confidence in their technology skills, understanding of cognitive tools approach, their intrinsic motivation to change their classroom practices, and their adoption of the resources provided by the PD. The school-level factors include the administrative support, school culture in technology integration, and preparation for high stakes standardized tests and teacher appraisal associated with students' standardized testing results (such as state regents exams and teachers' annual professional performance review [APPR]).

Among the 25 participant teachers, we categorized them into four groups: (1) high enactment, (2) medium enactment, (3) low enactment, and (4) zero enactment. 56% of the 25 teachers were in the high enactment group; these teachers replicated all four modules in their classrooms, continued to use the technology they learned from year 1 PD modules during year 2 implementation, and figured out ways to apply the cognitive tools approach to other topics in their curriculum. The medium enactment group constituted 12% of the teachers; they replicated all four modules in their classroom and continued to use the cognitive tools approach in year 2, but rarely demonstrated the application of the cognitive tools approach in other topics across the curriculum. Another 12% of the teachers were in the low enactment group; they occasionally had student use ICTs as cognitive tools for selected learning activities. Finally, 20% of the teachers fell under the zero enactment group; they demonstrated no sign of adopting ICTs as cognitive tools approach. Even though a total of 68% of the teachers reached the goal of this project, 32% of the teachers did not meet our expectations. Moreover, 20% of the teachers did not even try to adopt the cognitive tools approach. Our PD addressed the factors influencing technology integration at the teachers' levels. At the teacher-level, we provided technology skills training, increased their understanding and belief in adopting cognitive tools approach, and provided them resources needed for implementation, but teachers in the low or no change group (32%) did not demonstrate significant changes in these areas. However, many of them encountered additional challenges other than their own ability to use ICTs as cognitive tools. Some of them were reassigned to teach students who have special needs or high needs during the course of PD. It is extremely difficult to use cognitive tools approach science with students on IEPs (Individualized Education Programs) with different learning goals and objectives. Students' technology skills were not their primary concern. A few teachers did not have access to any technology because the resources had been allocated to prioritize certain subjects like ELA and Math, or their school culture did not emphasize the importance of preparing students' technology skills. In light of these factors, it is not surprising that 20% of the teachers could not replicate the modules in their classrooms.

Table 2
Technology integration barrier level.



Number of teachers in each group	Group 1-14 (56%)	Group 2-3 (12%)	Group 3-3 (12%)	Group 4-5 (20%)
Classroom				
Students technology skills	2	2	4	4
Student characteristics (ELLs, special Ed)	1	1	2	3
Technology Resources	2	2	3	4
Teacher				
Belief in cognitive tools approach*	1	1	2	3
Technology Skills*	1	3	3	3
Understanding of cognitive tools approach*	1	2	3	3
Adoption of the PD resources*	1	1	2	4
Intrinsic motivation to use cognitive tools approach	1	2	2	4
School				
Administrator's support	1	1	2	4
School culture to support technology integration	1	2	3	4
State exam and teacher evaluation	NV	NV	NV	NV

Note: 4- factor is very challenging to the teachers and is difficult to resolve, 3- factor is challenging, it may be resolvable but it requires time and effort, 2- factor may be a challenge but teacher feels comfortable to face or deal with the challenge, 1- factor is not challenging, is resolvable easily, or is not an issue to the teacher. NV: no variance among all teachers. *=These factors were the focus of the PD.

Most of teachers in the high enactment group overcame the teachers' level barriers, had reasonable support of technology or access to technology, and were encouraged to use technology by their administrators. Even though some of them still encountered certain barriers such as building students' technology skills, covering required curriculum and preparing students for the standardized tests, they managed to overcome these challenges. These teachers' descriptions of their changes in classroom practices are consistent: they value the changing technology integration paradigm from teacher-centered to student-centered and enjoy providing students the opportunity to use ICTs to practice their new literacy skills. Their students were highly motivated when they encouraged them to work on projects using ICTs, and these teachers were recognized and acknowledged by their administrators for using the cognitive tools approach in the classroom. Moreover, many of them became the technology showcase person or teacher leader to conduct PD in their schools. Their experiences are very important to future practitioners or researchers who plan to prepare teachers who are in the average school environment to adopt technology as cognitive tools.

The interviews with the teachers revealed the following reasons that helped them overcome certain barriers, especially in the classroom and school levels: (1) The ICTs adopted were free and reliable; hence, teachers could require students to work on the projects at home or at the library. The choice of technology made the technology availability not an issue at all. (2) The long PD contact hours helped them develop their technology skills and understanding of the cognitive tools approach. (3) The concept of the “flipped classroom” and the adoption of a social networking site (Edmodo.com) helped with distribution of learning materials and classroom management. These resources greatly helped students who needed an extra boost and more time in learning the technology and who were absent from the class, as well as students who had special learning needs and had to work on their own pace repeatedly at home. The advantage of archiving digital learning resources has greatly eased teachers' instructional burden. (4) The cognitive tools approach is in alignment with the Common Core Learning Standards and, therefore allowed them to communicate with the administrators the importance of this approach. (5) The social networking fostered the formation of learning communities, which greatly reduced the teachers' responsibility and allow students take up ownership of learning. For example, students usually post their questions on the social networking site when encountering problems while doing homework, and as a learning community, their classmates always responded immediately among one other.

5.4. Students' learning outcomes

Table 3 shows the ANOVA test within groups and the *t*-test results between three groups of students. The results revealed that Cohort 1 students' achievement performance was significantly higher than students in the control group (Table 3). Even though Cohort 2 students' average score was higher than the control group, the result was not statistically significant. We do not intend to interpret the result as students who use technology as cognitive tools scored higher on standardized tests than those who do not. The exam topics covered all four modules discussed during the workshop. Teachers might spend more time on these topics than those who were in the control group; or the approach of using technology as cognitive tools might have positive impact on students' comprehension and knowledge retention.

5.5. Students' ICT skills survey

Table 4 shows the mean comparison between the Cohorts 1, 2 and the control group students' ICT skills survey. The results revealed that students in the intervention group had stronger confidence in ICT scales C (basic ICT capabilities) and D (analysis and production using ICT) than students in the control group (Table 4) after the intervention. The findings provide evidence that students' gain in confidence of using technology can be attributed to the intervention, which affected their productivity skills and capabilities to utilize ICTs. Students in the intervention group had more opportunities to use technology to enhance their productivity skills than the control group students.

6. Design principles and implications

The intended outcomes of this DBR are twofold, 1) to optimize the impact of the Cyber-Enabled Learning PD on teachers' classroom practices, and 2) to identify reusable design principles related to initiatives of this kind. The PD trains teachers to adopt ICTs as cognitive tools, guided by the situated technology integration framework. Any research project has limitations. Data collected throughout the iterations of this study included classroom observation, students' learning achievement, students' ICT skills survey, teachers' assignment analysis, and the teachers' focus group. Interviews and focus groups are highly subjective, classroom observations were limited to once a year, and students' achievement might be influenced by many different factors and can be challenging to find the correlation directly linked to the PD's intervention.

Nonetheless, careful analysis of the teachers' assignments clearly reflected the change in their classroom practices. Teachers' assignments were collected throughout two years of their participation. Analysis of this data illustrated teachers' adoption of ICTs as cognitive tools approach and can be linked to the PD interventions that have direct impact on students' learning. This data helped us understand what teachers do differently in their classrooms that can be attributed to the impact of the PD. An objective, other than self-evaluation and self-selected lesson plans, and prolonged evaluation of how PD changes teachers' pedagogical practice is scarce in the literature and is needed to inform the future studies (Lawless & Pellegrino, 2007). Our data analysis indicated that the PD's intervention successfully affected 68% of the teachers' change in classroom practices by providing ample opportunities to foster the development of students' new literacy skills.

Table 3
Student learning outcomes.

Groups	Mean	SE	F-test	*P*-value	Comparison	Mean Diff	SE	T value	*P*-value
Cohort 1	33.57	0.61	17.01	<0.0001*	C1-C2	1.45	0.84	1.73	0.084
Cohort 2	32.12	0.57			C1-Control	4.19	0.76	5.51	<0.0001*
Control	29.38	0.45			C2-Control	2.74	0.72	3.78	0.0002

Note: * = 0.001, N: C1 = 212, C2 = 245, Control = 398. Highest score = 45.

Table 4
Student' confidence in ICT skills.

Groups	Mean	SE	F-test	*P*-value	Comparison	Mean Diff	SE	T value	*P*-value
ICT Scale A = problem solving									
Cohort 1	4.18	0.039	5.68	0.0034	C1 vs. Control	0.18	0.053	3.36	0.0008
Cohort 2	4.09	0.034			C2 vs. Control	0.09	0.049	1.84	0.0652
Control	4.00	0.036							
ICT Scale B = communication and metacognition									
Cohort 1	4.13	0.046	5.94	0.0027	C1 vs. Control	0.18	0.061	2.91	0.0037
Cohort 2	4.13	0.039			C2 vs. Control	0.17	0.057	3.03	0.0024
Control	3.95	0.041							
ICT Scale C = basic ICT capabilities									
Cohort 1	4.10	0.046	14.78	<0.0001	C1 vs. Control	0.32	0.061	5.18	<0.0001*
Cohort 2	4.00	0.039			C2 vs. Control	0.22	0.057	3.96	<0.0001*
Control	3.78	0.041							
ICT Scale D = analysis and production with ICTs									
Cohort 1	3.93	0.047	9.19	0.0001	C1 vs. Control	0.27	0.064	4.25	<0.0001*
Cohort 2	3.75	0.040			C2 vs. Control	0.09	0.059	1.59	0.1122
Control	3.66	0.043							
ICT Scale E = information and internet-related skills									
Cohort 1	3.81	0.049	10.71	<0.0001	C1 vs. Control	0.23	0.066	3.49	0.0005
Cohort 2	3.71	0.042			C2 vs. Control	0.13	0.061	2.15	0.0314
Control	3.58	0.044							

Note: * = 0.001, N: C1 = 270, C2 = 372, Control = 332. 1 = Lowest confidence, 5 = Strongest confidence.

Moreover, once these teachers mastered these ICTs to support students' cognitive skills, they further explored ways to integrate ICTs and continual use ICTs beyond and across the topics discussed during the PD.

The followings are the implications for the refinement of PD and are intended to shed light on preparing teachers to adopt ICTs as cognitive tools approach.

(1) Long duration of PD: It takes time to master the technology skills. Cyber-Enabled Learning provides 240 h of PD for teachers, and prepares their skills through four workshops in two years, two summer and two winter workshops. The long contact hours enables a comprehensive approach to meet teachers' ongoing needs to learn technology integration strategies and make connection with their classroom practice.
(2) Teacher ownership: One of the essential elements of the PD is to allow teachers to reflect on their learning and pedagogy through the sharing of their newly developed curricular units and their students' artifacts. It allows teachers to take ownership of the technology and resources, and hence increase their confidence in integrating technology (Kubitskey, Fishman, & Marx, 2003).
(3) Affordable technology: Cost (e.g., resource, support) is often deemed as the major barrier of the technology integration (Hew & Brush, 2007; Karagiorgi, 2005). The technology chosen for teachers in this project is affordable, free, reliable, easy to access to, and can be used across curriculum. Teachers did not have to ask administrators to purchase additional resources for the implementation. The affordable cost helped many teachers overcome economic issues and enhanced the implementation.
(4) Relevance of design and learning activities: In our study, the new literacy framework convinced these teachers and guided them to explore ways of using ICTs to facilitate students' inquiry skills. During the PD, teachers were given opportunities to conduct inquiry activities using ICTs. These activities developed their skills and knowledge in using ICTs, and they improved their confidence in modeling ICTs in their own classrooms. The ICT activities were designed as a scaffolded learning sequence, starting from the mini-projects that helped teachers master the ICTs skills, and then expanded to introducing teachers to the science integration strategies.
(5) Involvement of practitioners (teacher leaders): The involvement of teacher leaders helped the team understand the classroom culture, integration barriers, learning needs in science education, technology advantages in various topics, and the alignment of the learning standards. Their presence during the workshop also made the PD more relevant and credible to other teachers.
(6) Alignment with standards: There are several sets of standards that science teachers need to address in New York State, including the Common Core Learning Standards and the science learning standards. The PD modules were designed to align with these learning standards and hence helped teachers familiar with the standards set and increase their confidence of integrating technology into the existing curriculum, while also addressing the components in their teaching evaluation.
(7) A meaningful technology integration framework: The new literacy concept aligns with science literacy components, providing a convincing framework to help teachers understand the cognitive skills required in the inquiry process and how technology can support the cognitive strategies. Explicit discussion of a technology integration framework not only helped teachers understand the advantage of using ICTs in science education but also encouraged them to apply these tools in other topics.
(8) Flipped classroom concept: The team modeled the flipped classroom concept by using the social networking site to disseminate and archive the instructional tutorials regarding the technology skills. Many teachers also adopted this approach to create their own tutorials so the students can access to these resources inside or outside of school through social networking site. The modeling process convinced teachers of the strengths of the flipped classroom concept, and enabled them to learn how to resolve potential challenges while implementing flipped classrooms.
(9) Formation of a virtual learning community: We modeled the use of ICTs and a social networking site not only during the PD, but also throughout the project period. The team used a social networking site to facilitate teachers' communication and presentation, help them review ICTs skills by archiving the learning video clips, share learning resources, and exchange information. Teachers mirrored

the use of ICTs and a social networking site in their classrooms. The social networking site became a learning community and a support system for teachers.

(10) Scaffolded PD learning experience for using ICTs as cognitive tools: During the PD, teachers went through the same process as if they were learners to conduct their own studies. For instance, in the module where they learned how to use mapping tools to collect data, they first started with a mini-project on using Google Earth/Google Map to locate their homes and then creating placemarks to show their favorite field-trip locations. Once they felt comfortable of using the tool, we then introduced them to the cyber databases and facilitated their use of spreadsheets to enter data collected from these databases. Teachers could easily translate their skills learned from the mini-projects to the inquiry activity and used mapping tools to create placemarks to compare and analyze the objects they chose to investigate. These mini-projects improved teachers' confidence in using ICTs and prompted them to think of different ways to use ICTs as cognitive tools with topics.

(11) Scaffolding writing template (lab report template): The PD covers a variety of dimensions to prepare teachers to teach not only content, but also skills such as cognitive skills, technology skills and collaboration skills. To ease teachers' burden in technology integration and ensure the consistency of the replication of the models, the team designed a writing tool (lab report template) to guide (scaffold) students to use technology in their inquiry activity. The lab report templates (http://goo.gl/07sBeb) have been adopted by most of the teachers in this project and its usage can be observed from teachers' assignments and students' artifacts. This tool greatly helped teachers in the adoption of ICTs as cognitive tools approach.

7. Limitations

There are limitations to this study. We only studied 25 teachers across New York City from 24 schools; therefore, the generalization of the results is limited. Our study results may only be applicable to the population of middle-school science classrooms in urban areas. The design principles are primarily applicable to teachers who teach in the regular classrooms, with acceptable variations in students' characteristics, reasonable technology support and access to resources, and are in an environment that encourages technology integration. Lastly, the factors affecting teachers' technology integration are much more complex than we might assume. Actual classroom practices are affected by a variety of factors. Teachers' technology integration might be shaped and affected by factors beyond what we've discussed here, such as their teacher training, content knowledge, or parental involvement. It is not feasible to investigate all these factors within one study.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.compedu.2014.07.006.

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