

PROJECT SUMMARY

Overview:

The proposed ITEST Strategies Project will iteratively design, develop, implement, and study a socio-technological system for group-centered STEM teaching and learning. The system consists of: (a) a flexible set of communications technologies, which provide a network infrastructure that can be deployed reliably and robustly in classrooms, even when the surrounding school network is unreliable; (b) an integrated array of representation technologies, which support data-rich collaborative learning in specific STEM disciplines; (c) a suite of research-based collaborative activities, which deploy the representation and communications infrastructure for group-level learning in the tradition of Generative Design; (d) a powerful approach to teacher education and preparation (UTeach STEM), which marries training in STEM disciplines with practical and theoretical questions of classroom instruction; and (e) an instrumentation plan, which will produce data about classroom interactions with the emerging system, both in elementary and secondary classrooms in the field and in classrooms within the UTeach program, to drive cycles of design-based research.

The Group-based Cloud Computing for STEM Education Project team consists of leading researchers and implementers, whose expertise spans the five systems components described above. Two of the PIs were co-founders of the UTeach STEM program and are actively engaged as professors of courses in the program at UT Austin, where they have integrated prototype versions of the technology to be developed in this project. And three of the PIs have been actively involved in the design, development of technology components of the proposed system in both research and corporate settings, as well as in and study of teacher practices with group-centered teaching and learning at small and large scales. The qualifications of the team, their preparatory work in design and prototyping the system, and the resonance of the UTeach goals and philosophy with the capabilities of the technology, enable us to propose an ambitious research plan to address the following questions:

(1) How can the integrated GbCC environment be shown to be capable of supporting participatory and more fully socially mediated forms of classroom activity through use in an innovative, STEM-focused pre-service program?

(2) Can we develop ways of understanding how teacher capacity building presents a credible strategy for transforming student understanding and potential career trajectories by attending to what issues are raised, and how they are addressed, relative to the implementation of innovation both of the specific sort advanced in this project but also, plausibly, in support of attempts to introduce similar, group-oriented, technological innovations in STEM education.

Intellectual Merit :

This project focuses on group-centered approaches to teaching and learning, and on the design of technology to support Generative Activities that leverage the diversity of thinking in classrooms. This work significantly advances an extensive tradition of research spanning the past thirty years, which has demonstrated the power of such approaches. The current project offers detailed analyses of activity designs and implementations that foster authentic STEM practices in group-centered learning environments, as well as nuanced studies of high-leverage teacher ?moves? and strategies within such environments.

Broader Impacts :

The success of Generative Design within the cross-colleges UTeach STEM Education certification program, now being adopted by more than 40 universities nationwide, suggests that a group-based approach to STEM education is both appealing to teachers and feasible to implement in real classrooms. As of Spring 2015 Enrollment at UT Austin is 490 students and enrollment nationally stands at 6,892 students. The projected number of secondary STEM students taught by UTeach graduates nationwide by 2020 is more than 4 million. The proposed Group-based Cloud Computing technology is highly resonant with this approach to classroom instruction. Classrooms implementing these approaches have been shown to impact learning, especially among traditionally underserved populations.

Group-Based Cloud Computing for STEM Education Project

Project Overview

The proposed Group-Based Cloud Computing (GbCC) for STEM Education project integrates three prior and continuing research, development, and design frameworks to address directly the potential for group-situated learning and teaching in STEM classrooms. The three frameworks to be integrated in this ITEST (Strategies) proposal are (1) the NetLogo (Wilensky, 1999) agent-based and aggregate modeling and participatory simulation (HubNet, Wilensky & Stroup, 1999) capabilities, (2) the completely open-standards based, group-situated, device independent, and database mediated cloud-in-a-bottle (CiB) network architecture (Remmler & Stroup, 2012) and (3) the use of socially-mediated generative activity design for supporting STEM focused learning and teaching in classrooms (*c.f.* Stroup, 2007). The goal of the project is to use the browser-based GbCC capabilities to advance participatory and more fully socially mediated approaches to learning and teaching in STEM classrooms as a vehicle to broaden and deepen the involvement and engagement of all students with in-depth understanding of STEM domains and their possible pursuit of STEM-related careers.

To realize this goal for students, we will leverage the full programmatic capabilities of the nationally recognized UTeach STEM Education certification program, begun at the University of Texas at Austin and now being implemented at more than 40 universities and colleges around the country (UTeach Institute, 2015). The UTeach program will be used as innovative context to iteratively improve and support the potential for large-scale adoption of the flexible, authorable, GbCC architecture, related STEM-focused activities, approaches to teacher-driven lesson design and implementation. We expect the project to produce a fully-functional, entirely browser-based GbCC learning environment, model lessons, documentation for existing lessons and how to author new GbCC-based lessons, and research based insights related to programmatically supporting the introduction and adoption of innovative technologies and related pedagogies in classroom-based STEM education.

Our focus on developing the abilities of teachers to work with, and develop, participatory and more-fully socially mediated approaches to classroom-based learning is framed by the observation that the most consistent and conspicuous feature of school-based learning is that it takes place in a group setting. A teacher and a collection of students gather in a physically contiguous location with the intent of advancing meaningful domain-related insight and learning outcomes. More often than not, however, the potential of these group settings for pursuing highly interactive and immersive forms of content-specific learning is underutilized. Instead most of the activity that typically takes place in classrooms centers on relatively isolated forms of individual activity and, particularly at the secondary level, most of the interactions between the teacher and students follow a Initiation (teacher) – Response (student) – Evaluation (teacher) sequence (*c.f.*, Wells, 1993). Student-student interactions or other forms of teacher-student interaction occur much less frequently and are rarely sustained even within a single teaching episode, much less over the multiple class periods typically associated with presenting a topic from standard STEM curricula. By contrast, the on-going use of generative activity design -- like the ongoing lesson-specific use of modeling and simulations based on the use of NetLogo or the data-base mediated, browser-based, network capabilities of the Cloud-in-a-Bottle architecture -- has grown out of more than of decade of field-based experience within the UTeach STEM certification program and is meant to support a much richer array of forms of socially-mediated interaction and diverse participation by all students in STEM-related learning (Stroup, 2007, Ares, 2009, Brady, 2014).

The use of network supported, generative design based learning and teaching has been shown to improve student outcomes in algebra (Stroup, 2012) and the development of student understanding of agent-based and

aggregate forms of systems reasoning (Stroup & Wilensky, 2014) using network-mediated, NetLogo-enabled participatory simulations (i.e., HubNet, Wilensky & Stroup, 1999). The proposed integration of this development within a well-specified but flexible, low-cost, and open architecture and the generative lesson design framework draws heavily on the many instances and iterations of working with UTeach students to advance the learning of challenging and important STEM curricular topics in diverse classrooms in high-needs schools and communities.

Consistent with our on-going work in diverse, typically urban, settings, the UTeach program itself has three cross-cutting themes unifying the programmatic commitments and design consistent with those of the ITEST program: STEM-related inquiry, equity and the on-going integration and lesson-specific use of STEM-related technologies. More than serving as a well established and nationally recognized program for field-testing and iteratively improving the capabilities of the proposed Group-based Cloud Computing for STEM education learning environment, the proposed targeting of the UTeach STEM teacher certification program will allow us to explore, within a framework of design based research, the issues and possibilities associated with capacity building related to introducing innovative, inclusive approaches to STEM education more broadly.

Developed principally as a four-year undergraduate program, the more than 500 students currently enrolled in UTeach STEM program at the UT Austin campus and the more than 6,800 student enrolled across the 44 university based implementations sites complete both a STEM-specific major and teacher certification (UTeach Institute, 2015). The STEM focused coursework and the on-going, schools-based, field experiences – typically beginning in their first year and supported throughout the multi-year program – are structured to have the students bring together their still-developing domain-specific abilities with the challenges of designing within an increasingly inclusive and nuanced understanding of what it means to teach and learn STEM-related concepts, as well as specific, research-based and empirically validated approaches to designing for a classroom as a unit of engagement and analysis. In addition to our documenting, as part of the proposed project, the many school-aged students who would directly experience the GbCC for STEM architecture and socially-mediated forms of classroom learning, we can further justify our focus on developing teachers as a vehicle for positively impacting the competencies and career trajectories of diverse students by noting that by 2020 current projections are that UTeach graduates will have had direct responsibility for instruction of five million school-aged students.

The research and design team to be brought together for the proposed GbCC Project includes the key innovators associated with each of the three elements to be integrated in this project, all of whom have extensive experience working within design-based research frameworks to realize high impact, STEM-specific outcomes. The connection to the UTeach STEM certification program is similarly direct with two of the Principal Investigators being among the co-founders of the UTeach program, with on-going responsibilities for developing and teaching three of the unique, program-specific, core courses within UTeach (Knowing & Learning, Classroom Interactions, and Project-Based Instruction). These investigators also teach elementary mathematics and science methods courses (including in the bi-lingual cohort) at UT Austin, which should support the integration of the GbCC capabilities within the two initial, elementary and middle school situated, UTeach field experience courses, Step 1 and Step 2, taught within the College of Natural Science.

Year 1 deliverables will include the development and documented implementation of the GbCC capabilities throughout the UTeach program (on campus and in schools), twelve model lessons to be used in courses and at UTeach affiliated schools, presentations at research and professional development conferences, research publications and preliminary analyses of findings related to the issues and insights gained from the introduction of the GbCC innovation within the UTeach with the primary focus being at UT Austin. Year 2 deliverables will include iteratively improving the capabilities and implementation of the GbCC learning environment, refinement of the model lessons, particular focus on the authorability of new lessons by program staff as well as our pre-service students, presentations at research and professional development conferences, research publications and generalizing the features of implementation so as to facilitate the adoption of the GbCC capabilities in the

UTeach community beyond UT Austin or in other STEM education programs. The Advisory Board and external evaluator will help ensure we obtain the project outcomes and deliverables by meeting with the project team and providing feedback relative to our on-going efforts specified in the project time line. The budget for the project is tightly aligned with the project goals and is multiplied significantly in terms of implementation and impact by our leveraging the substantial programmatic infrastructure and participation of the investigators in the UTeach certification program.

Project Research Questions & Methods

Cognizant of the commitments and scope of characterizing the development of technology-supported innovation within an ITEST Strategies project, we will address two research questions within a design experiment methodological framework. As a set of closely related methodologies for developing fit-for-purpose innovation, design experiments have continued to be deployed and developed over the past two decades across a wide array of educational interventions and research contexts. Brown and Campione (1996) frame a way of understanding how the elements of the proposed GbCC project, with its focus on group-situated STEM teaching and learning in classrooms, are to work together: “it has become increasingly clear that we need a new type of learning theory to inform the design of learning environments, including those that are situated in settings of formal schooling” (p. 290). “Learning theory” emphasizing participation and the importance of socially mediated development is to “inform” the development of the GbCC learning environment for classrooms “situated in settings of formal schooling” within a pre-service program with commitments supportive of the ITEST goals of broadening the participation and career-related self identity of students in STEM-related domains.

The primary focus of the activities of this project are on the design and development of GbCC capabilities within, and consistent with, the commitments of an existing pre-service program. While prior work has characterized the importance and effectiveness of the capabilities to be advanced in this project for student learning, including results on high-stakes test outcomes, the initial focus of the proposed the design-based research of GbCC project is to develop the investigative *frameworks* that might then be used to make more formal causal claims across a range of possible programmatic and student-specific outcomes. The *what* and the *how* of the innovation itself need to be *developed* and *well-characterized* prior to being able to address hypotheses related to the effectiveness of the GbCC-supported approaches for improving specific student outcomes and/or related teacher practices.

Following from this focus on developing and specifying the what and how of an innovation targeting classrooms “situated in settings of formal schooling,” the two research questions to be address in this project are:

- (1) How can the integrated GbCC environment be shown to be capable of supporting participatory and more fully socially mediated forms of classroom activity through use in an innovative, STEM-focused pre-service program?
- (2) Can we develop ways of understanding how teacher capacity building presents a credible strategy for transforming student understanding and potential career trajectories by attending to what issues are raised, and how they are addressed, relative to the implementation of innovation both of the specific sort advanced in this project but also, plausibly, in support of attempts to introduce similar, group-oriented, technological innovations in STEM education?

These two research questions are meant to address both to the iterative development and implementation efforts of the project and make a contribution to understanding how to support teachers’ use of classroom-situated innovations meant to improve students’ access to and self-identification with STEM-related careers.

More recent literature makes it clear that design experiments are not to be about “tinkering to perfection” or simply iteratively tuning “what works” (Cobb, et al., 2003, p. 9); rather, there must be a significant sense in which design experiments “must place” the “theories” or approaches “in harm’s way” (Cobb, et al., 2003, p. 10). As a practical matter, we have established a demanding set of design expectations for the GbCC Project. In order for our effort to address the research questions and investigations relative to group-based design, however, we need to further specify criteria, likely sites for attending to GbCC-supported teaching, and the kinds of data to collected relative to the criteria. We have opted to use the well-established criteria of design experiments proposed by Collins (1992) to address the research questions and analyze the activities of the proposed GbCC Project. Specification of the criteria and how they are to related to, and be implemented within, the proposed GbCC Project are outlined in the following table.

Criteria of Design Experiments. (Adapted by Hurford (2004) from Collins, 1992, pp. 17-18)

Criterion & Clarification	Relation to GbCC Specific Design Framework and Research Questions, (1) & (2) from above
<p>(1) Teachers as co-investigators</p> <p><i>The experiments “must work within the constraints that the... teachers think are necessary.”</i></p>	<p>A key aspect of the proposed GbCC project is that building teacher capacity relative to group-situated activity is a vehicle for transforming student understanding and identification with STEM-focused careers. Feedback (using on-line forms and other media) from every use of the GbCC related capabilities will include how well and in what ways GbCC works “within the constraints” of the requirements of teachers.</p>
<p>(2) Comparison of multiple innovations</p> <p><i>Tests at each site, holding “teachers, students, school culture” constant; tests across sites, varying those “same factors systematically.”</i></p>	<p>The UTeach program involves multiple forms of innovation beginning with, and retained throughout, the use of the 5-E’s approach to lesson design (Bybee, 2006). The 5-E’s are significantly augmented by other frameworks including, most prominently, a whole field-based course focused on project-based instruction (Petrosino, 2004). Each episode of field-based practice in the current program has detailed rubrics and requirements for student analysis. In addition other technologies and tools (e.g., PhET simulations of Vernier probes) are a significant presence. While the socially-mediated aspects of generative design and related tool use has become increasingly central in many aspects of the program, we expect to be able to attend to, and compare, the interaction of ‘multiple innovations’ related to both project-specific research questions.</p>
<p>(3) Objective Evaluation</p> <p><i>“We want to break the pattern of developers testing their innovations to see if they work” (emphasis added). Instead the focus needs to be on “how well... and under what conditions” the innovations were successful [and unsuccessful, see (7) below].</i></p>	<p>While year 1 focuses on development and implementation at the UT Austin campus, in year 2 the focus will shift much more significantly to what it will take to support the innovation ‘out’ from direct contact with the project personnel and existing capacity at either UT Austin or Northwestern University. It will not be enough to have tools that “work” (although that will be necessary). We will be compelled, in attending to our research questions, to systematically attend to “how well” and “under what conditions” the highly participatory and socially mediated approaches to supporting classroom-based STEM learning and teaching are successful and, just as important to this project and projects also looking the emphasize group-based design, how and under conditions the innovation is unsuccessful.</p>

<p>(4) Testing Technologies Most Likely to Succeed First</p> <p><i>Technologies that “require the least restructuring of the school milieu” have the most probability of returning near-term dividends.</i></p>	<p>In a sense, although the shift to group-based design requires a shift from individual activity and I-R-E based interaction in classrooms, the fact that we are attempting to leverage the potential of classrooms as a group-based context for learning and teaching allows us view the STEM-focused GbCC capabilities as having a high probability of being adopted. A core claim of this project is that there is a good ‘fit’ between the capabilities being developed and the realities of teaching in classrooms.</p>
<p>(5) Multiple forms of Expertise in Design</p> <p><i>There are a “vast number of different variables” in classrooms—adequate characterization will require the application of multiple theoretical and practical perspectives resident in one or several persons.</i></p>	<p>A key aspect of the UTeach program is to introduce and support the application of multiple theoretical and related practical perspectives in addressing inquiry, equity and technology integration in classroom settings. While multiple forms of expertise are to inform the pre-service educators lesson development and implementation -- consistent with what will be the case after completing the program -- the lessons they develop require their integration of the perspectives into their own practices. With support, we expect our students, in using the GbCC capabilities, to engage with the “vast number of different variables” in classrooms and then, as part of current requirements, closely analyze what does take place. Each field-based experience has well-specified requirements for supporting these analyses and, as a result, we expect to gain valuable insights relative to both research questions.</p>
<p>(6) Systematic Variation within Sites</p> <p><i>“To test <u>specific</u> hypotheses... make <u>specific</u> comparisons within a site... this way most variables can be held constant.” (emphasis added).</i></p>	<p>While the commitments of the UTeach program remain constant and are consistent with the goals of the ITEST program, there is a progression in the field experiences in terms of the demands of lesson development and implementation. Early on (Step 1 & Step 2) the 5-E’s are an explicit requirement. Later lessons are evaluated, as examples, in terms of the use of formative assessment and levels of participation by secondary students. Then in Project-Based Instruction student work to implement aspects of lesson development that are, in most cases, the farthest removed from their own experiences in K-12 STEM education. This systematic programmatic variation will enable “specific comparisons” with the UTeach as a site for introducing and supporting the GbCC capabilities.</p>
<p>(7) Flexible Design Revision</p> <p><i>When designs aren’t working, adapt them and carefully document the entire process. Document failures as well as successes, and the “repairs to the design.” Failures are “of equal value to successes.”</i></p>	<p>Of course, even for as experienced a team as that assembled for this project the need to document and learn from design that <i>doesn’t</i> work can present a challenge. To address this aspect we will attend to the difference between simply asking “Does it work?” and the more situated question of “Whom does it work for and how?” Consistent forms of web-based documentation (e.g., Google Forms) by any user as well as by members of the project team will be compared to help ensure the “failures” are of “equal value” as the successes in addressing the research questions. To augment the abilities of the project team, the project budget includes support for an External Evaluator and Advisory Board whom we expect to be as insistent in having us present failures and “repairs to the design” as we are in presenting design successes.</p>
<p>(8) Multiple Evaluation of Success or Failure</p> <p><i>Use mixed methods of evaluation, “standardized pre and post-tests... ongoing evaluations of the classroom milieu... observations and</i></p>	<p>Although formal analyses of student-related high-stakes test results or quantitative analyses of pre-test & post-test results are not part of the research design for this ITEST Strategies proposal, we do expect to leverage what we learn from our UTeach students analyses of the video-recordings of their lessons, their interviews with their students (required in most of our field</p>

interview techniques and perhaps primary trait scoring based on videotapes”.	experiences) and the kinds of evaluation standards they use to characterize the quality of student understanding and identification with STEM-specific activity. We have also begun to support our students in developing and using conceptually-oriented non-dichotomous multiple choice questions (Stroup, 2015) as an alternative to using released high-stakes test items that may or may not be sufficiently sensitive to differences in instruction to warrant their use within the time frame of one, or even a few, consecutive lessons.
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Worth noting, the Principal Investigators and graduate research assistants to be supported by this project would have overlapping responsibilities as researchers and as instructors of record for core courses and field experiences related to implementation within the UTeach program. Moreover, many elements of technology integration and generative design have been integrated into the activities and teaching responsibilities of Master Teachers (instructors of record for the STEP 1 and STEP 2 classes) and UTeach staff. Finally, in addition to in-person observations and field notes we will deploy on-line forms and a user-related project wiki to log use and readily share observations, concerns and suggestions. A mentor teacher from one of the schools we work with could decide to try out the capabilities she saw used by a UTeach student in teaching an earlier section of her classes and, far from being a threat to the research design, her input via the on-line forms, wiki-post or in other forms would feed into our efforts to address the project-related research questions. Similarly, in year 2 when we will be more systematically supporting the use of the GbCC environment, materials, and capabilities out to UTeach programs beyond UT Austin, such open forms and forums for exchange will be further leveraged and improved. The NetLogo research and development team from the Center for Connected Learning at Northwestern University has more than a decade of experience of supporting project related capabilities and community building including collecting, assessing and responding to on-line feedback and supporting experts and novices in developing models and simulation. Finally, the External Evaluator is committed to attend (virtually) eight of the bi-monthly cross site, web-mediated project meetings per year as a “participant observer” and use memos and other artifacts from these meetings to both support consistent attention to the research questions and design experiment criteria outlined above and to help ensure the goals of the ITEST (Strategies) Program for increasing student understanding of, and self-identification with, STEM domains are met.

Qualitative (e.g., text from on-line forms, web posts, observations by the project team or UTeach students) and quantitative data (e.g., how often were the GbCC capabilities used to support lessons in Algebra I and how many school-aged were in the respective classes) are to be collected and used to address the eight criteria as part of engaging the project-specific research questions. As a result of our work within a design experiment framework we expect that the *what* and the *how* of the innovation will be *developed* and *well-characterized* in ways that would directly support subsequently addressing hypotheses related to characterizing the effectiveness of the GbCC-supported approaches for improving specific student outcomes and/or related teacher practices.

Prior Project-Related Work

Most of the core technical capabilities, learning research, and approaches to developing and implementing effective, socially-mediated, lessons in a wide array of STEM-specific classroom settings that lie at the heart of the proposed GbCC Project build on extensive prior effort, innovation, and schools-based field testing. This prior work allows the primary focus of this ITEST Strategies project to be on integrating these capabilities into a coherent, potentially transformative, package and to test, and iteratively improve, the GbCC capabilities within a well-established, innovative, STEM-focused, teacher certification program. Highlighting critical components and capabilities from these prior efforts is important to understanding what is being proposed, why it is we are confident in our ability, within the proposed time frame, to integrate these capabilities into a coherent GbCC package, and how -- by better supporting teachers’ ability to work with participatory and socially-mediated

approaches to lesson development -- students' understanding of, and personal identification with, STEM domains, practices, and career paths will be significantly advanced.

NetLogo (Agent-Based Modeling) & HubNet (Participatory Simulations)

NetLogo (Wilensky, 1999a, 2015) is a widely-used and powerful agent-based modeling environment used by researchers, teachers and students to explore dynamic systems behavior across a wide range of domains. Agent-based programming is based on identifying individual “agents” of a system, endowing them with computational behaviors that govern their interactions with other agents, and observing the “emergent” behavior when the computational ensemble is “run”. A large range of complex, real-world phenomena can be modeled in this way. Agent-based models and simulations have become a critical tool for research (Grimm & Railsback, 2005) and NetLogo makes this type of programming accessible to education. The NetLogo Models Library (ccl.northwestern.edu/models) contains over 400 educational models covering a wide variety of content domains and illustrating NetLogo features. Each model includes materials that explain its core learning goals and how to use the model to reach those goals. In addition to the standalone models in the library, the CCL has developed several model-based curricula that are in use in classroom contexts. Notable among these are the Connected Chemistry high school curriculum (Levy & Wilensky, 2009a, 2009b; Wilensky, Levy, & Novak, 2005) developed in partnership with Concord Consortium.

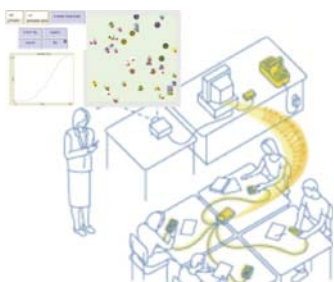


Figure 1 - Disease Participatory Simulation (HubNet)

HubNet (Wilensky & Stroup, 1999b, 2015) extends the agent-based modeling framework of NetLogo out to supporting highly interactive, multi-player, participatory simulations. The participants themselves assume control, via an interface deployed to local devices (“my space”), and the emergent results, like for the stand-alone NetLogo models, develop in a shared group space (“our space”). Figure 1 shows students controlling their individual icons (my space) in a projected display (our space) while a simulated ‘disease’ spreads through contact (a red dot appears on the student icon). Graphs of the number infected are displayed in the projected space and, in addition, the data from each trial can be sent back to the devices for further analysis by students. Using the HubNet architecture participatory simulations are authored with the NetLogo language

and implemented using either a network of computers or a network of graphing calculators using the TI-Navigator™ Network. The participation of all the students contributes to the emergent results and the various strategies (avoidance, changing step size, decisions about what to do prior to or after infection), gestures, utterances, and discussions of the significance of the overall shape of the graphs (epidemic curve) or when each person became ‘sick’ (and how that may have been related to their strategies) are socially mediated and advance the overall learning. Parameters of the simulation can be changed (e.g., being able to see who is sick, the probability of infection, the number of computer control ‘androids’ added into the class) in subsequent iterations of using the simulation and participation and socially mediated engagement with understanding what matters and how in the dynamics of the spread of a disease are deepened and clarified.

Cloud-in-a-Bottle

Building on and significantly extending our previous NSF-funded work aimed at exploring the use of agent-based modeling and network-supported, STEM-specific, interactivity, using proprietary languages (Java) or networks (e.g., the TI-Navigator system), the “Cloud in a Bottle” architecture uses open, cloud-centered components, programming capabilities, and database standards to implement all the interactive and display functionality (Figure 2). The unique, *group-situated capabilities* are designed for classrooms and can be run either over the internet or from a self-contained wireless network (“in a bottle”) with *no installation* on the

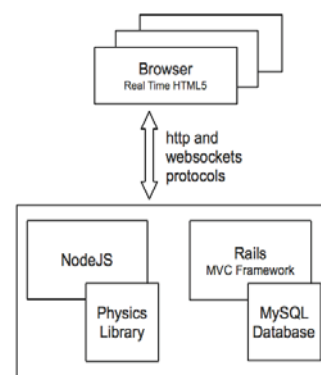


Figure 2 – Schematic for CiB

client side (for either the teacher or the students), and can be used with *any device* capable of running a standard browser – e.g., Firefox or Safari – including PC’s, smart phones, and tablets (with iOS or Android operating systems). Compared with what is currently available for classroom-based learning, much of this group-based functionality of the CiB system is unique to this system and can support the key forms of browser-based and database mediated interaction required for the GbCC Project.

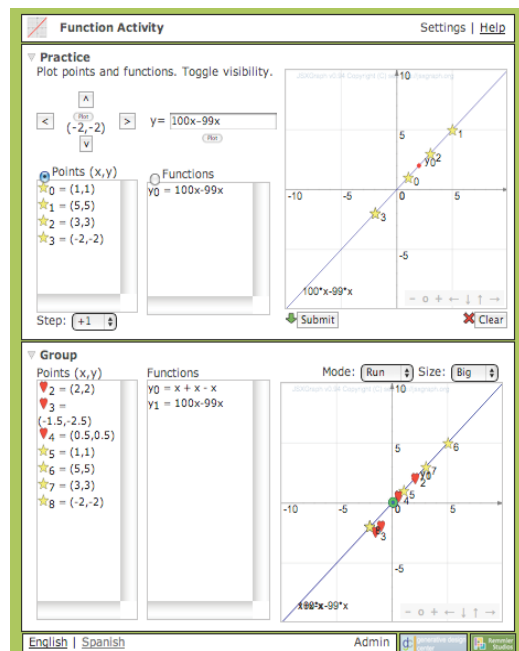


Figure 3 – Function Activity Example

One way of understanding the benefits of the CiB system is to think of it as a substantial “next step” beyond the capabilities of widely used “clickers” for polling student responses in classrooms. With the CiB architecture students are able to use any combination of computers, tablets or smart phones to simply click on a section-specific link and find themselves *immersed in an interactive, network- and database-mediated, ‘world’* populated by their peers and where the interactions are structured by STEM-related content. Based on the prior work with the NetLogo/HubNet architecture described above, to learn about population dynamics, students can assume the roles of a rabbit or wolf in an interactive predator-prey simulation. To learn about the formal properties of functions (see image from field-tested prototype), students can start off assuming the role of movable “points” on Cartesian Coordinate system (top portion of Figure 3) and then can look for, and mark, locations satisfying a rule like “find places where your x-value plus your y-value is equal to 2”. They can share these points to the group space (bottom of Figure 3) and then “shoot” lines through the points marked by the class by submitting $y=f(x)$ expressions. To learn about traffic management in a civil engineering course each student can control an individual light in a

simulated traffic grid, and then work together to try and improve/optimize traffic flow.

The ‘world’ students enter using the browser-based CiB architecture can also be one that interacts with Google Maps in a site-specific way. Our plant locating and identification activity (Figure 4), shown with local data collected by multiple sections middle school students, and our magnetic declination activity (Figure 5) are examples of where student-collected data is entered and displayed in a Google Maps world. Each allows for individual, small group, and whole-class display and analysis of site-specific data. Both also allow data from other classes on campus, nearby sites or, indeed, from around the world to be included. In these cases, students can then make use of the zoom in/out features of Google Maps for further exploration and

investigation. Additionally, the interface allows for data queries and filters. Students can display “all plants located in the shade”, data collected in a specific range of dates, or compare the locations of “native” vs. “non-native” species. Then, with the click of a tab, the query results are displayed graphically (histograms of species, light, height and health are shown) as a complement to the geo-spatial display in Google Maps.

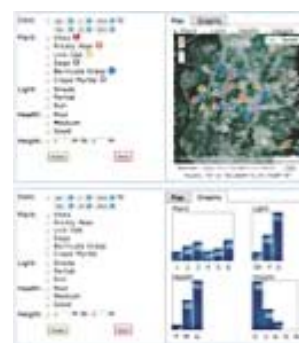


Figure 4 - Google Maps Example



Figure 5 - Magnetic Declination

The working CiB prototype has been used successfully in a number of our core courses in the UTeach program (Step II [see letters of support] & Classroom Interactions), in area schools (e.g., elementary, middle and high schools) as well as at teacher/researcher workshops in Texas and in Minnesota. Figure 5 shows our system displaying magnetic

declination data collected from a workshop in rural Veracruz, Mexico. Currently, with one click, the user interface will switch between English and Spanish. This would allow for its ready use in dual-language classroom settings.

Just as the existing NetLogo/Hubnet capabilities are open, we also anticipate that there would be continuing benefits for future technology development and innovation related to the highly interactive, group-oriented design. For each of the activities developed so far, we have solved sets of specific, group-interaction related, technical challenges (e.g., supporting real time interaction and display for class-specific, multi-player simulations or managing data entry, display and queries for interaction with Google Maps). With a GbCC 1.0 Release these solutions would be “hardened” and standardized and fully integrated with the NetLogoWeb (JavaScript) and HubNet capabilities. The components we are using and the architecture we would release would continue to be “open” and extensible. This would allow for a credible trajectory forward for GbCC functionality to be maintained, updated, and further developed much like some of the open components we are currently using have developed.

Release 1.0 would be a complete open server-based system capable of being installed on most computers anywhere in world. Indeed, to help illustrate the benefits of this approach, we now have a working self-contained Linux version, supporting wireless access by any nearby device (e.g., tablets or students’ smart phones), running on small (book sized), battery powered, <\$100, Raspberry Pi computer. A benefit of such a low-cost, self-contained, systems is that they can be used in any setting where access to the Internet is restricted, unstable, or simply not available. The “cloud” in a small box could be carried by an instructor in a purse or backpack between classes in a building with limited wireless, on field trips (e.g., a geology class going to Enchanted Rock in Texas) or remote/rural settings. Most of our activities work in the self-contained system. But for the ones that don’t (e.g., the interactions with Google Maps) we will explore developing “off line”/asynchronous versions that would then be able to “update” data to another server if/when the portable system is (re-) connected to the Internet.

Generative Design

One way of understanding the nature of generative design is to consider an example related how the topic of “simplifying expression” might be addressed in an Algebra class. A typical task might be “simplify the expression $2x + 2x$.” The form of the exchange might be, “What did you get?” (initiation by teacher), “ $4x$ ” (response by a student), “Correct” (evaluation by teacher). Generative design would change this kind of I-R-E task through a strategy of “making the answer the question.” Instead of asking “What’s $2x + 2x$ (in simplified form)?” the answer, $4x$, becomes the question: “Can you create five expressions that simplify to $4x$?” Graphing calculators can be used for students (my space) to ‘test’ their responses: When entered as functions, are the graphs everywhere coincident (overlapping)? The students were then call on to come enter one of their expressions into a calculator connected to a Viewscreen™ for the whole class to see (our space). When this task was posed to a group of sixth graders in inner city Boston as part of the work of the Boston Algebra Project (an affiliate of Bob Moses’ Algebra Project), the list of shared expressions included: $2x + 2x$, $8x - 4x$, $100x - 96x$, $40x/10$, $200x - 196$, $8x/2$, and $100x/25$. Both the students and the teacher can learn from the examples generated. Evidence of the student learning includes the facts that students can self-correct ‘wrong’ answers ($200x - 196$ get changed to $200x - 196x$); the class’s examples become increasing complex; and threads of kinds of responses can be identified and extended by the students themselves (e.g., $40x/10$ to $8x/2$ to $100x/25$).

Patterns that emerge in the set of responses from the students allows the teacher learn about the students’ thinking and to make pedagogical decisions about what to do next. While the teacher mentioned above noticed the students created multiple instances of rational expressions ($40x/10$ etc.), he also saw that none of the student-generated examples involved negative terms, fractions or decimals, or expressions with more than two terms. In response, he challenged the students to now make, test, and then share expressions that involved

these aspects. Iterative cycles of engagement with student generated examples continued until one student asked about the “sin” (sine) key. Illustrative of how the teacher’s knowledge of the generality of the patterns of equivalence could extend beyond expressions involving x ’s and constant coefficients, and illustrative of how the technology can make novel explorations of equivalence possible, he then asked his students to “see if they could find expressions that were “the same as $4\sin(x)$ ” (the students continued to say ‘sin’ despite the teacher’s continued use of “sine”). The students readily extended the patterns for $4x$ to $4\sin(x)$ (e.g., $40\sin(x)/10$) and even “reached inside the parentheses” to create $4\sin(3x-2x)$.

As part of situating the work of the GbCC project relative to prior work, a video of this sixth-grade class was shown to a group of engineers at Texas Instruments and was part of what initiated the development of the classroom network of calculators (my space) integrated with a projected “Activity Center” on a teacher’s computer with display and bi-direction exchange capabilities (our space). This proprietary network was released commercially as the TI-Navigator™ system. The GbCC project team includes Corey Brady who, while at TI, led the engineering and development group responsible for the Navigator system. Figure 2 now shows much of this functionality implemented using the open, browser-based, CiB architecture. In a related way, the development of the NetLogo/HubNet capabilities extended the kinds of group-based activities to include group role-playing activities or “participatory simulations” (Resnick & Wilensky) using either internet protocols and laptops or building on top of the proprietary TI-Navigator system and graphing calculators (e.g., the ‘disease’ participatory simulation shown in Figure 1. What is important to emphasize in this account of more than a decade of prior work related to the proposed GbCC Project, is how classroom-situated activity design and STEM-focused, group-oriented and network-mediated technologies have co-evolved and informed one another.

Our prior experience also suggests knowledge in STEM domains, like that required in the UTeach program, plays a vitally important role in the teacher’s being able to respond to, and engage, the patterns of responses and the forms of interaction the students generate. Within the UTeach program, generative design has become an increasingly central framework for lesson planning, activity development, and the analysis of teaching episodes in part because, like the prior and proposed technology development discussed herein, the support of participatory and socially-mediated approaches to group-based teaching and learning fits well with the realities and potential of schools-based STEM education. The integrated set of STEM focused capabilities can serve to extend and situate already existent design commitments (e.g., the 5-E’s or the use of the legacy cycle in Project Based Instruction) in ways meant to better leverage the affordances of group-based learning and teaching. This integration, we believe, is likely to significantly advance the STEM related career-identification and domain-specific understanding of all students in ways that are fully supportive of the goals of the ITEST program.

Project Deliverables and Timeline

Figure 6 provides one example of how the three areas of extensive prior work – (1) NetLogo/HubNet modeling and simulation, (2) the Cloud-in-a-Bottle architecture and capabilities and (3) generative design – are to be integrated. This example is to be illustrative of how the broader set GbCC capabilities, specified in Table 1, are to build on prior work, are to structure a set of project deliverables, and are to organize the timeline for the proposed project.

The left side of Figure 6 shows a working example of a Cloud-in-a-Bottle based “blue-ness” activity that has been used in elementary school mathematics classes to explore ratio and proportion ideas, and in middle school science classes to explore the relationship between extensive quantities (e.g., milliliters of water or number of drops of dye) and intensive quantities (e.g., blue-ness or concentration expressed as a ratio). Using generative design, students are asked to come up with multiple ways of matching the blue-ness of a given ratio of drops of blue dye and water. They can work on and test their ideas at the top of the browser screen (my space) and then press the submit button when they’re ready to share their example (we should note, ultimately students create solutions with the same blue-ness in real bottles, water and dye to display in the window of their classrooms).

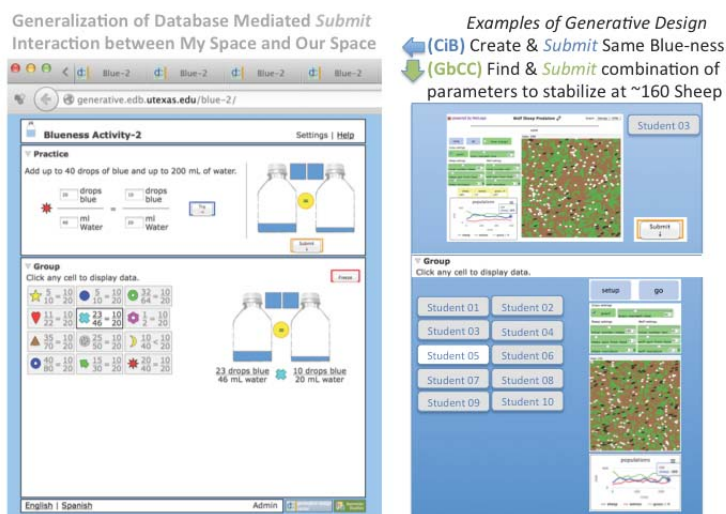


Figure 6. Example of Using Generative Design and ‘Submit’-Based Interaction between My-Space and Our-Space in CiB Blue-ness (existing) and NetLogo Population (proposed) activities

the extensive NetLogo/HubNet library and ability to create new models with the same database mediated functionality of the CiB architecture we will be able to have students work with a NetLogoWeb model in the “my space” area and then submit their parameters to a group space with the same kind of capabilities that are used in the blue-ness activity. A generative task for the predator (sheep) – prey (wolves) model might be first to run the existing model and notice the relative populations tend to stabilize with the number of sheep being ~160. Then students would be asked to change the parameters to create a new systems that also have the number of sheep stabilize around 160. When they find a combination of parameters that works, then they can submit their results to the group (our space) portion of the webpage for further discussion and iterative exploration. The same ‘submit’ and ‘display’ functionality that supports the blue-ness activity can support a wide range of the existing models as well as allow for the authoring of new models that can make use of this capability.

A set of forms of kinds of interaction between my space and our space – like the ‘submit’ capability used in this example – are already working as part of the CiB architecture and we are proposing to integrate these with the agent-based modeling capabilities of NetLogoWeb to support a range of forms of group-based, socially mediated teaching and learning in STEM classrooms. By implementing these integrated capabilities across the UTeach STEM program (both by using and/or modifying sets of classroom-tested activities and by developing new models and participatory simulations) we anticipate being able to directly address the proposed research questions within the design experiment framework discussed above.

Deliverables by Year

The CiB architecture receives the parameters and returns an updated list of responses that appear in the lower portion of the same web page (our space). This lower space is interactive in that any one of the examples can be ‘clicked’ on and the bottles in the lower space will display the respective results. The “freeze” button is introduced so that the teacher may project and discuss the examples without more recent examples continually updating the screen. Note, too, that at the bottom of the screen any student or the teacher can toggle between English and Spanish allowing any student or the teacher to switch, at any time, between languages.

As useful as this particular environment is, a shortcoming of the current CiB approach is that the top and bottom portions have to be “hard coded” by a programmer. By combining

Table 1 outlines the *Key Functionality* that will characterize the Group-based Cloud Computing for STEM education environment and *Implementation* of this key functionality. The top portion of the table highlights the collection of capabilities that are now available and the lower portion highlights how these forms of

Implementation →	Key Functionality →								
	Requires Local Installation (Java :: Requires Computer)	Network Mediated	Browser Based (No user install :: Any device)	Supports My Space - Our Space Interaction	Local Network (w/o Internet)	User Extensible/ Author-able	Supports Multiple Classes by Teacher (Database Mediated)	Interacts with Google Maps	Can Embed Other Browser-Capable Functionality & Open Libraries
NetLogo Java									
Models (400+) •	✓					✓			
HubNet • (participatory simulations)	✓	✓		✓	✓	✓			
NetLogoWeb									
Models •		✓	✓			✓			
- Centralized Site or HTML File									
Cloud in a Bottle									
Internet Server •		✓	✓	✓			✓	✓	✓
Local Server • & Access Point (Raspberry Pi)		✓	✓	✓	✓		✓		✓
Proposed GbCC									
Internet Server •	No Longer Required	✓	✓	✓	✓	✓	✓	✓	✓
Local Self-contained Server •		✓	✓	✓	✓	✓	✓	✓	✓
& Access Point (Raspberry Pi)									
NetLogo Cloud •		✓	✓	✓	✓	✓	✓		✓

Table 1. Outline of the Existing Capabilities (top) to be Integrated in the GbCC Environment (lower).

functionality will be integrated into the proposed GbCC environment so as to support teachers in advancing more fully participatory and socially mediated forms of group interaction for their students in STEM classrooms. Based on more than a decade of work with related technologies in schools, equally important to the proposed consolidation and integration of the STEM-related technical functionality is the absence, with the GbCC environment, of any need for the installation or setup of platform specific/limited or proprietary software (e.g., Java) or hardware (TI-Navigator). The classroom specific STEM activities are setup and managed by the database-mediated cloud architecture that can be accessed by *both* the teacher and her students *from anywhere* and *using any device* supporting a standard browser window. We expect findings related to the importance of both the integration of group-based capabilities and the reductions of barriers to use represented by the development of the proposed GbCC to figure significantly in our efforts to systematically address the two research questions presented earlier. In addition to addressing these key research questions and presenting our findings at research conferences and in peer-reviewed publications as part of implementing the GbCC capabilities and generative design across the breadth of the UTeach STEM certification program, the deliverables will include making the server-mediated, browser-based, functionality available in multiple ways: Open standards and components running on an internet-based server (e.g., a district or school can use the

project server or setup their own internet-connected server [see Year 1 below]), a sub-set of the these capabilities implemented in ‘self-contained’ ways (i.e., by establishing a server and access point using either a small, portable computer or using a bootable flash drive with a school computer) and a version that would be included in the NetLogo download that could support a local server architecture using either the internet or a local wireless network.

Year 1 development efforts will focus on implementing the GbCC capabilities on a Linux server like the one currently supporting the CiB capabilities but dedicated to this project. This means Year 1 deliverables will include implementation of the Functionality on this dedicated internet server as depicted across the first row of the Proposed GbCC portion of Table 1, documenting every instance of the use of the GbCC across the UTeach program using web-based forms (e.g., Google forms) as well as blog, wiki, and user-group input, research findings related to developing these capabilities within a design experiment framework, making available twelve classroom-tested and iteratively improved GbCC Model Lessons, and project related reporting supported by input from the Advisory Board and Project Evaluator.

While continuing to iteratively update and improve the functionality and research-related insights from Year 1, in Year 2 the development efforts will focus on (1) implementing as inclusive a subset of the GbCC capabilities on a Local Self-Contained Server and a NetLogo ‘Cloud’ release to be included in the standard NetLogo download (the rows below the Internet Server row) and (2) the ability of users to extend (e.g., add links to other web pages either on the local server or on the Internet) existing GbCC hosted models and participatory simulations or author “from scratch” GbCC-based models or simulations related to lesson development (the User Extensible/Authorable column in Table 1). The development of the GbCC capabilities on the dedicated Internet Server in year one is to be done so as to make the implementations on a Local Self-contained Server & Access Point and as a NetLogo Cloud extension relatively straightforward. As noted in the previous section, we have a working prototype of implementing much of the Cloud-in-a-Bottle functionality with a portable, compact, battery powered, <\$100 Raspberry Pi computer running as a local Linux server and wireless access point capable of supporting browser-based, device-independent, data-base mediated functionality. In addition to iteratively improving the functionality implemented in Year 1, the deliverables for Year 2 will include versions of the GbCC functionality capable of running on a self-contained computer (including the teacher’s computer as well as on a system like the Raspberry PI) and an implementation running within a system included in future releases of NetLogo/HubNet. Deliverables related to user extensibility and/or authoring of GbCC lessons will include insights and findings related to the project research questions and supported by the project-focused design experiment methodology where we draw particular attention users making models, simulations and activities that are “their own.” Three additional model lessons will be added to the twelve developed in year one, but for these we will look to have one be the result of relatively minimal (from a technical point of view) changes (adding links to other web sites or videos or re-authoring the sequence and emphasize of a lesson), one from modifying the NetLogo code of an existing model (e.g., any one of the model lessons or the 400+ STEM focused education models currently available), and one from someone authoring “from scratch” a model or participatory simulation. Of course, we expect there will be many more examples than these or UTeach students, staff or faculty making models “their own” by modifying them in ways like these three examples. But by having three additional examples illustrating three levels of modification/authorship we will help ensure that the research questions and related methodology will attend to this vitally important aspect of developing and implementing the GbCC capabilities within the UTeach STEM certification program.

Project Timeline/Milestones

Consistent with what is discussed above and with a proposed start date of June 1, 2016, Milestone 1 (July 15) would include setup of the project-dedicated GbCC server, establishing (on separate servers/sits) web-based forms, wikis, user groups and other web-based capabilities to provide on-going data collection and input. GRA’s would be appointed and both site based and project wide virtual meetings will take place. The Advisory Board

will meet. Milestone 2 (September 1) a set of six prototype GbCC based activities will be available for initial use within the UTeach Program and supported by development efforts at both The University of Texas and Northwestern University. Milestone 3 (January 1, 2017) an initial prototype of the general, fully internet-based GbCC architecture will be ready for iterative implementation and refinement during the spring semester. Milestone 4 (June 15) a set of twelve model activities and sets of support materials will be completed, an initial set of presentations at research conferences will have taken place as will sessions at the UTeach Annual Meeting, the Advisory Board will meet to review the progress of Year 1 of the project and annual reporting including that from the External Evaluator will be submitted. Milestone 5 (September 1) the internet-based version of GbCC will have a fully integrated capability for user extensibility and authorship and the prototype versions of the self-contained (local server) version of the GbCC capabilities will be implemented for project-wide testing, a plan will be in place for supporting implementation of, and obtaining feedback from, the use of the 12 model lessons at UTeach sites beyond Austin. Milestone 6 (January 1, 2018) iterative improvements in the GbCC architecture and results from developing the three model examples of user extensions to existing activities or authorship of novel activities will be incorporated into the functionality for the GbCC capabilities and the self-contained versions the GbCC architecture will be fully functional. Milestone 7 (March 15) the pre-release version of the GbCC architecture, the 12 model activities and support materials, the three examples of activity extension and authorship will be documented, the self-contained versions of the GbCC architecture will be available, all code will be commented and available in open-source formats, and sets of findings related to the project research questions will be presented at professional conferences and in related journal article submissions. Milestone 8 (May 31) the Internet based and self-contained versions of the GbCC architecture as well as project materials and research will be completed and available for use across all the UTeach sites, a full release event will take place at the UTeach Annual Meeting, and project-related reports submitted including that from the External Evaluator.

Senior Project Personnel and Responsibilities

Walter Stroup is the developer of generative design as an approach to support group-based, socially mediated, STEM focused classroom learning for grades three through university and of highly interactive network technologies to support group-situated learning and teaching including both the HubNet (Wilensky & Stroup) and the Cloud-in-a-Bottle architectures (Remmler & Stroup, 2012). He serves as Co-Director of the Generative Design Center and much of his research is focused on having young learners understand advanced topics, and systems-based approaches, in STEM domains. Funding for his research has come from the National Endowment for the Humanities (philosophy), the National Science Foundation (including a CAREER Award), Ministries of Education in Mexico, as well as from various private foundations and corporations. He is a Co-Founder of the UTeach STEM program and has developed and continues to teach the Knowing and Learning in STEM Education and Classroom Interactions courses. He will serve as Principal Investigator of the GbCC Project.

Uri Wilensky is a professor of Learning Sciences, Computer Science and Complex Systems at Northwestern University. He is the founder and current director of the Center for Connected Learning and Computer-Based Modeling (CCL) and a co-founder of the Northwestern Institute on Complex Systems (NICO). He is the author of the NetLogo agent-based modeling environment and the HubNet architecture (Wilensky & Stroup, 1999b) for supporting network-mediated participatory simulations, which have hundreds of thousands of users worldwide, including scientists from a wide range of disciplines and students from middle school through graduate school. His research interests include the design of learning technologies and agent-based modeling environments, and connections between computational thinking and STEM education. He will serve as Co-Principal Investigator and lead the research and development team from Northwestern University.

Anthony Petrosino is a Learning Scientist and an Associate Professor of Science and Mathematics Education and the Elizabeth G. Gibb Endowed Fellow at The University of Texas at Austin. He was a seven-year member of the

NSF funded VaNTH ERC, a Principal Investigator of a Department of Education funded PT3 grant and has received over 15 million dollars in grants from the National Science Foundation, the Department of Education and the McDonnell Foundation for Cognitive Studies. His research interests include students understanding of experimentation, engineering education and the development of expertise. He is Co-Founder of the nationally recognized UTeach Program and has developed, and continues to teach, the UTeach Project-Based Instruction and the Knowing and Learning in STEM Education courses. Dr. Petrosino will serve as Co-Principal Investigator of the GbCC Project.

Corey Brady is a Research Assistant Professor at Northwestern University. For the past 15 years he has been engaged in group-centered technology design and while at Texas Instruments led the development team for the TI-Navigator classroom network. He has extensive experience in working in Latin America to support teachers in implementing generative activities and socially mediated pedagogies with both the TI-Navigator and HubNet network architectures. He will serve as Co-Principal Investigator at Northwestern University.

Project Advisory Board and External Evaluator

Christopher Dede is the Timothy E. Wirth Professor in Learning Technologies in the Technology, Innovation, and Education Program at the Harvard Graduate School of Education. For more than two decade he has been at the forefront of research in modeling and in virtual environments (including animated agents) and, as an Advisory Board member, his widely used Framework for scaling-up innovation will play an important role in guiding the GbCC Project.

Marcia C. Linn is Professor of Development and Cognition in the Graduate School of Education at the University of California, Berkeley with a research focus and extensive background in STEM teaching and learning, gender equity, and design of learning environments. As Advisory Board member her recent work on visualization, automated guidance, classroom assessment and design of inquiry learning environments will be particularly relevant.

William R. Penuel is Professor of Educational Psychology and Learning Sciences in the School of Education at the University of Colorado, Boulder and will serve on the Advisory Board. During his thirteen years at SRI, including serving as Director of Evaluation Research at the Center for Technology in Learning, he had the opportunity to conduct a variety of design, assessment, and evaluation research studies and developed expertise in educational technologies, classroom assessment, and implementation research. Currently he is serving as Principal Investigator at the National Center for Research in Policy and Practice for a project funded by Institute for Education Sciences to examine practices associated with greater use of research in schools and school districts.

External Evaluator: Nancy Ares, Associate Professor of Teaching & Curriculum in the Warner School of Education at the University of Rochester, has extensive research background and project-related evaluation experience centering on the interaction of schools and communities including systematic analyses from informal and informal educational settings, a focus on resource-rich approaches to understanding school and community revitalization and a commitment to bridging multiple theoretical and methodological perspectives in studying learning and pedagogy as complex phenomena. Her specific commitments to the project will include attending the annual Advisory Board Meetings and providing on-going advice related to the research questions and methodologies discussed earlier. As part of her evaluation work she will help maintain consistent attention to the research questions, design experiment methodologies, and the goals of the ITEST (Strategies) Program by attending (virtually) eight of the bi-monthly cross site, web-mediated project meetings as a “participant observer.”