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DEVELOPMENT ARTICLE

Maximizing research and development resources: identifying and testing “load-bearing conditions” for educational technology innovations

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Abstract Education innovations often have a complicated set of assumptions about the contexts in which they are implemented, which may not be explicit. Education technology innovations in particular may have additional technical and cultural assumptions. As a result, education technology research and development efforts as well as scaling efforts can be slowed or made less efficacious because some of these basic assumptions (called load bearing conditions) about the match and prerequisites for the innovation are not met. The assumptions-based planning model is adapted as a methodology to help identify the load-bearing conditions for innovations. The process and impact of its use with two cases of education technology-oriented research and development efforts is reported. The work demonstrates the potential value of this LBC process for recruiting, selecting, and supporting research sites, for innovation designers to target efforts that strengthen implementation and support of scaling. Recommendations are made for others engaged in partnerships with education providers around developing, implementing and testing new education technology based innovations in more effective ways.

Keywords Research and development · Implementation · Assumptions-based planning · Scalability · Education technology · Innovations · Formative evaluation

Introduction

Over the last several decades, many countries have made significant public investments in education technology infrastructure and innovations. In the US, between 1983 and 2003 over $40 billion in public and private investments were made for education technology

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infrastructure (Dickard 2003). However, a recent study published by the non-profit Education Superhighway found that 72 % of public schools in America still lack the Internet speeds needed for today's economy (Education Superhighway 2014).

Investments continue to be made. For example, the 2015 US federal budget invests $2.9 billion in science, technology, engineering, and math education (STEM) research and development (R&D), with $50 million of this directed specifically to high-risk, high-return research on next-generation learning innovations and technologies (White House Office of Science and Technology Policy 2014). In addition, there is a range of grant programs through the US Department of Education that target R&D in educational technology (e.g., Small Business Innovation Research and Technology & Media). The US National Science Foundation also makes large investments in R&D for STEM-related innovations [for example, Innovative Technology Experiences for Students and Teachers (ITEST), Career and Technical Education (CTE), and Discovery Research K-12 (DRK-12) grant programs]. Increasingly, education R&D projects have integrated educational technology components even if the project is not solely technology-focused.

In the US private sector, ed-tech startups are exploding. According to TechCrunch statistics reported in Education Week (Molinar 2014), 99 startups in education raised more than $500 million in the prior year. This represents a five-fold increase in the number of startups and a nearly eight-fold increase in total dollars raised 5 years earlier. These startups are often conducting rapid prototyping and product development for widespread use in schools across the US.

The focus on leveraging technology for educational purposes is global. The European Union (EU) recently launched an initiative called "Opening Up Education" which aims to bridge the technology skills gap among EU citizens by bringing the digital revolution into education systems. In February 2014, the 28 EU ministers responsible for education committed to this strategy and encouraged Member States to develop new digital content that would leverage emerging technologies to improve educational opportunities (European Commission 2013). Another initiative in the EU, the "Open Education Challenge" implemented in partnership with the European Commission, provides opportunity for education startups to receive seed money and mentoring to develop new products and tools. In the current awards, 611 applications from 74 countries have been received (Open Education Challenge 2014).

R&D projects are generally intended to provide the time and resources for researchers to design, test and refine innovations. Implementation projects take new innovations and test the ways in which they are best adopted or adapted in a given educational context. The time afforded for testing and refinement is critical for later scalability so that materials or tools are intentionally shaped for the contexts in which they will be implemented, increasing the likelihood that they will not only be used, but used *as intended* (Fishman et al. 2009; Rogers 1995).

A number of barriers and complications can arise in research site selection and pilot implementation that limit the efficacy of the testing phase. Two common problems arise: (1) a research site does not have adequate technology capacities to use the innovation, and (2) a research site does not implement the innovation fully, so the test is of implementation fidelity rather than of the innovation and any underlying theory of change inherent in its design. These barriers and complications may be tied directly to the design of the educational technology itself, or they may be rooted in variations in the organizational contexts in which the innovations are being tested but which are not essential to the efficacy of the innovation's change theory. Finding ways to reduce these barriers could help to maximize the power of the R&D process and, cumulatively across grant programs, have powerful payoffs for educational technology innovation.

With the proliferation of education technology products that result from the R&D process, education practitioners and decision-makers have faced new challenges in understanding how to choose among the myriad of options available to them and how to appropriately incorporate these into their existing practice (Martin 2014; Molinar 2015). Mechanisms that help decision-makers and practitioners better understand the purposes of various innovations and the conditions under which they work best could increase the "match" between needs and solutions.

This article describes a process called "Load Bearing Conditions (LBC)" that can be used by R&D project leaders in unearthing and mitigating potential barriers related to the development, implementation, and scaling of educational technology innovations. This can include issues that are directly related to the education technology itself, testing conditions that are needed to permit a test of the actual theory embodied in the innovation, and extraneous conditions that might influence the discovery and use of the innovation. Relevant literature on implementation and scaling barriers is briefly described and the context of this work, the methodology, and evidence of methodology efficacy from two cases in which it was applied are presented. It is argued that more widespread use of the LBC approach in conjunction with formative evaluation activities could, in aggregate, accelerate the pace of effective R&D by reducing unusable sites and data during an innovation's testing and refinement phases and ambiguity in decision-making during scaling.

Literature

Implementation processes in social and organizational settings pertaining to educational reform and innovation are complicated and have important effects on outcomes. This is true whether the innovation concerns the installation of a developed program or if the activity is an R&D effort of the kind described in this article. Although the specific implementation factors of concern may be different in use versus testing contexts, a number of studies assert their importance in influencing desired outcomes whatever the context. These factors include:

- Characteristics of the innovation, the innovators, and participating teachers (Durlak and DuPre 2008; Kraus 2008);
- Sense making by the teachers of the changes being called for through the innovation (Meyer et al. 2007);
- The fit of the innovation with existing curricula and system priorities (Coburn and Stein 2010); and,
- Systems in place to support the innovation and implementation processes including the capacity for sustaining innovative practice once the initial enthusiasm, funding, and other support of the innovation passes (e.g. Coburn and Stein 2010; Durlak and DuPre 2008; Kraus 2008; Meyer et al. 2007; Culp et al. 1999).

The literature clearly supports the notion that these kinds of factors have important effects on the outcomes achieved. Given the importance of such influences, researchers are paying more attention to these issues in the R&D efforts by using more rapid cycles of prototyping—testing and revising in practical circumstances in response to what is being learned from the realities of classroom practice and from learning outcomes associated with the application of the innovation (Boulet 2009; Culp et al. 1999; Jones and Richey 2000).

The goal of taking an innovation to scale brings with it additional concerns. Raudenbush (2007), in commenting on scale, notes:

> In taking the innovation "to scale," the challenge is to implement these practices in a much larger range of settings without sacrificing the qualities that made the innovation appealing in its original venue. Characteristic difficulties arise in exporting the innovation from its setting of origin to its setting of destination … (p. 23)

The difficulties can include: less control by the inventor, diminished resources and enthusiasm in new settings, new organizational constraints, and the need to adapt the innovation in new and unanticipated ways to address variations in teacher skill levels and organizational routines. Radenbush observes, "if this is the case, essential ingredients for success present in the original setting may no longer characterize the innovation as it is enacted in the new settings" (p. 3). This may be especially true if the innovation is "home grown" in one setting and then exported to other contexts.

If scale is the ultimate goal, then isolating the critical ingredients for innovation adoption and success (whether in the R&D context or for installation) becomes important. In particular, it would be important to understand what conditions are core to the innovation and what variations can be tolerated.

Coburn and Stein (2010) in their comprehensive discussion of lessons about the "relationship between research and practice" echo this theme of context complexity as an important influence on R&D, including when taking innovations to scale. They note that "most designers of educational innovations—whether research based or not—have had the experience [of] struggling with implementation because of contextual conditions in schools or districts" (p. 218). Importantly, they observe that this need to understand conditions is true for both the researcher and practitioner sides—"district leaders [need] to place attention on the conditions for engagement with research" (p. 219). It is critical during the testing phase to know and understand exactly what conditions, resources, and characteristics are essential to the innovation's success so that the extent of adaptation that will be necessary in the various scale-up settings is known.

Hew and Brush (2007) examine in considerable detail barriers related specifically to the integration of technology in K-12 settings and how these might be overcome. They reviewed literature from 1995 through 2006. In this review of the research they turned up 123 barriers that were further categorized into six broad domains listed in order of frequency: *resources, knowledge and skills, institutional, attitudes and beliefs, assessment, and culture* (p. 226). The authors provide some detail on each of these in Table 1 (pp. 226–231).

While the Hew and Brush analysis focuses on the integration of technology in classrooms during installation, many, or perhaps all, of the barriers identified apply to technology-oriented R&D efforts as well. Although the Hew and Brush work is 8 years old, recently published research suggests that the salience of access and support issues may be declining while the other barriers are still evident and new concerns such as users' ability to discover, align, and procure education technology products have emerged (see for example, Wachira and Keengwe 2011; Ertmer et al. 2012; Martin 2014). Thus, one of the most critical challenges now facing both users and developers involves clarity and precision around the needed conditions and purposes of the innovation. Developers must understand and articulate: *What problem or need does the innovation address well? What are the organizational characteristics and/or resources needed for the innovation to operate as intended?*

Table 1 Barriers to Technology Integration (constructed from Hew and Brush 2007)

Barrier domain	Examples of specific barriers
Resources	Lack of access to technology Time Technical support
Knowledge and skills	Lack of: Specific technology knowledge and skills Technology-supported pedagogical knowledge and skills Technology-related classroom management skills
Institutional	Leadership issues/lack of support School scheduling issues School planning for technology implementation
Attitudes and beliefs	Negative or skeptical beliefs about technology value Limited view of application possibilities (e.g., using technology as a way of keeping students busy)
Assessment	Pressure from high stakes testing on teachers to “cover” material limits time for teachers to learn and adapt new technology applications Teaching and learning functions can be supplanted by use of technology primarily for assessment functions External exam requirements (e.g., ban on use of “graphic calculators) can discourage teacher use in classroom
Subject culture	Traditions in subject culture may not encourage use of technology (e.g., art classes) Resistance to innovations developed elsewhere

In sum, this brief review of literature underscores the importance of a wide range of variables that can affect technology implementation in educational settings generally, and R&D efforts in particular.

Methodological context

Several of the authors served an evaluation and planning function on two separate National Science Foundation (NSF)-funded R&D initiatives. In this capacity, they provided assistance at both the strategic level and in supporting evaluation and data use throughout the projects. Both projects were examples of “design experiments” implemented in an “engineering research” tradition. Design experiments typically have “explicit theoretical grounding, with data gathered before, during and after the intervention” in order to test theory; engineering-oriented research focuses on producing quality solutions to practical problems (Burkhardt and Schoenfeld 2003, pp. 4–5).

The Robot Algebra Project, funded through the NSF ITEST program, involved a 3-way collaboration between a learning scientist, a mathematics education expert, and a robotics curriculum developer. The focus was on crafting and testing instructional materials designed to significantly improve the capacity for project-based learning activities that improve students’ mathematical competency in informal learning environments. At its core, the R&D focused on the iterative development of units centered around physical and virtual robots with teacher-led and intelligent-tutoring-system instruction. In this project, educational technology was central to the innovation in terms of its substantive focus and delivery mechanisms.

The “Biology Levers Out Of Mathematics” Project (BLOOM), a project funded through the NSF DRK-12 program, was designed to address three fundamental challenges in K-12 STEM education: (1) “providing all students with high quality STEM learning opportunities;” (2) “enhancing the ability of teachers to provide quality STEM education;” and, (3) “finding ways to scale innovations in STEM education” (Schunn and Stein 2010a, b). The core approach is to target big ideas in high school science and develop instructional approaches and materials that utilize mathematical modeling to elucidate the science concepts, provide an interactive web-based way for teachers to engage with and learn from the materials, and support teacher professional development (PD). If successful, the work would both craft new models of STEM integration and produce mechanisms for instructional change at scale. In this project, educational technology is not the focus of the innovation but is central to scaling up teacher learning and support.

The two contexts are dissimilar both in terms of the specific educational innovations that were the focus and in the specific role that educational technology played. However, both projects involved educational technology R&D efforts exploring ways efficiencies could be attained in the development process with more deliberate emphasis on what the use of these innovations demand of the organizations and individuals implementing them.

Methodology-load-bearing conditions framework and process

In the early 1990s, the RAND Corporation developed the *Assumptions-Based Planning* (ABP) process for the United States Army’s national security planning (Dewar et al. 1993). ABP was conceptualized as a way to respond and plan flexibly in uncertain times. The gist of the approach is to identify the critical assumptions underlying an organization’s thinking and operations, and then to understand which of those assumptions may become vulnerable and how. The original ABP process includes five basic steps:

(1) Identify important assumptions
(2) Identify assumption vulnerabilities (e.g. risks that the assumptions injected into the planning process)
(3) Define signposts- an event or threshold that clearly indicates the changing vulnerability of an assumption/condition
(4) Define shaping actions- organizational action to be taken in the current planning cycle and is intended to control the vulnerability of an important assumption
(5) Define hedging actions- organizational action to be taken in the current planning cycle with the intention of better preparing an organization for the failure of one of its important assumptions

This approach and process has the potential to be helpful to planning in contexts and/or for innovations that are complex or which may not align well with the environments in which they are to be implemented. This process was employed previously in a complex education transformation project as a strategy for managing complexity in the systems-change effort (see Iriti et al. 2010). One of the key lessons learned from that experience was that the term “assumptions” was less helpful than the term “condition” when referring to educational reforms or innovations. When thinking about effecting intentional change, designers and leaders were better able to conceptualize what *conditions* had to be in place for success rather than to articulate *assumptions.* Thus, the adapted process that was employed is referred to as the identification of and planning for “load-bearing conditions” (LBCs).

In general, LBCs can be conceptualized in two ways. In the first, LBCs are the initial conditions that must exist at testing sites for an educational innovation to be effectively tested. What are the necessary components to implement the innovation to a level that allows testing the innovation's underlying theory? A building design and construction analogy was used to illustrate the concept of "load-bearing conditions" to the project leaders, designers, and staff. Construction support beams and walls were used to discuss elements that were structurally critical to maintaining the building's integrity versus those that were aesthetically appealing but structurally superfluous. The second conceptualization focused on *the required conditions inherent within the innovation design itself that influence whether the innovation will function as intended*. This conceptualization is much more about understanding the innovation's underlying theory of change and the conditions that are necessary for its successful use. Beyond this broad conceptual framing, the LBC process was customized within each of the two case examples.

This approach to identifying LBCs can be conceptually linked to theory-driven evaluation approaches (see for example Chen 1990), In evaluation discourse, theory-driven evaluation refers to the articulation of the intended change pathway of an effort as a predecessor to examining whether that change pathway is validated by empirical evidence. An example from the BLOOM project might be: Use of the biology units with mathematical modeling combined with the support of an online professional community will result in teachers' adaptive use of the materials from which students will benefit by understanding the deep structures of the biology concepts. The identification of LBCs can be thought of as surfacing elements of the intended change pathway as theory-driven evaluation would demand. While each education technology R&D context may call for and benefit from various forms of evaluative activities, the focus is on the application of such theory-driven evaluation models and the potential value-added to the R&D process and scaling of the innovation.

Chen (1990) made a strong case that atheoretical evaluations (evaluation efforts which are not guided by an explicit theory of change for the object of study) tend to result in gross assessments of efficacy but cannot offer insight into the causal mechanisms or conditions for observed changes (outcomes). In the BLOOM change pathway example mentioned earlier, atheoretical evaluation might attempt to measure student learning without regard to the teacher practices and adaptations or to the processes in place to support teacher practice. Reynolds (1998) notes that theory-driven evaluations allow one to apply causal criteria such as temporality, size, gradient (dosage/response), specificity, consistency, and coherence that is difficult or impossible in atheoretical approaches. Evaluations grounded in clearly articulated theory allow the complexities of the treatment circumstances and the causal relationships to be attended, including the specific outcomes sought. This is true in R&D contexts as well as in implementation contexts—evaluation grounded in theory of action is more likely to take into account the variations that influence overall efficacy.

Although the potential value of an LBC process is not unique to the educational technology sector, it may be even more important than for other, non-technology oriented innovations in education. In general, technology-focused innovations have a more diverse set of potential LBCs (those that are common for non-technology oriented and the additional issues introduced by technology).

The LBC approach described in this paper generally includes four phases, which are listed here and then explicated within the case narratives:

(I) Brainstorming to generate proposed LBCs for an innovation under development;
(II) Gathering evidence about the proposed LBCs within testing contexts;

(III) Refining LBCs; and,
(IV) Codifying LBCs and implications for innovation design, testing site recruitment, and/or curating for implementation/scale-up.

Phase I draws on the expertise of the developers and researchers to determine those conditions upon which the success of the innovation hinges. Oftentimes, the nuance of development and the technical intricacies of the innovations can cause some of the needed conditions to recede into the background and thus “fall off the radar” of the designers. This brainstorming stage is intended to create a reflective moment in which the developers can think and talk about the innovation from a higher altitude. Phase II is a step intended to verify that the LBCs exist as designers describe, understand the nature and variations of the LBC, and to more fully understand the how the LBC influences the efficacy of the innovation. Phase III applies the learning from Phase II to the LBC descriptions. Phase IV is derived from the ABP shaping and hedging actions with the intent of activating the LBCs to strengthen the innovation design, the testing approach, and/or implementation and dissemination.

Details of the two case studies and the application methodology in each are described in the next section. In the Robot Algebra Project, the LBC process was employed *to better understand and articulate the conditions that are necessary to identify and support research sites.* In the BLOOM project, the LBC process was utilized *to surface the assumed conditions inherent within the innovation’s design.*

Case evidence

Case one: Project-based learning with robots as the R&D context

The focus of the Robot Algebra Project was on crafting and testing project-based instructional materials designed to significantly improve students’ mathematical competency in informal settings. At its core, the R&D focused on iterative development of units centered around physical and virtual robots with teacher-led and intelligent-tutoring-system instruction.

The major goals of the project were:

(1) To test and iteratively improve project-based instructional units which, when implemented effectively in informal settings, significantly increase students’ algebraic reasoning abilities.
(2) To design robotics-focused units and support materials in ways that are educative to both the teacher and the student. Educative materials for the instructor include design features that support their understanding of student thinking and the underlying rationale for each instructional activity.
(3) To evaluate the extent to which the units and support materials have met goals one and two.
(4) Increase the project’s and the field’s understanding of how policy and organizational features shape instruction and learning outcomes (Schunn and Stein 2010a).

Research outcomes and findings on goals 1–4 are reported in Schunn and Stein (2013a) and Kessler et al. (2014). The last goal area is germane to the focus of this paper. The case provides an illustration of the responsive development, application, and eventually the utility of implementing elements of the assumption-based tool described above as the Robotics Project enacted its R&D processes.

The evaluation team was brought into an R&D process that was already underway. In its second year of implementation the collaborative research team was aware of considerable site variation in the degree and quality of implementation achieved. The variation was enough to actually threaten the testing of the innovation. The evaluation team was asked to assist in collecting data that could be used to both shape current implementations and to improve the recruitment of new test sites that would be more likely to be able to implement the materials appropriately so that the innovation's change theory and outcomes could be fairly assessed.

As a first step, the evaluators led the R&D team in an LBC-orientation process. The basic planning approach was explained, and with that as background a free flowing discussion was engineered to engage the researchers and developers in the identification of LBCs relevant to their R&D work. This Phase I of the LBC methodology included an open-ended discussion that was structured in part by insights from the literature regarding factors that can impinge upon implementation processes. The R&D team was invited to identify LBCs that might be related to the following broad domains:

- Student characteristics
- Amount of exposure to the innovation
- Teacher capacities
- Curriculum characteristics
- Technology
- Materials
- Organizational environment

Key LBCs identified through this process included some pre-requisites, that is, conditions that need to exist at the outset and beyond for the innovation to be fully implemented (in contrast to conditions that must be established early when the intervention is first introduced). Table 2 presents the key LBCs generated through this process.

With these key LBCs identified, the evaluation team began Phase II of the LBC approach—gathering evidence about the LBCs in testing contexts. Primary data from current individual participants (researchers, teacher, and program administrators) were collected using interviews and surveys in order to verify the LBCs identified in the group discussions, establish priorities among them, and assess where given sites were in relation to the specific LBCs. This primary data collection involved the development of customized instruments that were then implemented across participating sites. Data were analyzed and arrayed against the identified LBCs. In addition to the LBC function, these activities served a formative evaluation function providing the research team with information that guided mid-course corrections strengthening site implementations (e.g., requesting missing extra resources from school principals and program leaders).

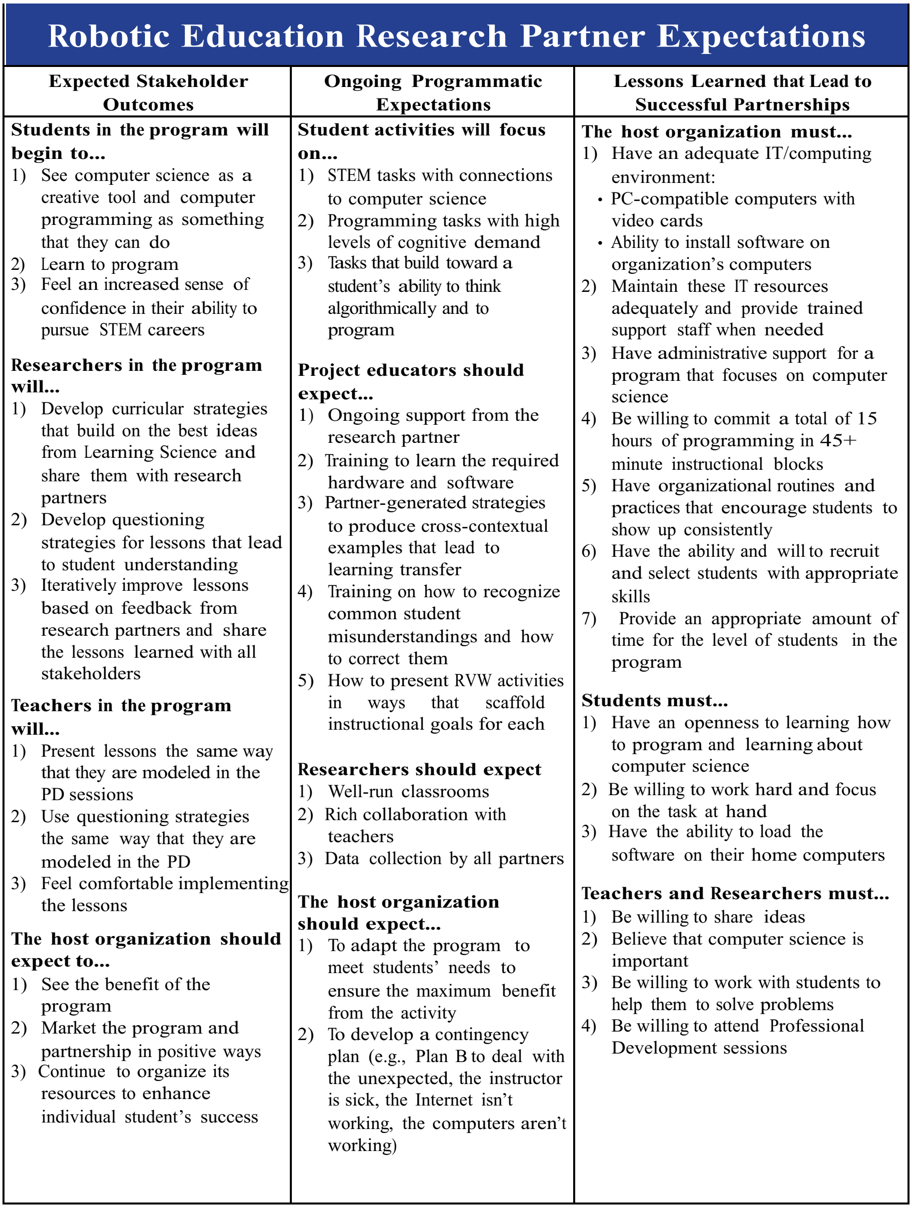
The assessments were also used to develop individual site profiles along dimensions such as organizational mission and purpose, human capacities and expertise, programming focus and structure, decision structures and processes, technology capacities, organizational load, youth demographics and expectations, messages about the innovation and rationale for participating (Bickel and Iriti 2012). These profiles made it clear that about a quarter of the sites were participating in the R&D process based upon shared instructional goals—increasing student math knowledge using innovative technology applications (i.e., robot constriction). However, about three quarters struggled to successfully implement the R&D process because of a variety of violations of LBCs (e.g., internet access with complex

Table 2 Robot algebra LBCs

Host organization
Adequate IT environment (hardware, robots, software, network, internet)
Technological infrastructure and resources are maintained adequately by trained staff
Administrator with moderate or better interest in technology and mathematics
Will commit a total of 15 h of programming in 45 min or longer instructional blocks
Organizational routines and practices that encourage students to show up consistently
An adequate number of student participants can be recruited
Committed to supporting the students in developing along academic and career dimensions
Ability and will to recruit and select students with appropriate skills
Student ability/effort level is aligned with how program is implemented in the organization (amount of time allotted for curriculum implemented corresponds to student needs)
Curriculum is used in a timely manner after educator completed professional development (PD)
Students
Willing to work hard on math
Can add, subtract, multiply and divide
Have an openness to and non-negative affect toward robots
Students are not already highly motivated for and competent in robots and proportional reasoning (ceiling effect)
Basic computer fluency
Teachers
At least moderate interest in technology and mathematics
Basic computer fluency
Willingness to work with students on academic topics
Attends PD on the innovation

or poorly maintained firewalls; very old computer systems that could not run the software; irregular attendance by learners leading to skipping key early instructional episodes; implementing educators being poorly informed of the goals and purposes of the curriculum). These profiles, which summarized the empirically collected data, provided a basis for the R&D team to make adjustments in implementation supports. For example, in the first few sessions in which an organization implements the materials, a number of technological glitches may emerge which can cause the educators to abandon or radically downsize use of the materials. After surfacing this in the LBC process, the researchers were able to work with organizations to ensure that IT specialists from the host organizations were onsite to troubleshoot during the first several sessions. A second example involves research project staff meeting with host site administrators to talk through the student and teacher LBCs, and recruit their assistance in identifying the right contexts for testing implementation—teachers *ready* for implementation rather than the principals mandating the intervention into places with readiness gaps. This iterative process led to refinements and clarifications in the LBCs for this innovation (Phase III in the LBC methodology).

During Phase IV, the LBC activity led to the crafting of a checklist for use in the recruitment of new implementation sites (Shoop 2012, see Fig. 1). Based upon the codified LBCs isolated in the earlier conversations and then confirmed in subsequent data



Robotic Education Research Partner Expectations

Expected Stakeholder Outcomes

Students in the program will begin to...
1) See computer science as a creative tool and computer programming as something that they can do
2) Learn to program
3) Feel an increased sense of confidence in their ability to pursue STEM careers

Researchers in the program will...
1) Develop curricular strategies that build on the best ideas from Learning Science and share them with research partners
2) Develop questioning strategies for lessons that lead to student understanding
3) Iteratively improve lessons based on feedback from research partners and share the lessons learned with all stakeholders

Teachers in the program will...
1) Present lessons the same way that they are modeled in the PD sessions
2) Use questioning strategies the same way that they are modeled in the PD
3) Feel comfortable implementing the lessons

The host organization should expect to...
1) See the benefit of the program
2) Market the program and partnership in positive ways
3) Continue to organize its resources to enhance individual student's success

Ongoing Programmatic Expectations

Student activities will focus on...
1) STEM tasks with connections to computer science
2) Programming tasks with high levels of cognitive demand
3) Tasks that build toward a student's ability to think algorithmically and to program

Project educators should expect...
1) Ongoing support from the research partner
2) Training to learn the required hardware and software
3) Partner-generated strategies to produce cross-contextual examples that lead to learning transfer
4) Training on how to recognize common student misunderstandings and how to correct them
5) How to present RVW activities in ways that scaffold instructional goals for each

Researchers should expect
1) Well-run classrooms
2) Rich collaboration with teachers
3) Data collection by all partners

The host organization should expect...
1) To adapt the program to meet students' needs to ensure the maximum benefit from the activity
2) To develop a contingency plan (e.g., Plan B to deal with the unexpected, the instructor is sick, the Internet isn't working, the computers aren't working)

Lessons Learned that Lead to Successful Partnerships

The host organization must...
1) Have an adequate IT/computing environment:
   - PC-compatible computers with video cards
   - Ability to install software on organization's computers
2) Maintain these IT resources adequately and provide trained support staff when needed
3) Have administrative support for a program that focuses on computer science
4) Be willing to commit a total of 15 hours of programming in 45+ minute instructional blocks
5) Have organizational routines and practices that encourage students to show up consistently
6) Have the ability and will to recruit and select students with appropriate skills
7) Provide an appropriate amount of time for the level of students in the program

Students must...
1) Have an openness to learning how to program and learning about computer science
2) Be willing to work hard and focus on the task at hand
3) Have the ability to load the software on their home computers

Teachers and Researchers must...
1) Be willing to share ideas
2) Believe that computer science is important
3) Be willing to work with students to help them to solve problems
4) Be willing to attend Professional Development sessions

Fig. 1 Checklist for robotics research partners developed as a result of LBCs (Shoop 2012)

collection, the tool identified in considerable detail the expectations of involvement in the R&D process one would have for program and research personnel (see Table 2). The checklist was developed through the R&D team reflecting with the evaluation team on both the practical on-the-ground experience in implementation sites and the systematically collected data against the LBCs. The checklist was subsequently used in several ways. It facilitated recruitment and grounded decision-making for involvement on both the researcher and program sides. With clear expectations, each side could assess the sensibility of engaging in the R&D partnership at the outset. Additionally, the pre-assessment based upon LBCs surfaced key capacity building actions that might need to be in place in order to optimize the R&D collaboration.

This case illustrates some of the payoffs gained by applying the LBC framework to this R&D effort. It supported a shared understanding on the R&D team about LBCs that were "critical human, social, and physical capital conditions that are necessary for successful implementation of the developed materials" (Schunn and Stein 2013a). The identification of LBCs made for better communication with potential partner districts, fewer failed R&D sites, and contributed to more efficient scale up and dissemination processes outside of the immediate R&D contexts. In this context the LBCs served as a powerful tool for implementation fidelity.

Case two: Biology Levers Out of Mathematics (BLOOM)

This ongoing, multi-year NSF-funded project was designed to address three fundamental challenges in STEM K-12 education, namely, "providing all students with high quality STEM learning opportunities, enhancing the ability of teachers to provide quality STEM education, and finding ways to scale innovations in STEM education" (Schunn and Stein 2010b). The core approach was to target big ideas in science (e.g., natural selection and inheritance) and develop instructional materials and methodologies to support teacher PD in order to craft models of STEM integration and levers for instructional change that scale. The instructional units were unique in that they infused the scientific practice of mathematical modeling into biology units. The teacher materials and delivery were unique in that they were designed specifically to be educative for teachers (Davis and Krajcik 2005) and a virtual community was designed to provide access to the materials and to provide teacher implementation support in a scalable fashion.

The project had several core goals including:

(1) The development of engineering-design based units for high school biology classrooms that also teach mathematics, and to understand what unit design characteristics best support learning of biology, mathematics, mathematical-biology, and engineering design.
(2) The development of teacher support materials (e.g., PD workshops [physical and virtual], and teacher guidance documents [physical and virtual]) that aid teachers with varying backgrounds in biology, mathematical, and engineering knowledge, and reform pedagogy in the "successful implementation" of these units, where success was defined in terms of both learning outcomes for students and teacher perceptions of unit utility such that they would continue implementation after the project was completed.
(3) The development of an understanding of factors that prevent successful adoption of such units into urban classrooms, and to iteratively test strategies that overcome those barriers (Schunn and Stein 2010b).

Work focused on the development and testing of two engineering design-based biology units in multiple classrooms in two states. The deployment gradually moved from face-to-face support structures to an increasingly "virtual format for teacher guidance materials, to allow more dynamic updating by the development team, submissions by the teachers (to developers and each other), and material-focused discussions throughout implementation" (Schunn and Stein 2013b). The virtual space was a newly created web-tool called iPlan that included unit overviews and instructional goals, handouts and worksheets for students, detailed scripts for teachers, explanations to teachers regarding the purposes of each task and its specific sequencing, and a collaboration space in the form of implementation notes and discussion boards for teachers to collaborate with each other and with the curriculum developers. All materials for both units were moved into iPlan and were deployed with the main group of implementing teachers.

The third goal area of the project—understanding factors that prevent successful adoption of such units as deployment scales by relying on largely virtual curriculum and professional growth supports—is most germane to LBC. This goal area was shaped in part by LBC work and represents a significant educational technology component of the innovation.

The LBC process was employed at the outset of the R&D to determine the conditions that were needed to be present in order for the innovation's change model to be viable and then to systematically test whether these conditions were present throughout the development process. A collaborative, facilitated group brainstorming session was conducted with R&D project leaders and designers for Phase I of the LBC process. The LBCs underlying the innovation's design (which included technology and non-technology related aspects of the innovation) were identified, and then refined over the course of several months by the group. These LBCs included:

(1) Intensity of PD combined with the educative teacher materials are sufficient to reach expected teacher outcomes.
(2) Volunteer experience can generalize to other populations; Alternatively, project can reach scale with only voluntary teachers.
(3) Teachers will be motivated based upon student outcomes they observe during the first couple of implementations to continue to use the units without external incentives; Teachers will enjoy using the units.
(4) Teachers have an online identity and are comfortable accessing materials online.
(5) Virtual teacher communities can be built that teachers will use as a tool for improving the quality and depth of their implementation of the units.
(6) Units avoid friction with curriculum adoption decisions (small footprint and implemented at the high school level with more teacher autonomy) and accountability frames (critical biology concepts valued in current and forthcoming revised standardized tests).

During Phase II of the LBC process, these LBCs were monitored throughout the R&D process in order to understand whether they were actually playing out as theorized. Teacher surveys after preliminary PD and after completion of teaching the units, surveys of teachers who "dropped out" of the study, and document review were sources of evidence compiled to better understand the degree to which LBCs were being met and the impact of specific LBCs on implementation trends.

During Phase III of the LBC approach, the data about LBCs were shared with the project personnel in an iterative fashion and the findings were used to adjust the design and implementation of the innovation and refine the LBCs themselves. For example, data regarding LBC #4 suggested that teachers do indeed have online identities and are comfortable accessing both teacher and student materials online. In addition, the data suggested that teachers generally do have the authority to adopt the units without layers of bureaucratic approval within their schools (related to LBC #6).

In some cases, however, the data suggested more friction between the LBC and reality. For example, although teachers are comfortable accessing materials online, the teacher survey data and early iPlan usage patterns suggested that teachers were uncomfortable using a virtual space with unknown teachers to collaborate, reflect on their practice, and receive support for implementation. As a result, the project began testing ways to increase teacher engagement with the collaborative tools available within iPlan. One strategy was to seed teacher participation by specifically asking certain community members to make postings and solicit feedback from others. More broadly, this LBC and the corresponding data suggested the need to address this cultural barrier if iPlan is to be used to its full potential. One possibility going forward would be to design the PD in a way that allows face-to-face relationships to develop first and then employ the virtual space as an extension of the face-to-face community in order to ease teachers into a virtual community with colleagues that they already know and trust rather than with strangers.

In Phase IV of the LBC process, the evidence-based LBCs were listed and used in the next round of testing for site recruitment. As this ongoing project continues, the findings from the LBCs and data collected to test their veracity will inform the design and implementation efforts in order to strengthen the alignment between the innovation and the contexts in which it will ultimately be scaled, including guiding the design of later projects that build on this project.

Conclusion and implications

As investments in educational technology applications continue to skyrocket, there is opportunity to maximize the payoff from R&D efforts by systematically identifying LBCs and monitoring these throughout the development and refinement processes and to design intentionally for scale.

Education technology researchers and developers often employ a range of methodologies to support their work, including formative evaluation strategies, design-based research, case studies and short-cycle evaluation studies (e.g. Kelly et al. 2000; Jones and Richey 2000). Given that the LBC approach is, at its heart, a way to isolate the critical design and implementation features of an innovation and link those with the testing or use contexts, it can be utilized within or alongside these common methodologies. For example, within the BLOOM case example described in this paper, the elucidation of LBCs was a slice of a much larger design-based research effort that included assessment of teacher and student outcomes as a result of the innovation. The identification of LBCs could, for example, be the basis of a series of short-cycle evaluation studies in which the innovation's efficacy is tested across several variations of conditions identified in the LBC process as potentially important. Likewise, case study methodology could be applied to explore how variations in a particular LBC shape the use of the innovation and what adaptations must be made to support successful use.

As research by Hew and Brush (2007) revealed, there are a wide range of potential "barriers" to successful use of innovations in schools, including those pertaining to *resources, knowledge and skills, institutional capacities, attitudes and beliefs, assessment, and culture*. More recent work has highlighted emergent challenges specific to educational technology in the curating and procurement of innovations appropriate to specific contexts. The LBCs that are relevant to an innovation are tightly tied to the intended users of an innovation and its particular design features. For example, "teacher buy-in" may seem like a common LBC applicable to almost any educational technology endeavor but its relevance is dependent upon the target and design of the innovation. A student-facing innovation that does not involve teacher mediation would have a very low bar for "teacher buy-in" while an innovation such as the BLOOM iPlan requires a high level of teacher motivation. It is because of this variation that a process like identifying the LBC can be so powerful. Most important is for the designers to clearly understand and articulate the LBCs of their innovation in relation to implementation contexts so that both the innovation design and the communication about the dimensions influencing its efficacy are explicit.

The LBC process is also a potentially important component of teasing out whether an innovation did not achieve its intended outcome due to theory failure or implementation failure. During the development phase it is critical to understand whether the innovation can produce the desired results and then, perhaps, to assess how robust the innovation is in a range of contextual variations. The landscape of education products is becoming more and more customized (See for example Cavanagh 2014; Molinar 2015) and districts are demanding interoperability and integration. Education practitioners are seeking products that are designed for specific purposes with specific populations and want these products to interoperate. Thus, "one size fits all" innovations may be a thing of the past as education practitioners become smarter consumers of ed-tech products. If this customized or "boutique" model of education solutions is to work, it becomes even more critical for the needed implementation conditions and the targeted users to be clearly identified and communicated.

The two cases described in this article provide concrete examples of how the LBC methodology can be used for specific purposes during innovation R&D phases, including:

- Surface and communicate critical "pre-requisites" for research implementation sites that can be used to improve recruiting and screening of sites for field-testing. If screened against the LBCs of the innovation, it increases the likelihood that the sites will be well positioned to implement adequately so that the study can test the theory of the innovation rather than the sites' capacity to implement. In the Robot Algebra example, the resulting set of innovation pre-requisites (see Fig. 1) was used to shape and improve the research site selection.
- Identify specific areas in which some targeted capacity building may need to happen within individual research sites prior to implementation. For example, the LBCs may indicate the import of teacher beliefs with regard to a particular innovation and that without such investment the innovation will be poorly implemented or not implemented at all (Wachira and Keengwe 2011; Ertmer et al. 2012). The value of targeted capacity building was evident within the Robot Algebra case wherein the LBC process revealed early in the process that technology glitches could derail the entire implementation but a small proactive support process for the first 1–2 days of use could keep the research site implementation on track.
- Serve as a process for surfacing conditions critical to the innovation's change model that can then be tested throughout the R&D cycle using a range of other methodologies (e.g., formative evaluation, case studies, and short-cycle evaluation studies). Particularly important for scalability of innovations is the use of the R&D phase to determine potential barriers to large-scale adoption and, to the extent possible, mitigate or design for these during the development phase. For example, in the BLOOM project, the LBC process identified teacher comfort with online collaboration with unknown colleagues as a significant barrier. The R&D process was able to incorporate this reality into the next round of innovation design by nurturing some initial face-to-face interactions among teachers and then using the virtual space as an extension of the in person collaboration.

- Another important contribution of the LBC process is that it requires developers and researchers to articulate the use conditions necessary for the innovation to be efficacious. This explicit articulation allows all parties to consider whether those use contexts actually exist in large enough quantities to make the R&D of the innovation viable; if the LBCs are so restrictive as to not scale to large groups of students or only in narrow settings, then investors and/or potential users are able to understand this from the outset. This is in line with calls by Fishman et al. (2009) that design experiments should keep the use context at the forefront. It is also a useful process to employ for those who believe that "one size fits all" innovations are less useful than those customized for specific contexts and purposes and clearly communicating those specification to support the filtering and procurement process.

Beyond the R&D phase, the LBC process could also be helpful as an innovation moves to scale up. Once identified and tested during the R&D process, LBCs can be used to help communicate appropriate use of the education technology innovation to decision-makers in the use context when rolled out. One of the major barriers in the current education technology landscape is that education decision-makers have difficulty sifting through the myriad of available products to discern what each is intended to do, how it works, in what contexts it will work best, and the evidence of efficacy (Martin 2014). Developers who spend time articulating and testing LBCs can translate these into communications with user audiences.

One could imagine the pre-requisites being adapted for use when taking the innovation to scale by providing a systematic approach to determining if an organization is ready to adopt the innovation and provide an implementation monitoring checklist for those that do move forward with its use. Such use of LBCs during scale may help reduce false positives and false negatives and for both sides make the terms of engagement realistic for sites that become involved. Of course, development, implementation, and scale up of educational technology innovations is not always hyper-rational and cannot be fully predicted and/or controlled by developers. However, the LBC process offers one way to be more deliberate and thoughtful about designing and testing with actual innovation and use context constraints at the fore.

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Compliance with ethical standards

The work described in this manuscript is not considered human subjects research by the University of Pittsburgh's Institutional Review Board.

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