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Dissemination in STEM Education R&D: Perspectives on Knowledge Use

Community for Advancing Discovery Research in Education

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The National Science Foundation's Discovery Research K-12 (DR K-12) program supports "development and study of innovative resources, models, and technologies for use by students, teachers, administrators and policy-makers." In the overall landscape of research, the program sits in Pasteur's quadrant, aimed at both fundamental understanding and considerations of use (Stokes, 1997). Achieving the program's purpose of enabling "significant student and teacher learning" in the disciplines of science, technology, engineering, and mathematics (STEM) depends not only on sound research and development (R&D), but also on sound strategies for dissemination. It is dissemination that builds bridges between the R&D enterprise and the potential users of the resources, models, and technologies that R&D generates.

This paper argues that DR K-12 grantees can enhance the long-term consequences of their work by using insights from research on dissemination. In education and other fields, studies of dissemination have identified processes by which research knowledge reaches (or fails to reach) the practitioners and policymakers who could use it.

A key insight from dissemination research of the 1970s, and 1980s, a time when major dissemination programs were funded and studied in education, was that *sustained interaction* with user communities was essential. Interestingly, with the advent of new technologies that enable more interaction, this idea has been revived and is gaining currency in R&D policy. Thus, in reviewing lessons from research on dissemination, this paper addresses not only communication strategies for the latter stages of an R&D project but also the sustained engagement of potential users as partners throughout the R&D process. Its central point is that DR K-12 projects at all stages, from early design work through completion, can benefit from an awareness and understanding of the challenges of knowledge use, so that what is designed can be suitably adapted and scaled.

The research studies reviewed here placed dissemination in the context of knowledge use by practitioners or policymakers. Thus, they do not depict it as a simple matter of broadcasting information but instead emphasize that eventual *use* of knowledge is the aim. For example, Louis (2003, p. 4) emphasized the premise that dissemination in education is aimed at knowledge use:

> …the intent of dissemination in education is not simply to disperse information, but *to do so in ways that promote its use*. The goal is improvement and change in educational organizations and systems, and in individual practice.

She went on to highlight the same lesson from dissemination research that this paper will focus on: that sustained interaction is critical and, indeed, that "sustained interaction may blur the line between creators and users of research" (Louis 2003, p. 4). Similarly, in a paper reviewing research relevant to dissemination in K-12 mathematics and science, Hutchinson and Huberman defined knowledge dissemination as:

> …the transfer of knowledge within and across settings, with the expectation that the knowledge will be "used" conceptually (as learning, enlightenment, or the acquisition of new perspectives or attitudes) or instrumentally (in the form of modified or new practices). (1993, p. 2)

In this paper, like the authors just cited, I also emphasize knowledge use. Building on past research in dissemination, this paper emphasizes core, research-based principles of dissemination that apply to the dissemination of varying knowledge resources for varying contexts of use. The first section of the paper discusses communication strategies. Whether the aim is dissemination to teachers, administrators, or policymakers, communication should address the incentives and the customary practices in knowledge use that characterize the particular group to be reached. In particular, dissemination research makes clear that merely releasing announcements about new research knowledge is not an effective approach for reaching anyone beyond interested researchers.[1] For the results of their work to reach different communities, researchers must attend to their means of communication.

Next, the paper explores the types of partnerships with potential users that can inform all stages of an R&D project and foster greater scalability of the results. With new technologies bringing greater possibilities for interaction, there is little reason for R&D projects to do much of their work in isolation from users. Thus the image of dissemination advanced in this paper encompasses ideas of co-construction spanning research, practice, and policy communities, as the last section of the paper discusses.

Communication Approaches Informed by Dissemination Research

Here, I address dissemination in a conventional sense: knowledge transfer from an R&D project to potential users, when the aim is to transfer usable resources, models, technologies, or research insights from the project into practice. Research indicates that dissemination requires repeated communication of tailored messages through different modalities and with "purposeful redundancy" (Hutchinson & Huberman, 1993, p. 16; Sechrest, Backer, & Rogers, 1994). As technology brings new communication media into widespread, routine use, the number of potential communication forums continues to multiply.

But a major challenge to the dissemination of research knowledge is the problem of communication between "two communities": when researchers hope to reach non-research audiences, whether in practitioner or policy realms, they must recognize that they are hoping to reach a community that differs from their own in important ways. Thus, researchers must take a deliberate and strategic approach to communication that bridges a gap. They must abandon some of the communication habits that serve them well within the research community, understand the community they seek to reach, and enlist the help of intermediaries or translators. I discuss findings on each of these matters, and their implications, in turn.

[1] Some projects are conducted by researchers for researchers. Where the target system for dissemination of findings is limited to the research community to which the investigator already belongs, dissemination poses no particular challenge. In these cases, appropriate dissemination follows a well-worn path of presentations at research conferences and publication in peer-reviewed journals. There is no need for this paper to elaborate on this type of dissemination, and it does not do so.

Recognizing the Limits of Traditional Research Dissemination

Handing research reports to members of practice or policy communities is not an effective means of communication. Hemsley-Brown and Sharp (2003), based on a systematic review of literature, highlighted the following empirical findings on practitioners' views on using typical research products:

- Zeuli (1994) gave a sample of teachers a set of research articles to read, then interviewed the teachers. She concluded that most only found an article credible when it matched their own experience, and that most scanned the articles in search of concrete cases, examples, and techniques that they could use in their classrooms.
- Castle (1988) found that "the volume, lack of applicability and ambiguity of research material were barriers to the use of research by teachers" (Hemsley-Brown & Sharp, 2003, p. 454).

Educational administrators report in surveys and focus groups that they perceive research as impractical, difficult to understand, and confusing (Nelson, Leffler, & Hansen, 2009; West & Rhoton, 1992).

With respect to the use of research findings in the policy arena, Smith and Smith state flatly that research reports are not a means of communication: "Few policymakers or even their staff will read a study or report" (2008, p. 9).

The media are not a likely channel for conveying researchers' peer-reviewed presentations and articles to the policy conversation: a recent study (Yettick, 2009) found that papers delivered at the Annual Meeting of the American Educational Research Association or published in any of 176 peer-reviewed journals were cited in *The New York Times, The Washington Post*, or *Education Week* at a much lower rate, relative to their numbers, than papers produced by advocacy-oriented think tanks. (This is not a surprising finding, however; Carey [2009] has commented in response that few of the 15,000 scholarly papers were written with the intention of garnering media notice, whereas the think-tank papers included in the study generally were.)

Indeed, the limits on completeness and accuracy in communication through the media often trouble researchers. Misunderstandings and frustrations ensue, not only when researchers feel that their findings are wrongly ignored, but also when a researcher is in the unaccustomed position of having findings widely disseminated. An example is the experience of a graduate student whose conference presentation on Facebook use among college students was widely reported and sensationalized, to the author's dismay (Karpinski, 2009). In a similar vein, Pellegrino (2006) comments on the way "…research finds its way into the public arena. Sometimes this occurs very badly, such as popularizing neuroscience research and drawing inappropriate implications for instructional practice."

Communicating with Practitioners

The communication of knowledge resources to practice settings requires a concerted effort, as well as recognition that faithfully following the prescriptions of R&D is not habitual for either teachers or administrators. To identify more effective means of reaching practice communities, dissemination researchers have explored these communities' customary means of attending to new knowledge. A key take-away message from these studies is that research messages are filtered through habitual ways of using knowledge. For teachers, the habits of knowledge use were captured in Huberman's "Recipes for Busy Kitchens" (1983). According to more recent research (Ratcliffe, Bartholomew, Hames, Hind, Leach, Millar, & Osborne, 2004) today's teachers, trolling the internet for lesson ideas (Rich, 2009), bring to that search the same set of habits and dispositions toward knowledge use that Huberman identified:

- A focus on short-term outcomes and immediate indicators of success, including students' attentiveness and the completion of the week's work
- Belief in a lack of underlying order, in contrast to researchers' quest for findings that impose a logical order on the complexity of instruction
- Based on their belief in the unpredictability of classroom events, a reliance on intuitive judgment in selecting from a repertoire of skills and practices
- A craft or artistic orientation
- Practice mastery through individual trial and error

This work suggests that use of a new resource in the classroom—a curriculum unit or a formative assessment, for example—can be promoted by emphasizing the immediate payoff in student engagement and in helping meet the teacher's aims for efficient coverage of required material. The dissemination strategy should enable teachers to explore the resource through trial and error, bringing their judgment and craft skill to its use. On the other hand, communication messages that imply that classroom environments are predictable will not be credible.

Some studies have identified settings and conditions in which teachers routinely pay attention to increasing their professional competence. While dissemination strategies may not be able to create such settings or conditions, they can recognize them and perhaps capitalize on them. Small communities of practice serve as the filters for understanding and use of new knowledge, according to Spillane (1999) and Coburn (2001), whose studies illuminated the ways in which discussion among teachers affects the understanding and uptake of policy mandates, including efforts to introduce research-based practice. Fullan (1991), summarizing several studies, pointed to the presence of collaboration:

> Within the school, collegiality among teachers, as measured by the frequency of communication, mutual support, help, etc., was a strong indicator of implementation success…. Significant educational change consists of changes in beliefs, teaching style, and materials, which can come about *only* through a process of personal development in a social context. (p. 132)

This suggests working with teachers in groups that provide mutual support to their members and, in an interactive dissemination approach, listening carefully to the communication that goes on among users (and non-users) of a new resource in a school community. Just as a teacher recognizes and addresses student misconceptions in STEM, disseminators can recognize and address teachers' misconceptions about an innovative knowledge resource. In addition, dissemination is advanced by identifying influential individuals in local networks of interaction who can be important supporters or foes of use (Dearing, 2008).

Although teachers' customary practice in seeking and using knowledge is important in the dissemination of knowledge resources, nevertheless teachers are not the ones who make adoption decisions for innovative curricula or assessments. Teachers work in schools and districts, whose practices and incentives have a tremendous influence on the extent to which new knowledge resources will be effectively introduced. As Elmore writes (commenting on the shortcomings of NSF's curriculum-development efforts of the 1950s and 1960s as a change strategy):

> What this model overlooked… was the complex process by which local curricular decisions get made, the entrenched and institutionalized political and commercial relationships that support existing textbook-driven curricula, the weak incentives operating on teachers to change their practices in their daily work routines, and the extraordinary costs of making large-scale, long-standing changes of a fundamental kind in how knowledge is constructed in classrooms. (1996, p. 14)

Some of the incentives, pressures, and opportunities facing districts and schools have changed since Elmore published this passage in 1996, but much remains constant in school districts. A recent study of districts' response to encouragement for the use of research found that the result was symbolic use, not instrumental use (Coburn, Toure, & Yamashita, 2009)—echoing insights about districts and innovation that were identified 35 years earlier (Pincus, 1974): that superintendents have incentives to adopt changes that give the system an up-to-date, professional, or responsive appearance, and to engage in symbolic or cosmetic adoption of the trappings of reform.

A sustained partnership with school and district decisionmakers may help R&D projects make inroads in the face of the weak incentives for implementing new knowledge. The Consortium on Chicago School Research has worked in a way that is highly consistent with this advice, using long-term engagement and tailored reporting among its means of influencing both district-wide policy and school practice (Roderick, Easton, & Sebring, 2009). The Strategic Education Research Partnership, for example, puts large teams to work on solving practitioner-generated problems of practice over periods of years, engaging disciplinary and applied researchers along with superintendents, district staff, and school-based practitioners. In the DR K-12 program, some projects work relatively intensively with decisionmakers in one or more large school districts, addressing their incentives for knowledge use and incorporating what is learned into later stages of dissemination.

Often, communication between researchers and practitioners can benefit from the engagement of a "dissemination specialist," who might serve as not only a translator of research but, perhaps more important, a resource for users' knowledge search and capture. For example, a large-scale study of dissemination programs supported by the U.S. Department of Education in the 1980s found:

> The process that succeeds best . . . involves frequent contact, some face-to-face interaction, and an exchange between dissemination specialists and participants that lasts more than a few months over time. (Louis, Dentler, & Kell, 1984, p. 17)

Similarly, the amount of time field agents spent with local educators before and after adoption was associated with successful implementation of an innovation, according to another large-scale study of a dissemination program (Louis, Rosenblum, & Molitor, 1981).

The engagement of linking agents in education was originally borrowed from a venerable tradition in agriculture. Evidence supports the effectiveness of linkers in helping with productive knowledge use (Crandall & Loucks, 1983; Sieber, Louis, & Metzger, 1972). The linking functions that have contributed to effective knowledge use were identified in early dissemination research (Butler & Paisley, 1978; Crandall, 1977; Havelock, 1973) although they have not been systematically investigated in the education field recently:

- Finding and organizing resources by collecting and analyzing information
- Monitoring the availability of innovations and disseminating them as appropriate
- Participating in the diagnosis of local problems, and facilitating problem solving
- Providing content-specific advice
- Evaluating the early results of a change, or helping clients do so
- Contributing to the client's continuing capacity to solve problems

This list includes a number of functions that might be carried out virtually.

Linkers can be found in state education agencies and the regional intermediate agencies that exist in many states, federally supported programs of dissemination and technical assistance, and research and consulting organizations. Whether delivered in person or through webinars, help from these organizations may provide some of the linkage that bridges the gap between research and practitioners. If linkers can be brought into partnership with an R&D project, their networks and skills may be enlisted in communication.

A variety of different avenues can lead to the application of research results in practice. One possibility is the development of innovative materials for practitioners' use in curriculum, assessment, or professional development. However, as Pellegrino (2006) observes, the development of materials is not the only avenue by which research travels to practice. There are other "mediating arenas," including policy. State-level curriculum adoption is a vehicle for influencing practice through policy. A new state requirement, such as an increase in the number or content of science courses required for graduation, creates burgeoning demand for new STEM education resources. Assessment requirements are, if anything, growing in their power to drive practice. For many reasons, then, researchers may want to communicate in policy arenas, and I turn next to that subject.

Communicating with Policymakers

Studies of the dissemination of research findings into the policy arena offer insight into policymakers' customary ways of accessing and using knowledge and, based on that insight, ideas about effectively communicating with policymakers.

Based on a major study of recent policy debates about charter schools, Henig has identified points of contrast between the research and policy communities with respect to their understandings and uses of knowledge resources, which he summarizes as follows (2008, p. 223):

- ***Time:*** Researchers want to take ample time to "get it right" while political actors need answers fast
- ***Multiple studies:*** For the research community, multiple studies permit the eventual cumulation of knowledge; political actors faced with multiple studies ask instead, "Which ONE is right?"
- ***Causality:*** Researchers are trained to be very cautious in asserting causality, while political actors are willing to attribute causality post hoc as a basis for the decisions they need to make
- ***Abstraction:*** Generalization of patterns across settings is crucial in research, but policymakers distrust it, preferring to rely on examples that more fully capture the detail and complexity of real life
- ***Simplification:*** In research, painstaking abstraction is the route to simplification. Political actors instead want to "get the gist" quickly.

After many years of leadership in the organization Policy Analysis for California Education, Kirst (2000) wrote about factors that made a difference in communicating effectively with policymakers:

- The ***source*** of knowledge was individuals with government experience who knew the political culture of the state capital
- The ***formats*** used for communication included concise policy briefs, oral briefings, and op-eds, not lengthy reports
- The message fit the ***users' contexts and characteristics,*** which were revealed through many interactions over time

Complicating the interaction with policy communities is the increasing polarization of positions on issues (Henig, 2008; Schwartz & Kardos, 2009). Polarization can afflict the use of research knowledge about STEM curriculum, as veterans of the "math wars" attest (Schoenfeld, 2004). In polarized discussions, a rapid point-counterpoint of contending studies, each with an accompanying press release, exacerbates the effects of the differences in outlook and norms between researcher and policy communities, further impeding the productive use of knowledge resources in policy (Henig, 2008). Communicating in policy arenas is not for the faint of heart. It may require deliberate efforts to build greater consensus—or at least common ground—among researchers as well as communicating in the channels and formats that are effective with policymakers.

Research on dissemination in policy arenas suggests that knowledge use depends on a fluid process of agenda setting, in which "policy entrepreneurship" often plays a major role. This is not the same thing as lobbying; it is a process by which ideas enter the policy conversation—usually through many channels—for consideration by policymakers and their aides. An R&D project may want to engage in policy entrepreneurship or enlist the help of policy entrepreneurs to influence policies on assessment, teacher preparation, or other matters that are important in teaching and learning.

Policy entrepreneurs gain influence because the agenda-setting process in policy is far from orderly. To describe it, Louis cites the work of Kingdon (1995) as describing a non-linear process that involves multiple "streams":

> ….a "problem stream" in which issues are identified and given priority, a "solution stream," in which various competing policies are discussed, and a "political stream" that consists of potential key participants…. It is the quasi-organized, fluid nature of the agenda-setting process, which often cannot even be described to an outsider, which accounts for the fate of "good knowledge" in affecting decisions. (Louis, 2003, p. 9)

It is in the "solution stream" that policy entrepreneurs actively promote particular ideas, and research has found that these policy entrepreneurs make a difference in the use of knowledge in policy. For instance, Mintrom (1997) showed empirically that these individuals, through providing information to policymakers, increased the likelihood that policymakers would consider and act upon the issue of school choice. As in any communication network, there are influential individuals whose support makes a difference (Dearing, 2008).

Cross-state issue networks, to which policy entrepreneurs and also policymakers typically belong, also assist in the dissemination of knowledge about issues (Kirst, 2000; Mintrom & Vergari, 2003; Soule & Zylan, 1997). An example is the Pew Forum, which disseminated research, development, and policy proposals for standards-based reform that influenced the participating policymakers in the early 1990s (Smith & Smith, 2009). Establishing or joining an issue network may thus be a powerful means of communication with policymakers.

Summary

In short, recognizing that R&D results will not be effectively communicated to practice or policy through traditional research publications (whether on paper or online), investigators need to understand the knowledge-using behaviors of the community that might potentially use their results. They will benefit from enlisting the help of linkers who interact regularly with practitioners or policymakers. Linkers can translate research for other communities. They can also be a trusted resource and can effectively place knowledge in context for potential users.

But dissemination research offers another type of guidance for R&D: major studies of dissemination have implications for all stages of a research project, including design. I turn next to less traditional ways of applying dissemination knowledge in R&D.

NONTRADITIONAL APPLICATIONS OF DISSEMINATION RESEARCH: WHAT SUSTAINED INTERACTION COULD MEAN

If one finding emerges with clarity from decades of research on dissemination, it is that sustained interaction across communities bolsters the use of knowledge resources in the target community. For science and mathematics education, Hutchinson and Huberman (1993) described sustained interaction as "the best single predictor of knowledge use and gain" across studies. They recommended "interactions, interventions, and exchanges between researchers and users… prior to the actual conduct of the study, during the conduct of the study, [and] during analysis and write-up." I discuss next how this could be done, and how all stages of an R&D project can use insights about knowledge use.

Although thinking about dissemination may be difficult and even counterintuitive in the early stages of an R&D project, in fact much groundwork can be laid from the beginning of a project. This advice is drawn in part from work in other fields that provide food for thought for education R&D. For example, early and continuing attention to dissemination made a difference in use of research on natural hazards and in the electronics field (Yin & Moore, 1985). The authors recommended a variety of ways in which researchers could arrange for and capitalize on informal interactions with potential users:

- Become active in associations and other organizations to which both knowledge producers and knowledge users belong
- During the design of a new research project, identify the specific groups that may use the results of the project
- In the course of a research project, consider ways in which the design might be modified, without compromising the integrity or the quality of the work, to meet potential users' needs
- Plan to produce a major product for user groups

All of these steps are feasible for DR K-12 projects. In some projects, user associations are active partners. Identification of potential users typically begins early—but projects vary in how specifically they do this, and more specificity is better. Modifications of design based on pilot testing are common, but this paper will suggest a particularly active contributing role for the pilot testers, and as much openness as possible to adaptations tailored to different users' needs and purposes.

The "lead user" concept in industrial product development offers a way of establishing and using contact with a target field early in the design and development phases of a project (Urban & von Hippel, 1988). Lead users are entities (often organizations rather than individuals) that face new needs that will, over time, become more widespread, and that are in a position to benefit greatly from solutions to these needs. Interaction with lead users can inform the conceptualization of products (or, by analogy, research inquiries or policy analysis) that are likely to enjoy success in the market of products or ideas. Recent discussions of technology-enabled interaction have emphasized the blurring of the boundaries between producers and users (Bollier, 2007).

The work of Yin and Moore and of Urban and von Hippel has implications for dissemination to both practitioners and policymakers; in both cases, investigators can feasibly arrange for early and frequent contact, engage with lead users, adjust their study (as appropriate) for a better fit with users' contexts, and produce something aimed at user groups.

In medicine, translational research forms a bridge between the laboratory and clinical settings. The National Institutes of Health support partnerships among researchers and care providers, generally centered in tertiary care hospitals, aimed at moving findings into use. The "translation continuum" includes several phases of field trials, regulatory approval, and health services research supporting dissemination and adoption (National Cancer Institute, 2007). Some have argued that education would benefit from more translational research that would forge connections among disparate groups such as neuroscientists, social scientists, and teacher educators (Brabeck, 2008). Such connections exist in many DR K12 projects, and many projects also bring front-line practitioners, including teachers, into the development team.

What can be learned from addressing dissemination issues early and often in the life of an R&D project? I discuss here the important lessons about user contexts and the design of innovative knowledge resources, supports for implementation, staged development, and adaptation.

User Contexts and the Design of Knowledge Resources

Investigators would do well to consider the complexity of the innovations they are developing (or the innovations that could be developed by others on the basis of their research findings). Surry and Farquhar (1996) suggest an Adoption Analysis that takes into account the characteristics and perceptions of potential users as well as their environments and available support systems.

In particular, the "ambition" of the innovation will place demands on the resources of practitioner systems, whether ambition is defined in terms of a major disruption to classroom regularities, new learning goals for students, or some other aspect of the innovation. The potential demands on practitioner systems will imply design challenges:

> In general, as reforms become more ambitious—in the sense that they aim at more complex intellectual work for students, require more teacher learning, or demand more expert management systems—many more design problems arise. (Bryk & Gomez, 2008, p. 189).

In looking at the demands that a practice-oriented innovation is likely to make on user systems, investigators should consider:

- Time—the innovation's compatibility with fixed school schedules
- Practitioner knowledge and skills—what it expects teachers to bring to their classroom interactions
- Organizational routines—e.g., for professional development, curriculum adoption, instructional supervision, or ongoing purchasing

In other words, the resource demands of an innovation can be deduced from properties of the school contexts in which it is expected to be used. If resources permit, however, rather than trying to guess what these will be, investigators can and should study resource demands empirically (Penuel, Frank, Fishman, Sabelli, & Cheng, 2009). Clarke, Dede, Ketelhut, & Nelson (2006) describe an inquiry that has systematically studied the contexts for enacting an innovation in technology-based science curriculum. They identified four important factors:

- Teacher preparation (including the teacher's knowledge of science and content-specific pedagogy, as well as fluency with educational technology),
- Class size (affecting the degree of individualization and interaction possible),
- Learner academic achievement (including factors such as students' perceived self-efficacy in learning science and foundational knowledge in science, technology, and literacy), and
- Learner engagement (illustrated by indices such as student attendance at school and teachers' perceptions of student motivation and classroom behavior. (p. 13)

Having described their findings in the field and how they used these findings, members of this research team went on to describe how implementation design teams might build a "scalability index," assessing the sensitivity of an innovation's effects to variation in each contextual factor (Clarke & Dede, 2006). McDonald and colleagues offer a similar recommendation, suggesting that scale-up research could build models of "the key contextual variables that must first be controlled and later varied to ascertain an intervention's ability to consistently produce the desired impact on student learning" (p. 17). Mosher and Smith, observing that instructional regimes are enacted in contexts, suggest the systematic study of contexts, (2009, p. 43).

Clarke et al. explored possibilities of trying to influence the context when they identified ways of compensating through design for some commonly occurring weaknesses in school contexts. For example, having found that some teachers ignored the available online professional development, they "produced a just-in-time, 'light' version of the professional development that teachers can skim for ten minutes per day during the unit" and piloted a train-the-trainer approach with district science coordinators (p. 14). Subsequently, the team addressed the challenge of increasing teachers' comfort level with the program by providing a "dashboard" through which the teacher controlled aspects of implementation such as student grouping (Clarke & Dede, 2006).

Instructional regimes and other classroom interventions often pose challenges related to teachers' knowledge and skill. Based on R&D experience, Dede comments that resolving such problems

> ….presents choices about alternative approaches to the iterative evolution of a design… [such as] changing the design so that the intervention is more "teacher-proof," expanding the design so that extensive teacher professional development is now part of the "treatment," or abandoning the design as unpromising because its effective use require a level of knowledge and skill likely unattainable in the typical teaching population in the near future. (2005, pp. 346-7)

More generally, to address anticipated or observed issues of knowledge use in practice, researchers can consider whether the innovations resulting from their work will require more elaboration (Cohen & Ball, 2006). "Elaboration," in Cohen and Ball's terms, implies extending and deepening the work of development to provide "information, detail, and guidance":

> An intellectually ambitious elementary mathematics curriculum that was designed to encourage students' active engagement in mathematical reasoning and problem solving might be elaborated only in terms of its broad objectives…. Or it could be more elaborated in terms of its objectives, main mathematical themes, and the specific types of instructional activities. It could be even more elaborated in terms of all those things, and extensive examples of desired student performance. Or it could be differently elaborated in lists of topics, the order of coverage, suggested tasks for each topic, and even scripts of teacher-student interactions. Each of these elaborations of the innovation offers users different information, detail, and guidance. More elaboration in this case offers users more resources, thus enabling—not constraining—them. (pp. 7-8)

Investigators in even small-scale research projects could incorporate attention to knowledge use into the early stages of their work. They could conduct "rapid prototyping"—that is, they could develop very simple prototype innovations based on the research findings and try them out in the field, so that time would permit some cycles of field-based learning and modification. If they engage in field trials or classroom-based research, the observed teaching and learning behaviors can be sources of data that inform next steps in the project. To the extent that potential users are brought into an R&D project as active participants, and emerging research knowledge is subject to trial and refinement in practice settings, "[s]uch work entails an engineering orientation where the varied demands of local contexts are a direct object of study and design, rather than being decried as a failure to implement properly" (Bryk & Gomez, 2008, p. 186). Investigators could also, as described above, begin to catalog the influences of participants and contexts on implementation and adapt the innovation accordingly—or at least identify potential options for elaboration.

In this process, it is useful to attend to the attributes of the innovation using a conceptual scheme that Everett Rogers (2003) honed through decades of research in a range of fields. Although "attributes of the innovation" would seem logically to be inherent properties of the knowledge resource, in fact most of them are best understood from the vantage point of the eventual user, and thus will vary to some extent with the user's context. They are the following:

- ***Relative advantage*** can include effectiveness demonstrated through the developer's rigorous inquiry, but also must be understood with reference to the advantages offered to adopters in view of the incentives that face them. In policy, the advantage of a particular knowledge-based option is relative to others in the solution stream.
- ***Compatibility*** refers to consistency with the potential adopters' existing values, past experiences, and needs. This is related to the "truth tests" and "utility tests" applied to new knowledge before it is used.
- ***Complexity*** is the perceived difficulty of understanding and using an innovation, which is related to the extent and kinds of change required. It includes the attributes of clarity and prescriptiveness.
- ***Trialability*** is the possibility of experimentation or pilot use of the innovation, including reinvention for customization (which Rogers notes is a very frequent occurrence in innovation), and divisibility into a series of incremental changes
- ***Observability*** is the ease with which prospective adopters can see the results of using the innovation. It also helps explain the tendency for policy innovations to diffuse among neighboring states.

These attributes offer a conceptual framework with which investigators can begin to shape the dissemination prospects of their results at a very early stage. In pilot practice settings, for example, investigators should be aware that participating educators are assessing the relative advantage, compatibility, complexity, and trialability of the innovation as it begins to take shape. If these educators see attributes that leave them reluctant to join the project or to continue participating—something that often happens in projects like those of DR K-12—their perceptions constitute data relevant to the prospects for later adoption of the project's results on a wider scale. Discussions with these pilot users may offer insights that can help in refining what the project offers to the field, including the rationale offered for use, the tools it provides, or what it asks users to do. Rather than gathering cursory feedback and lamenting the challenges of retaining pilot subjects, investigators could instead embrace these challenges as a source of learning and engage in structured data collection to inform themselves about future implementation constraints and possibilities.

Scaffolding with Tools, Expert Help, and Networks

Research and experience related to the adoption process have generated useful findings about "scaffolding" for the dissemination of particular types of knowledge resources to practitioners. Scaffolding is "the materials and social processes that can support, or scaffold learning" on the part of those who will implement an innovative resource (Cohen & Ball, 2007, p. 8).

New tools, materials, and procedural specifications give concreteness to an innovative set of ideas and thus greatly expedite the adoption process, as well as providing benchmarks for the measurement and consequent improvement of implementation fidelity (Bodilly, 2009). For relatively simple innovations, for which fidelity to a set of standard procedures is important, artifacts such as these communicate and reinforce the innovation's technical core, and they may suffice to support implementation (Bryk & Gomez, 2008). But along with providing practical instructions, it is also important to articulate the concepts behind the innovation; Kennedy (1989) argues that adopters' commitment stems from knowledge about fundamental principles, not from checklists of techniques.

Research and experience with support for implementation suggest that two types of in-person help are useful. One is an expert resource—what Slavin and Madden (2007, p. 221) describe as "dedicated trainers operating from the project's home and/or regional training sites closely coordinated with the project headquarters." In a complex innovation such as Success for All, these trainers provide professional development and quality assurance that Slavin and Madden consider essential for implementation fidelity. But expert guidance for the development of local expertise is useful across other types of innovations as well, including those with less detailed specification than Success for All, such as the use of data by professional learning communities of teachers in schools (McLaughlin & Mitra, 2003). Whatever the philosophy associated with an innovative educational resource, experience suggests that outside expert help is needed in the implementation process.

Another type of help is the creation and support of practitioner networks. The National Writing Project offers an example of an innovation in which the network of participating individuals and schools is not only a vehicle for support but also the locus of considerable professional development for teachers, and even a means for ongoing refinement of the innovation (Lieberman & Wood, 2003). Some DR K-12 projects establish networks of users like this. Slavin and Madden stress the importance of a network in buffering an innovation from local leadership and policy transitions:

> To maintain over a long period of time, schools implementing innovations must be part of a national network of like-minded schools. To survive the inevitable changes of superintendents, principals, teachers, and district policies, school staffs need to feel that there is a valued and important group beyond the confines of their district that cares about and supports what they are doing. (2007, p. 221)

The experience of mature innovations like Success for All and the National Writing Project is instructive in illustrating the amount of R&D work that goes into creating and refining an infrastructure to support dissemination. Slavin and his colleagues have built complex and expensive implementation supports, documenting the lessons learned along the way. The results of scaling up other whole-school designs in the New American Schools initiative also underscore the lesson that R&D teams must invest in the design of implementation supports, just as they have invested in the research and design of the innovation (Bodilly, 1996).

Finally, research suggests that scaffolding support should be tailored to the stage that a site or individual has reached in using a knowledge resource. The "Levels of Use" framework (Hall, Loucks, Rutherford, & Newlove, 1975) is a helpful guide to stages, tracing the progress of implementation from concerns and questions about the disruptive potential of the change, through mechanical use of the innovation's surface aspects, to routine use and then to incorporation of the innovation into a repertoire of practice. These stages matter for the type of implementation support that will be productive. In a recent study of support for implementing an innovation in school leadership, those who were new to the project help with mechanical aspects of implementation, while the same type of help was deemed nearly useless by veterans (Turnbull, Haslam, Arcaira, Riley, Sinclair, & Coleman, forthcoming).

Stages in the R&D Process

The DR K-12 program supports projects at different stages, and at each stage attending to issues of knowledge use can advance the work. The current grant announcement suggests that a full R&D project focus at one of the following points in an R&D cycle:

- Design/ Develop/ Test—starting with an idea, and iteratively pilot-testing prototypes
- Implement/ Study Efficacy/ Improve—incorporating a wider range of implementation conditions
- Scale-up/ Study Effectiveness—includes projects taking as their main focus the implementation conditions required for the success of a STEM education intervention in typical schools

The prospects for knowledge use in practice are an appropriate subject of inquiry for projects at any of these points in the cycle. Furthermore, although DR K-12 projects are not required to work in close collaboration with practitioners, such an approach could be suitable for any of these types of projects.

Other R&D initiatives are taking an iterative and highly collaborative approach to development. For example, the Carnegie Foundation for the Advancement of Teaching is launching an initiative for a Design-Educational Engineering-Development approach to R&D (Carnegie Foundation, 2009), intended to foster broad uptake and use of innovations that solve high-leverage problems in teaching, learning, and educational institutions. The initiative calls for designers, developers, and researchers "to work in close collaboration with educational practitioners from the beginning… . [and] be driven by an engineering orientation where the adaptability of innovations to local contexts is a primary consideration" (pp. 1-2).

The initiative builds on earlier ideas about a development cycle in which researchers work directly with alpha and beta sites (Bryk & Gomez, 2008; Burkhardt & Schoenfeld, 2003):

- The alpha level involves "rapid prototyping" (cycles of field testing and modification) and development of initial evidence of effectiveness
- At the beta level, researchers "consider how diversity among individual participants and contexts shapes the take-up of an innovation and how the innovation itself may need to be modified" (Bryk & Gomez, p. 204).

In the beta-level field trials that Bryk and Gomez (2008, p. 204) propose for innovation engineering, the tasks include building the scaffolding to support implementation in two ways: designing "structured learning processes" for implementers; and "expanding the base of expertise available to assist others in using these new tools and social practices." These development tasks would accompany (rather than following) trials of the robustness of the innovation and its efficacy across environments. Practitioners would be brought into the picture much earlier than in some more traditional approaches to R&D. These initiatives, by casting knowledge use as an object of inquiry at all stages, begin to suggest a different philosophical orientation to knowledge building, which I discuss next.

Learning from Adaptation

Over the past decade or two, R&D policy in education has typically emphasized the faithful implementation of research-based interventions that emerge from painstaking trials of efficacy and effectiveness. On the other hand, adaptation could be seen as a potentially productive part of the scale-up process, offering opportunities to capture further data to inform further cycles of development (Century, 2009; Turnbull, 1996). It could yield:

> …generative learning about the innovation through large-scale use. Efforts [would be] made to amass and mine emerging new data bases, develop practice-improvement networks around new data and tools, and reflect on what has been learned that might help to inform the next round of activity. (Bryk & Gomez, 2008, p. 205)

Advances in technology provide improved opportunities for such learning, both by permitting the creation and mining of large data bases about implementation and results and by enabling practice-improvement networks to interact. More broadly, Dede calls for the use of Web 2.0 to provide "a virtual setting in which stakeholders of many different types could dialogue about rich artifacts grounded in practice and policy" (2009, p.). Similarly, Bollier (2007) reports that cloud computing brings new possibilities for virtual interactions, blurring the boundaries between developers and users.

Enlisting a broad base of implementers in co-constructing new knowledge resources based on emerging adaptations, while a potentially appealing and powerful idea, would require carefully structuring the interactions. Uncritical reliance on "the wisdom of crowds" (Surowiecki, 2004) will not necessarily produce good results. Bollier (2007) recounts the story of the Schaumburg Flyers, a minor-league baseball team that placed all of its managerial decisions (the batting order, the pitching rotation, and the like) in the hands of fans voting on the Internet. The season was a disappointment perhaps because of the fans' limited expertise or limited stake in the team's fortunes, perhaps because of the limitations inherent in voting as a means of registering views (and perhaps because fans of opposing teams took the opportunity to sabotage the Flyers). Clearly, processes of engaging multiple stakeholders in co-construction of educational knowledge would also have to be refined on the basis of learning from successes and failures. Penuel and his colleagues are careful to emphasize that the researchers must remain ultimately accountable for the quality of work, even though they collaborate with practitioners (2009).

But at a program or policy level, supporting this kind of work would require some shifts in assumptions and priorities related to evidence-based practice. As Smylie and Corcoran (2009, pp. 113-114) observe, recent federal policy has emphasized “a ‘product-oriented’ interpretation of evidence-based practice, putting a premium on validation and transportation of discrete programs and practices and emphasizing fidelity of implementation,” as opposed to “deliberate, evidence-based adaptation … [where] the assumption is that even the most robust intervention can be improved and that variation in effects among students and across contexts can be reduced through analysis of student responses and modifications of the program.” Articulating a similar view, Schoenfeld (2009, p. 188) comments: “there is an opportunity for an adventurous funding agency to jump start a new kind of educational enterprise, one with new roles for researcher/designers, designer/teachers, and others who could contribute productively.” Burkhardt and Schoenfeld (2003) have pointed to the types of changes that would be required in order to foster more useful education research more closely connected to practice, including the following:

- Team research on substantial projects
- Closer links between researchers and development groups
- Studies of widely available treatments, using successive iterative refinement

Also entirely feasible would be the incorporation of “practice-based evidence” into the conventional R&D arrangements in education. In medicine, based on experience with more than 20 PBE studies in which clinical practitioners participated, Horn and Gassaway (2007) conclude that such studies are a valuable complement to randomized clinical trials: they accept all patients; they record and monitor results in the presence of multiple interventions; they produce treatment options that are readily implemented; and application of their findings has improved patient outcomes (see also Westfall, Mold, & Fagnan, 2007). Adapting this approach in educational settings would be feasible and potentially productive.

Whether or not researchers embrace an approach as radical as practice-based evidence, the full application of insights from research on dissemination suggests roles for potential knowledge users as active participants in partnership with researchers. Lead users can be sources of initial ideas; R&D designs can incorporate what is learned through rapid prototyping or alpha and beta trials; adaptation can continue to support cycles of refinement and improvement in R&D knowledge. In crafting ideas that can be successfully disseminated in real-world settings, and in attending to the extensive implementation supports that may be necessary adjuncts to a new resource, model, or technology, R&D projects in STEM education can benefit from the findings of past and recent dissemination research.

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