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Exploring the role of instructional technology in course planning and classroom teaching: implications for pedagogical reform

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Abstract Instructional technology plays a key role in many teaching reform efforts at the postsecondary level, yet evidence suggests that faculty adopt these technology-based innovations in a slow and inconsistent fashion. A key to improving these efforts is to understand local practice and use these insights to design more locally attuned interventions. This exploratory study draws on systems-of-practice theory from distributed cognition research to provide a framework for producing comprehensive accounts of technology use. This account includes three components: (a) awareness of the local resource base for instructional technology, (b) decision-making processes regarding tool use, and (c) actual classroom use of technology. Interviews and classroom observations of 40 faculty in math, physics, and biology departments at three research universities in the U.S. were analyzed using thematic and causal network analysis. Results indicate that faculty have both a shared and discipline-specific resource base for instructional technology. The adoption, adaptation, or rejection of technology-based innovations is influenced by the alignment among pre-existing beliefs and goals, prior experiences, perceived affordances of particular tools, and cultural conventions of the disciplines. Classroom use of technology varied across disciplinary groups, with mathematicians and biologists exhibiting relatively limited repertoires of tool use while physicists used a larger variety of tools. Additionally, different tools were associated with different teaching methods and types of student cognitive engagement. Policymakers and instructional designers can use these insights to inform the design and implementation of technology-based initiatives, especially in ensuring that innovations resonate with existing belief systems and practices.

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Introduction

Considerable efforts are being made by the federal government, private foundations and individual Institutions of Higher Education (IHEs) to encourage faculty[1] to adopt inquiry-based teaching methods (e.g., National Research Council 2010; President's Council of Advisors on Science and Technology 2010). These efforts are particularly strong in undergraduate math and science, disciplines viewed as central to national economic competitiveness (NRC 2010). Given evidence showing that the passive absorption of information is a less effective mode of learning than active engagement with the material, many initiatives are focused on expanding faculty members' teaching repertoires to include interactive teaching techniques (NRC 2000). Several approaches utilize instructional technology as a key component in facilitating enhanced interactions between students and course content such as Peer Instruction (Mazur 1997) and Just-in-Time Teaching (Marrs and Novak 2004), and technology-based teaching innovations such as these are becoming increasingly common across the educational spectrum (Collins and Halverson 2009). Indeed, pedagogical innovations combining new technologies and constructivist teaching approaches comprise one of the major strategies being used to reform teaching at the postsecondary level (Garrison and Akyol 2009).

However, evidence suggests faculty adoption of interactive teaching methods in general (Lazerson et al. 2000) and of instructional technology in particular is relatively slow and spotty (Molenda and Bichelmeyer 2006). Further, while some adaptations maintain the original pedagogical intent of the designers, others are what are known as "lethal mutations" that essentially subvert these intentions to result in classroom uses that are less than effective (Brown and Campione 1994). But blame for the lack of the diffusion of pedagogical innovations cannot solely be laid at the feet of the faculty; instructional designers and policymakers face the challenge of introducing innovations into established patterns of tool use and educational practice. Research indicates that local actors will appraise innovations in light of their existing beliefs, experiences, and practices largely to assess the feasibility of adopting the new tool or practice (Rogers 1995; Spillane et al. 2002). As a result, when interventions are designed and implemented with little attention to existing local practices and workplace conditions, incompatibilities between the demands of the innovation and the actual constraints of the local setting may result (Fishman 2005). In particular, research on technology adoption indicates that a particularly important consideration is the perceived utility of a tool to accomplish specific tasks and its ease of use—information that can be used by managers to

[1] By *faculty*, we mean all people, including graduate students, who hold undergraduate teaching positions (excluding TA's)—whether full- or part-time, tenured or untenured—in postsecondary institutions, except for emeritus instructors and postdoctoral researchers.

design interventions that speak directly to users' needs and concerns (Venkatesh and Bala 2008).

Thus, instructional designers and educators would benefit from robust accounts of local practice to use as baselines upon which to design new initiatives, or to provide insights into why initiatives are encountering resistance or undesirable adaptations. A common approach to describing both teaching in general and technology use in particular, however, is to focus only on the use of specific pedagogical techniques (e.g., lecturing) or individual technologies (e.g., PowerPoint slides). Such an approach obscures the complex interactions among teachers, students, specific technologies, features of the organizational context, and the material being taught that are known to be critical features of the teaching and learning dynamic (Cohen and Ball 1999; Spillane et al. 2001). In addition, a more systematic analysis of instruction should integrate accounts of both the processes whereby faculty plan their courses, as well as how they actually teach in the classroom (Schoenfeld 2000).

In this paper we introduce a framework for developing such systemic accounts of teaching and technology use in higher education settings. This framework is comprised of three components: (a) faculty members' awareness of the local resource base for instructional technology, (b) decision-making processes regarding tool use, and (c) actual classroom use of technology. In developing this approach we draw on systems-of-practice theory from research on distributed cognition and school leadership research to examine the role of instructional technology in course planning and classroom instruction (Halverson 2003). With this framework, we suggest that it is possible to derive "detailed account(s) of how faculty use their knowledge of educational innovations and situational constraints to arrive at practical decisions in the moment-to-moment demands of the classroom" (Turpen and Finkelstein 2009, p. 14), which is precisely the type of account of teaching that is most beneficial to instructional designers and educators (Clark 2009; Cobb et al. 2009).

The exploratory study reported in this paper is based on interviews and classroom observations with 40 math and science faculty in three research IHEs in the United States. The classroom observations were conducted using a newly developed instrument—the Teaching Dimensions Observation Protocol (TDOP)—that captures interactions among teaching methods, use of instructional technology, and students' cognitive engagement. Given known disciplinary differences in the subject matter being taught and cultural conventions regarding teaching practice, we report our findings for each disciplinary group separately (Neumann et al. 2002). The study is guided by the following questions: (1) What instructional technologies are faculty aware of in their local environments? (2) What role do these tools play in faculty decision-making processes for planning a particular class? (3) What role does instructional technology play in the different configurations of teaching practices used by faculty, and how do these configurations vary by disciplinary group?

Research on teaching and technology use in higher education

In this section we briefly review the literature on teaching and technology use in higher education settings, suggesting that a systemic account of instructional practice is necessary to advance technology-based teaching innovations. Research indicates that one cause for the slow adoption of interactive teaching methods at the postsecondary level is the research and development approach to pedagogical reform, which is based on the assumption that innovations that are designed in one setting can to be transferable—with little or no adaptation—to other settings (Fairweather 2008). This approach is particularly common in the context of pedagogical reform efforts in math and science disciplines, and evidence is beginning to suggest that faculty resent being encouraged to adopt curriculum without any input into how it can be tailored to fit local conditions (e.g., Henderson and Dancy 2008). These findings are consistent with research showing how structures and policies associated with new practices may be thwarted by incompatibilities between the demands of reforms and the existing capacities and constraints of classrooms at the local level (Cuban 2001; Fishman 2005). Thus, what may appear to be recalcitrance or uninformed rejection of innovations could instead be motivated by valid concerns about the consequence of the innovation or allegiance to the cultural conventions of a particular group of professionals (Piderit 2000).

One way to avoid such antagonistic relations and perceptions while increasing the prospects for program success is to design interventions that reflect a grounded understanding of local practice and experiences (Cobb et al. 2009; Kezar and Eckel 2002). In producing such descriptions, it is important to view teaching not as reducible to the de-contextualized behaviors of a single individual, which is the "lone hero" premise of organizational practice that ignores critical features of the socio-structural underpinnings of work (Spillane 2006). Instead, faculty are "embedded in an organizational matrix" of influences including their discipline, profession, and institution (Umbach 2007, p. 263). Within these contexts faculty exert considerable agency in determining how to teach their courses, which is informed by their prior beliefs and experiences as well as the nature of the material (Hora 2012).

Research on school leadership from a distributed perspective provides a way to conceptualize educational practice in a way that accounts for both the tension between context and agency, as well as the multiple venues of teaching (i.e., course planning and classroom instruction). According to this view, practice is best viewed as "distributed in the interactive web of actors, artifacts, and the situation" (Spillane et al. 2001, p. 23). Thus, in order to adequately understand how faculty plan and teach their courses, it is necessary to consider how they interact with artifacts and with other people within specific contexts of activity (Lave 1988). Building on these ideas, Halverson (2003, p. 2) developed systems-of-practice theory, which focuses on the "dynamic interplay of artifact and tasks that inform, constrain and constitute local practice." In this study we build on Halverson's work and apply it to study two aspects of instructional practice: how these systems inform and constrain course planning, and how they actually constitute classroom instruction. In particular, this approach focuses on three aspects of teaching: (a) faculty awareness of the local resource base for instructional technology, (b) decision-making processes regarding tool use, and (c) actual classroom use of technology.

First, articulating how faculty view their local resource base for technology is important because when actually engaged in planning and teaching, they will draw upon the pool of tools and resources available in their departments and institutions. Therefore, when attempting to understand the practices of a group of teachers, it is important to account for their perceptions of these available resources as a precursor to decision -making (Halverson and Clifford 2006). This focus on the variety of technologies available to instructors also broadens the scope of analysis from individual tools (e.g., clickers, simulations, etc.) to the entirety of technologies that are salient to a group of instructors.

Second, another important facet of teaching is the process whereby faculty make sense of and negotiate their organizational environments while planning their courses. A sense-making perspective highlights how organizational actors extract or notice such cues from their environment when faced with a task, which is then compared to existing frameworks in order to identify appropriate responses (Coburn 2001; Weick 1995). In particular, individuals will perceive particular objects or environmental features as providing opportunities (or not) for particular actions (Gibson 1977; Greeno 1994). These *perceived affordances* are an important type of cognitive schemata that guides activity by suggesting to the viewer certain possibilities for behavior. As a result, local networks of artifacts provide teachers and educational leaders with a finite set of options in regards to fulfilling particular tasks (e.g., how to create a syllabus or teach a course). The concept of perceived affordances and its relationship to activity is also similar to the focus on how users perceive the potential utility of a technology in the widely used Technology Adoption Model (TAM) (Davis 1989; Venkatesh and Bala 2008). Indeed, the TAM emphasizes the critical role that environmental features such as system characteristics, social influences, and other conditions (e.g., organizational support) play in shaping decisions about technology use, and how these decisions may vary according to particular task situations (Venkatesh and Bala 2008). Importantly, the contextual factors that shape teaching and technology use include not only organizational policies and structures, but also socio-cultural aspects of an institution (Windschitl and Sahl 2002).

In addition to perceived affordances, a variety of other personal characteristics are known to influence faculty sense-making in regards to teaching in general (e.g., Hativa and Goodyear 2002) and instructional technology use in particular (Lane and Lyle 2011; Spotts et al. 1997). For example, individuals' pre-existing *beliefs* about technology and teaching (Ertmer 2005), *prior experiences* of success and failure with technology (Martinko et al. 1996), *instructional goals* and *lesson scripts* (i.e., schema for routine instructional tasks) all are known to influence faculty decision-making. As a result, when teachers are faced with a specific instructional situation, schemata associated with that situation will be activated that lead to the selection of a particular lesson script. Taken together, these activated schemata can be viewed as *decision-making pathways*, or the steps taken from situation awareness to option consideration to ultimate decision-making (Klein 2008).

Finally, the complexity of educational practice in general and classroom instruction in particular is not adequately captured by solely focusing on how teachers use particular pedagogical techniques or tools (Cohen and Ball 1999; Halverson 2003). Given evidence that instructional technologies can be used with varying degrees of pedagogical quality (e.g., Turpen and Finkelstein 2009), it is important to go beyond simply accounting for whether or not a technology is being used in the classroom. Instead, researchers should examine how these technologies are being used and to what ends. Regarding the use of instructional technology, three additional features of how technology is deployed in the classroom could shed light on these issues: how they are used to elicit particular types of student cognitive engagement (Blumenfeld et al. 2006; Porter 2002), how they are used in conjunction with particular pedagogical techniques, and the length of time with which these distinct dimensions of teaching interact throughout the course of a class period.

Methods

We employ a qualitative case study design allowing for in-depth analyses of practice and the processes by which individuals make decisions in a single instance or case (Yin 2008). The case focuses on 40 math and science faculty at three large research universities who taught undergraduate courses in the spring of 2010. The analysis reported in this paper is part of a larger study examining the cognitive, cultural, and contextual factors associated with teaching in IHEs. The three IHEs were selected for inclusion in the study due to their high level of National Science Foundation Department of Undergraduate Education (NSF-DUE) funding that indicates the level of pedagogical reforms underway at particular institutions and their similar undergraduate populations of approximately 25,000 students. In particular, initiatives focused on physics and biology faculty were underway at Institutions A and B that had considerable financial support and visibility. The sampling population included all instructors of record for the spring of 2010 semester. Individuals were contacted via email to participate in interviews and two classroom observations, and those who responded were included in the final sample (i.e., a self-selected non-random sample). As a result, when interpreting results from this study, selection bias must be considered, particularly in terms of the degree to which faculty were amenable to technology-related teaching innovations. The final study sample consisted of a total of 40 faculty in math ($n = 18$), biology ($n = 11$), physics ($n = 11$). Characteristics for the study sample are included in Table 1, below.

Data collection: measures and procedures

A team of three researchers, including the first author (and two graduate student assistants) conducted all data collection activities. For the interviews and observations, each of the three researchers observed two classes and conducted one interview either immediately before or after one of the observed classes.

Interviews

Semi-structured interviews, which took approximately 30–45 min, were conducted with each respondent in their offices or nearby classrooms. The interview protocol was based on techniques used in both the teacher cognition literature (e.g., Leinhardt and Greeno 1986) and naturalistic decision-making (Crandall et al. 2006) that revolve

Table 1 Characteristics of study sample

	n
Sex	
Female	16
Male	24
Institution	
A	14
B	12
C	14
Discipline	
Math	17
Physics	12
Biology	11
Level of course	
Lower division	27
Upper division	13
Size of course	
50 or less	10
51–100	10
101–150	9
151 or more	11
Position type	
Lecturer/instructor (non tenure-track)	22
Assistant professor	4
Associate professor	4
Professor	11

around asking individuals to report their decision criteria for particular situations. For this study, the situation was the planning of a class that the research team would be observing. As a result, the interview protocol focused on obtaining an account of the decision-making process leading up to the observed class, including key decision points that shaped the curriculum, selection of specific teaching methods, and class content. Analysts asked a question about the use of instructional technology in each respondent's classroom that was designed to capture broad accounts of tool use (e.g., Do you plan on using any specific types of technology in teaching your class?). Based on responses, analysts followed with probes regarding any constraints or affordances related to their instructional decision-making. The interviews were recorded using a digital recorder and transcribed.

Observations

As part of the larger study through which this analysis was conducted we adapted an instrument developed for use in observing middle school science instruction for use in a postsecondary context (see Osthoff et al. 2009). This instrument, the Teaching Dimensions Observation Protocol (TDOP) focuses on the following categories: teaching methods, cognitive engagement experienced by students, and use of instructional technology. Each category contains several codes that the analyst circles at 5-min intervals as they are observed throughout the class period. The instructional technology dimension includes 12 tools used by faculty during classroom instruction. The tools were identified first by a review of math and physics education literature and then through a pilot study in the Fall of 2009, where the actual tools used by respondents were included in the final instrument. It is important to note that this category was intended to capture not only digitized tools used by instructors, but any tools or objects used in the service of instruction. As a result, codes for items such as chalkboards and demonstration materials are included. Maintaining consistency among the three analysts involved in collecting classroom observation data was ensured through a two-day training where the final instrument was reviewed to ensure that all understood its use. In order to establish inter-rater reliability (IRR), the analysts coded three video-taped classes, with the following Cohen's Kappa results for each pair of analysts (averaged across the three categories): Analyst 1/Analyst 2 (.699), Analyst 1/Analyst 3 (.741), Analyst 2/Analyst 3 (.713).

Data analysis

The procedures for analyzing data unfolded in two distinct yet inter-related stages: analysis of interview data using thematic and causal network analysis and descriptive analyses of the classroom observation data.

Thematic analysis of interview data

All interviews were transcribed and entered into NVivo® qualitative software and analyzed using inductive analysis to identify themes and patterns in the data (Ryan and Bernard 2003), and causal network analysis (Miles and Huberman 1994), which was used to identify relationships between pairs of themes. The first step in the analysis involved two analysts developing a coding scheme in order to segment the data into manageable and thematically coherent units. The coding scheme was created using an inductive coding process in which new codes were created based on data in ten randomly selected transcripts, with each successive instance of the code compared to previous instances in order to confirm or alter the code and its definition (i.e., the constant comparative method) (Glaser and Strauss 1967). After this preliminary analysis, a final coding scheme comprised of 10 categories and 135 individual codes was developed and applied to five randomly selected transcripts, using utterances regarding a particular code (e.g., clickers) as the primary unit of analysis. Importantly, the coding process often resulted in particular passages being coded with multiple codes. After applying the coding scheme to the five transcripts, inter-rater reliability was assessed by calculating the percentage of agreement between the analysts in applying the codes (89 %). The analysts then applied the coding scheme to all 40 transcripts. The text segments coded as different types of instructional technologies were analyzed to identify the presence of a particular tool to answer the first research question.

Then, the text segments were analyzed to identify decision-making pathways. This analysis entailed identifying relationships among cognitive schemata (e.g., beliefs, goals, prior experience, perceived affordances, and lesson scripts) and particular instructional technologies. First, we identified utterances where the respondents clearly stated that a particular technology was going to be used in the observed class (i.e., a lesson script). Taking the lesson scripts as a starting point, we then followed the chain of associations backwards to its origins, which in most cases involved stated relationships to beliefs, goals, prior experience, or perceived affordances. This step in the analysis involved applying codes for these schemata types to the selected text segments. Text that included respondent's declarations regarding teaching and learning were coded as *beliefs,* text that included clearly stated instructional goals were coded as *goals*, text that referred to previous experiences salient to the topic at hand were coded as *prior experiences*, and text that included references to how specific tools constrained or afforded particular behaviors were coded as *perceived affordances*. The resulting decision-making pathways were summarized in the following general form: beginning element: type of cognitive schemata > type of cognitive schemata > lesson script. In order to ensure the reliability of this coding procedure, two analysts independently coded each transcript, and then met to discuss their rationale for selecting particular pathways. This process of identifying decision-making pathways was repeated for all respondents so that multiple instances of particular pathways could be identified. It is important to note that the resulting decision-making pathways represent the accounts of a relatively small number of respondents from our study, so these data should not be extrapolated to entire departments or institutions nor viewed as definitive accounts of action and behavior. Despite these limitations, causal network analysis and related methods such as verbal analysis (Chi 1997) are robust techniques for identifying relationships between concepts.

Analysis of observation data

The next step was to analyze the classroom observation data collected with the TDOP. The raw data for this analysis is in the form of a two-mode matrix that consists of faculty members' 5-min intervals as rows (mode 1) and instruction codes as columns (mode 2)[2] First, we simply calculated the proportions of times each code was observed being used across all 5-min intervals for participants in the decision cluster. Then, using the raw (two-mode) dataset we identified the prevalence of "practice triads" by calculating the simple proportion of 5-min intervals in which particular codes from each dimension of teaching were affiliated. A practice triad represents the affiliation of codes from each of the three dimensions of observed practice. For example, among the physics faculty in this study, the practice triad of "lecture-receive/memorize-PowerPoint" was observed in 50.7 % of the 5-min

[2] This means that, at least initially, each instructor has multiple rows of data, one for each 5-min interval that was observed.

intervals. This means that in half of the observed intervals the teaching technique of 'lecturing' was co-coded with the cognitive engagement of 'receive-memorize' and the technology 'PowerPoint' in the same 5-min interval.

Results

In this section we present findings pertaining to each of the research questions. Each set of findings is presented for each disciplinary group (i.e., math, physics, and biology).

Instructor awareness of their local resource base for instructional technology

When planning courses faculty will draw upon existing resources and tools when developing curriculum and lesson plans for specific classes (Spillane et al. 2002). Thus, a first step in describing instructional technology use in higher education is to identify which tools comprise the local technological resource base within a given department or institution. To identify the specific tools that comprise these resources, interview data were analyzed to identify those tools that respondents described as being actively used in the classroom, as well as those tools that they are merely aware of as being available within their institutions (see Table 2, below).

Some tools were referenced by all groups and thus indicate a shared resource base for instructional technology that crosses disciplinary boundaries. Three tools were referenced by at least two faculty from each group: clickers, course websites, and chalkboards. In the case of clickers, all groups reported being aware of the tool while only the physicists and biologists actually used them in the classroom. All groups utilized course websites as an integral feature of course administration (e.g., posting syllabi and readings online) as well as a tool to facilitate instruction itself (e.g., discussion boards). Finally, each group reported using chalkboards in their classrooms.

Math faculty

The tools that comprise the technological resource base for math faculty included 11 different tools. The tools most highly cited included chalkboards (11 references), computer programs (7), and clickers (6). One notable feature of these data are the dominance of chalkboards among math faculty and its close relationship to disciplinary tradition. As one respondent noted: "I'm a very traditional instructor, so I don't believe in… a lot of computer software, or heavy use of graphing calculators, or… fancy slides during class, you know. I'm a chalk person." This view of chalkboards as a core feature of disciplinary tradition indicates that the cultural conventions of the group are inextricably linked to the types of tools used in teaching. To further illustrate this point, another respondent stated that mathematics is a conservative discipline in regards to instruction, and that the chalkboard and chalk are the sole tools of the field. Such views also serve to demarcate the

Table 2 Instructional technologies referenced by disciplinary groups

	Math faculty references (n = 18)	Physics faculty references (n = 11)	Biology faculty references (n = 11)
Animations and video	1	3	1
PowerPoint slides	0	7	7
Chalkboards	11	5	2
Calculators	1	0	0
Clickers	6	10	5
Computer programs	7	1	1
Course websites	3	5	7
Demonstrations	1	8	1
Digital tablet	2	1	2
Digital projector	0	0	1
Gesture and body	1	2	1
Misc. objects	1	1	5
Other online resources	1	2	1
Overhead projectors	4	2	1

boundaries of permissible and appropriate behaviors, with the suggestion that new, "fancy" tools are frowned upon.

However, one respondent also noted the increasing role that computer programs such as Matlab played in the field, and that "there's a move afoot to change things" at his institution, including attempts to include a computer lab component to a calculus course. Interestingly, two respondents reported digital tablets as part of their technology resource base, and these were used largely to replace the chalkboard so that their notes could be posted to course websites for students. Finally, while math faculty reported clickers as a tool that was available to them, not a single individual reported that they actively used the technology in their own teaching. Instead, clickers were referred to as a technology that was being advocated by pedagogical reformers at their institutions, but that the tool was generally not suitable for the mathematics classroom.

Physics faculty

The instructional technologies reported by physics faculty in the study included 12 different tools. The most highly cited tools available included clickers (10 references), demonstrations (8), and PowerPoint slides (7). In contrast to the mathematics faculty, the physicists discussed clickers as part of their active repertoire of teaching techniques. In one department, clickers have become so widely used that new instructors are encouraged to incorporate them into their teaching, thus reflecting a nascent cultural convention at that particular institution. In most cases, clickers were described as a tool that was particularly useful to assess the degree of student comprehension in large classroom settings where interaction with each student was deemed impossible. With clickers, it becomes possible for the instructor to "figure out that they are just not getting it," which tells the instructor that more time is needed on a particular topic. Demonstrations are also widely used, and each department in the study had a staff person devoted to maintaining demonstration equipment and assisting instructors in setting them up prior to class. One respondent explained why she used demonstrations: "It makes so much more sense when you can see it, which is why quantum mechanics and relativity are so hard." Finally, physics faculty also referenced PowerPoint slides as a technology that was regularly used in the classroom.

Biology faculty

The instructional technologies reported by biology faculty in the study included 13 different tools. The tools most highly cited included course websites (7 references), PowerPoint slides (7), clickers (5) and miscellaneous objects (5). Respondents observed that course websites have become important and even indispensable tools in administering their courses and, in one case, in providing insights regarding student misconceptions from online quizzes that informed subsequent classes. Another widely reported tool was PowerPoint slides, as respondents appeared to organize and present their classes using this medium. Respondents also noted that PowerPoint slides and other tools that projected visual media (e.g., overheads, digital tablets, etc.) were particularly important for biology classes, as many ideas (e.g., gene mutation) were not amenable to drawing on a chalkboard or verbal descriptions. Clickers were also referenced as a tool regularly used in the classroom, as well as miscellaneous objects such as plant material that students handle during class.

Decision-making pathways for instructional technology use

In this section we present findings regarding the decision-making pathways that faculty reported in regards to their planned use of instructional technology. These pathways represent the chain of associations that were activated by some feature of the instructional task, which then set in motion a series of considerations about attributes of particular tools (i.e., perceived affordances) and/or associations with pre-existing beliefs, prior experiences, and instructional goals. Each pathway resulted in the discussion of a particular type of instructional technology, many of which the respondents planned to use in the classroom (i.e., lesson scripts). Overall, 59 pathways were identified among the study sample, and the most frequently reported pathways for each disciplinary group are reported below.

Math faculty

Seven decision-making pathways were reported by at least two respondents among the math faculty in this study (see Table 3, below).

The two most frequently reported pathways included perceived affordances related to chalkboards and course websites. First, the chalkboard was widely viewed as a tool that afforded the writing of formulas, problems, and theorems on a surface.

Table 3 Frequently reported decision-making pathways for mathematics instructors (n = 18)

Decision-making pathways	References
[PA] Chalkboard affords writing formulas/theorems > [LS] Regularly writes on chalkboard while also talking/lecturing	9
[PA] Website affords posting of course materials > [B] Students benefit from access to materials > [LS] Regularly posts homework, lecture notes and quizzes	5
[B] Students should not passively sit in class, but interact with material and instructor [PA] Students disliked clickers when required to use > [LS] Uses colored cards/hand-raising instead	2
[G] Project complex formulas and/or 3-D images > [PA] Overheads afford projecting complex images, which is easier than drawing on chalkboard and won't be erased due to lack of space > [LS] Regularly projects images/formulas for complex topics > will keep image up on screen for long periods of time	2
[G] Goal of course to teach programming > [PA] Matlab best way to learn > [LS] Regularly demonstrates Matlab problems in class	2
[G] Keep students from writing the entire class period > [PA] Data projector or digital tablet affords ability to project documents/writing on slides > [LS] posts notes on website that students can study and bring to class	2
[G] Maintain pacing and sense of "flow" in class > [PA] Technology would disrupt flow > [LS] Uses chalkboard	2

[G] = Goal, [PA] = Perceived affordance, [B] = Belief, [PE] = Personal experience, [LS] = Lesson script

While this observation seems obvious, it underscores the importance for math instructors to be able to write the symbols and computations that comprise mathematical discourse on a two-dimensional surface. Second, course websites were reported as enabling the posting of syllabi, exams, and homework. This perceived affordance was well-aligned with the belief that access to these materials benefited students, primarily in enhancing their ability to do homework and practice computations on their own time.

The other widely reported pathways included beliefs about learning and a variety of instructional goals. The belief that students should be actively engaged with the material was cited in relation to the use of colored cards, which students used to indicate their answers to a question. The instructional goals reported by math instructors as playing a key role in their selection of instructional technology included the goal to project complex formulas, to teach programming, to keep students from writing notes the entire class, and to maintain a sense of "flow" to the class. In most cases, the alignment between a goal and the perceived affordances related to a tool led to the planned use of that particular tool. In one pathway, however, the misalignment between a goal (i.e., maintaining a sense of flow) and the perceived affordances of a tool (i.e., technology in general) led to the use of the mathematician's traditional technology: the chalkboard.

It is worth highlighting one case where an instructor found that technology was able to integrate the best features of the chalkboard with those of digital tools. For this instructor, a digital tablet was able to satisfy multiple goals while simultaneously maintaining the benefits of chalkboard use and avoiding the pitfalls of other technologies.

> I've been relying on the digital tablet since day one, because it has the goods of many different worlds. When I was in school things were done in front of blackboards and students rarely fell asleep, because the instructor is moving, erasing, and there is chalk all over the place. It's very dynamic and very interactive. Whereas these days I see all these PowerPoint presentations with just one slide after another, and there is not enough to keep students engaged and involved. So the tablet provides me that kind of an interactive dynamic environment where it is almost as if I am in front of the board, but it is even better, because I have all of these color capabilities that can do graphics and draw pictures, which are things I cannot do on a computer keyboard. And then at the end of the day I save the file as a.pdf and put it on the website. Students really like that.

While this decision-making pathway represented only the experiences of a single instructor, it underscores how the alignment (or not) among goals, prior experiences, and perceived affordances shape faculty decisions about technology.

Physics faculty

Nine decision-making pathways were reported by at least two respondents among the physics faculty in this study (see Table 4, below).

The most referenced pathway included the belief that students learn best in interactive settings, and that clickers afford the realization of this goal in the classroom. In this case, the use of this particular tool is predicated by a particular view about student learning. Among the physics instructors in the study sample, beliefs that engaging and motivating students were widely expressed and influenced the selection of instructional technology. Thus, the alignment between beliefs and tool affordances appears to play a considerable role in the selection of instructional technology for this group of physics faculty.

This dynamic was especially apparent in the pathways related to the use of demonstrations, which were informed by the instructional goal for students to appreciate physics and the belief that students have many misconceptions about physics. Since demonstration equipment was perceived as facilitating student appreciation and understanding, this tool was regularly used by some physics instructors. Interestingly, two physics instructors reported the belief that students learn better with a well-paced class, and that PowerPoint slides often lead to an overly rapid presentation of material. Like the mathematics faculty described previously, this perception led to the use of chalkboards as a way to allow the instructor better control over the pace of the class.

Biology faculty

Seven decision-making pathways were reported by at least two respondents among the biology faculty in this study (see Table 5, below).

Prior beliefs played an important role in two of the most reported pathways. First, the belief that students learn best while actively engaged in the material was well-

Table 4 Frequently reported decision-making pathways for physics instructors (n = 11)

Decision-making pathways	References
[B] Students learn best in interactive settings > [PA] Clickers afford engagement with material > [LS] Regularly uses clickers	5
[PA] Website affords posting of course materials > [B] Students benefit from access to materials > [LS] Regularly posts homework, lecture notes and quizzes	4
[PA] PowerPoint affords succinct projecting of material > [B] Beneficial to motivate the material and explain why a topic is important > [PE] Learned best as a student this way > [LS] Regularly posts outline of class	4
[G] Goal to have students appreciate physics as experimental science > [PA] Demonstrations afford ability to demonstrate physics phenomenon > [LS] Regularly uses demonstrations	3
[B] Many students have misconceptions about topic > [PA] Demonstrations afford ability to visualize topic > [LS] Regularly uses demonstrations as launching point for lecture, and to address source of misconceptions	3
[PA] Demonstrations afford ability to demonstrate physics phenomenon > [PA] Support staff assists with set up > [LS] Regularly uses in conjunction with clickers	3
[PA] Chalkboard affords writing and pace-setting > [PE] PowerPoint can make the class move too fast > [B] Students learn better with a slower pace > [LS] Regularly writes on board and avoids PowerPoint	2
[PA] Simulations afford visualization of complex topics > [PA] Also more flexible than demonstrations > [LS] Regularly uses to demonstrate complex and dynamic phenomenon	2
[PA] Clickers afford question-posing > [LS] used with ConcepTests as part of Peer Instruction > [LS] Uses to spark conversations among small groups	2

[G] = Goal, [PA] = Perceived affordance, [B] = Belief, [PE] = Personal experience, [LS] = Lesson script

aligned with the perception that clickers afforded such engagement, which then led to the use of clickers on a regular basis for five biology instructors. Second, the belief that student learning is facilitated by making connections to the real world was aligned with the perception that PowerPoint afforded this connection through the projection of images related to biological phenomenon. These examples demonstrate the importance of the alignment between beliefs and perceived affordances in shaping decisions to use particular types of instructional technology.

Observed classroom practice

In this section we report results from observations of instructor technology use in the classroom. The data are reported in two formats. First, as the proportion of times that a particular code was observed across all of the 5-min intervals in the TDOP instrument. These data provide a snapshot of which teaching methods, types of cognitive engagement, and instructional technologies are used by each group. For example, a score of .45 for clickers would indicate that clickers were observed being

Table 5 Frequently reported decision-making pathways for biology instructors (n = 11)

Decision-making pathways	References
[B] Students learn best while actively engaged in the material > [PA] Clickers afford question-posing and are particularly useful in large classes > [LS] Regularly uses to engage students and to assess conceptual understanding	5
[PA] Website affords posting of course materials > Students benefit from access to materials > [LS] Regularly posts homework, lecture notes and quizzes	5
[B] Student learning is facilitated by making connections to the real world > [PA] PowerPoint affords projecting of multi-dimensional visuals > [LS] Regularly projects complex graphics in class and posts on website	5
[PA] PowerPoint affords succinct projecting of material > [B] Beneficial to motivate the material and explain why a topic is important > [PE] Learned best as a student this way > [LS] Regularly posts outline of class	4
[PA] Clickers afford question-posing > [LS] Used with ConcepTests as part of Peer Instruction > [LS] Uses to spark conversations among small groups	3
[G] Goal to have students appreciate biology > [PA] Demonstrations afford ability to demonstrate biological phenomenon > [LS] Regularly uses demonstrations/passes around plant material	3
[PA] Clickers afford question-posing—but awkward to use and takes lots of time to prepare > [LS] Uses intermittently and not in a pedagogically rich manner	2

[G] = Goal, [PA] = Perceived affordance, [B] = Belief, [PE] = Personal experience, [LS] = Lesson script

used in 45 % of the 5-min intervals across all respondents in the data set (see Table 6, below).[3]

In addition, we also provide data regarding how frequently each of the three dimensions of practice were observed together. This approach reveals the configurations within and between the dimensions of classroom instruction, especially how the use of instructional technology is associated with an instructor's pedagogical approach and how students are cognitively engaged in the class.

Math faculty

The data for the math faculty indicated that instructors relied primarily on a single instructional technology (i.e., the chalkboard), with a secondary set of tools used less frequently. The use of the chalkboard was observed in 75 % of all 5-min intervals, thus representing the core instructional technology in use by this group. Complementing the use of chalkboards are overhead projectors (8 %), digital tablets or document cameras (6 %), and miscellaneous objects (3 %). The large discrepancy between chalkboard use and that of other technologies indicates that for this group a single tool dominates their classroom practice.

Next, the data for triadic affiliations among the three dimensions of practice indicate that the chalkboard was observed in conjunction with lecturing and the receive/memorize cognitive engagement in 60 % of the observed 5-min intervals across all mathematics instructors. This type of instruction entailed the instructor

[3] A typical 50-min class would have ten 5-min intervals worth of data per respondent.

Table 6 Percentage of 5-min intervals in which instructional codes were observed across dimensions of practice, instructors, and class periods

Dimension of practice	Mathematics instructors (381 intervals, n = 18) (%)	Physics instructors (219 intervals, n = 11) (%)	Biology instructors (224 intervals, n = 11) (%)
Teaching methods			
Lecture	75	93	84
Illustration	7	13	18
Demonstration	1	40	0
Small group discussion	4	4	12
Multi-media	0	7	3
Worked out problems	66	18	0
Desk work	10	1	1
Rhetorical question	11	5	4
Display conceptual question	21	17	23
Display algorithmic question	24	3	0
Comprehension question	21	5	8
Novel question	8	3	9
Clicker question	0	13	9
Cognitive engagement			
Receive/memorize	83	93	91
Problem solving	58	28	14
Creating	6	11	14
Integration	7	7	5
Connections to real world	6	24	20
Instructional technology			
Chalkboard	75	48	7
PowerPoint	0	57	80
Demonstration equipment	0	33	0
Clickers	0	13	9
Misc object	3	11	3
Pointer	0	9	27
Digital tablet/document camera	6	9	9
Overhead projector	8	12	6

writing out equations, theorems, or definitions, followed by a verbal elaboration on these points. However, the chalkboard was also observed with faculty working out computational problems, which was associated with the receive/memorize cognitive engagement (50 %) and the problem-solving cognitive engagement (38 %). These data indicate that the chalkboard can be used to not only present theorems and other rules for rote memorization, but also to engage in extensive computational problem-solving activities. Further, it is important to note that working out problems can involve students passively sitting and observing the instructor who is working out the solution, or the instructor can actively engage students in working on the problem simultaneously with them.

Physics faculty

The data for the physics faculty indicated that instructors relied on a wider range of practices than the math instructors described above. The core practices employed by the physics faculty include specific teaching methods such as lecturing (observed in 93 % of all 5-min intervals) and demonstrations (40 %), the cognitive engagement of receive/memorize (93 %), and the instructional technologies of PowerPoint slides (57 %) and chalkboards (48 %). Complementing these core features of teaching are practices that are used less often, but still remain an important part of physicists repertoire of practice. In regards to instructional technology, these include demonstration equipment (33 %), clickers (13 %), overhead projectors (12 %), and miscellaneous objects (11 %).

Data for triadic affiliations for the physicists indicate that these technologies were associated with a variety of other teaching methods and types of cognitive engagement. The most observed set of practices for the physics faculty are lecturing with PowerPoint slides while asking students to receive and memorize information (50 %). Observed with almost the same frequency was lecturing with the chalkboard while asking students to receive and memorize information (45 %). Complementing these practices include demonstrating physics phenomena (e.g., simple harmonic motion) using demonstration equipment while asking students to receive and memorize information (28 %). However, the physics instructors included in this study also engaged students in a variety of other types of cognitive engagement using instructional technology, which indicates a diverse repertoire of practice.

Biology faculty

The data for the biology faculty indicated that they relied on a relatively limited set of practices including lecturing (observed in 84 % of the 5-min intervals), receiving and memorizing information (91 %), and the use of PowerPoint slides (80 %). The data do indicate some complementary practices to this core set of practices, particularly in regards to teaching methods such as asking students questions. The data for instructional technology use indicates that the instructors primarily use PowerPoint slides with laser pointers, which are occasionally supplemented with overhead projectors. Finally, the triadic affiliations for the biology instructors in this study indicate the dominant use of lecturing with PowerPoint slides while asking students to receive and memorize information. These practices are by far the most commonly observed repertoire of practice for biology faculty, with other uses related to PowerPoint (e.g., small group work) and the chalkboard being observed less often.

Discussion

In this paper we used a systems-of-practice framework to describe three components of how faculty utilize instructional technology: awareness of local resources, decision-making pathways for tool use, and actual classroom use of technology. In providing such descriptions our aim is to illuminate not only how faculty use technology, but also the factors that influence why they select particular tools over others. In this section we briefly discuss key findings along with implications of these results for undergraduate education in general and math and science pedagogical reform in particular.

Local resource bases of instructional technology

In analyses of educational practice it is important to not focus solely on an objective accounting of every single tool or resource available to an individual, but also which tools or resources they recognize as being salient to their work and thus use on a regular basis (Halverson and Clifford 2006). We suggest that the range of tools with which faculty are aware constitutes the resource base within which individuals then make sense of the role of technology in their teaching. While the data indicate disciplinary variation in the types of tools faculty recognize within their departments and institutions, three tools appear across all disciplinary groups that represent a combination of the traditional and the digital. Respondents reported that chalkboards, clickers, and course websites are all instructional technologies that are within their sphere of awareness and/or are regularly used in the classroom. That chalkboards are considered to be a tool available across all groups is unsurprising given their ubiquitous nature throughout classrooms from elementary to postsecondary levels. Clickers also are recognized as a widely available and utilized instructional technology, which is due in part to technology-based pedagogical reforms related to clicker use that had taken place at each of the institutions in the study. Finally, course websites are a widely recognized tool that suggests instructors' resource base for technology-based extends beyond those tools used solely in the classroom. As such, the use of course websites represents the expansion of the learning environment into cyberspace and even into students' homes. A growing number of studies are examining how faculty are using technology to complement in-class instruction as part of a shift towards blended instruction (e.g., Bonk and Graham 2005; Garrison and Kanuka 2004), and we suggest continued examination of how online resources are being used to complement classroom instruction. As the resource base of instructional technology continues to expand, faculty will be faced with an array of decisions regarding which tools to utilize and how.

Decision-making pathways: the importance of perceived affordances

When faculty make these decisions, the data reported in this study indicate that no single factor or consideration can explain why a particular technology is selected for use in the classroom. Instead, a variety of cognitive schemata and considerations of a tool's utility interact to shape decisions regarding technology use, a finding that corroborates prior research on teacher cognition and instructional decision-making (Ertmer 2005; Schoenfeld 2000; Stark 2000). In particular, the data reported in this study highlight the importance of alignment between pre-existing beliefs and goals on the one hand with perceived affordances related to particular tools on the other hand, and how the degree of alignment will shape an instructor's ultimate decision regarding whether or not to use a tool. In this way, perceptions regarding the instructional possibilities of a tool act as a sort of "filter" for an instructor's pre-existing beliefs about teaching and learning and their instructional goals for a particular class (Stark 2000).

An example of this filtering process is the case of clickers. For biology and physics faculty, clickers were used primarily because they allowed for the realization of a pre-existing goal: to engage students in their classes in actively answering questions or interacting with their peers. The technology was designed to afford these types of behaviors, and some faculty found that their goals and the affordances presented by the tool were well aligned. Importantly, the nature of the content will also play a role in this process. For example, while some math faculty reported similar goals for student engagement, they did not perceive clickers to be well suited to their field. As one math instructor noted, "We tried using them in classes and in recitations, but they just did not get us the information that we wanted," which was information about student misconceptions. The main issue with clickers reported by this individual was that the technology was designed to focus on multiple-choice questions, and was less well suited to open-ended or complex computational problems. As a result, this individual returned to simply posing verbal questions while problem-solving at the chalkboard, which allowed for the realization of the goal to engage students while also maintaining the instructor's ability to work through computations.

Another instance of beliefs and goals interacting with the perceived affordances of a tool pertains to the issue of pacing and instructional flow. Several faculty in this study articulated that a slow and even pacing during their classes was an important goal because it enhanced student learning. One math instructor noted that chalkboards best facilitated a smooth and effective lecture as they allowed him to completely control the pace of the class, whereas clickers were perceived to break a lecture's fluidity and were "just a little awkward." In addition, two physicists reported that while PowerPoint slides were effective tools for structuring a class and projecting complex graphics, it was easy to speed through them such that the flow of the class was too fast for effective learning. In response, these instructors found themselves turning more to the chalkboard in order to "control the pace" of the class. As Nakamura and Csikszentmihalyi (2005) suggest that "effective teachers choose pedagogies that allow them to enjoy the process and get their students involved" (p. 62), it is important to consider the role of perceptions regarding pacing in regards to how and why faculty adopt instructional technology.

Importantly, perceived affordances for particular tools may also be influenced by cultural convention (Norman 1998). The chalkboard is an example of a tool whose affordances can be viewed in this light. For respondents who described themselves as "a traditional chalk person" or "a lecture and board guy," the goal of conveying course materials to students, as well as the affordance of the chalkboard to realize those goals, was largely left unstated, which underscores the often tacit nature of both culture and affordances. Further demonstrating the role of culture in technology use, one math instructor described her field as being “culturally conservative” and that her efforts to bring a Matlab component to some undergraduate courses was running into some resistance. Thus, cultural tradition and convention can act to shape not only the pedagogical beliefs and goals of a group (Becher and Trowler 2002), but also their views about which technologies are appropriate for performing particular tasks (Norman 1998).

Use of instructional technology in the classroom

Researchers of instructional practice at the postsecondary level have documented disciplinary variations in approaches to student engagement (Umbach 2007), styles of lecturing (Brown and Bakhtar 1987), allocation of instructional time (Smeby 1996), and the use of specialized concepts and jargon (Hativa 1995). The data reported in this paper extend this body of research by documenting that another area of disciplinary variability is the use of instructional technology. Of the three dimensions of practice captured by the TDOP instrument, faculty generally exhibited similarities in their core teaching methods (i.e., lecturing) and cognitive demands (i.e., receive and memorize information), yet each disciplinary group used a very distinct set of technologies in the classroom. This finding suggests that instructional technology may be one of the more important features that distinguish disciplinary groups from one another in regards to classroom practices.

Further, the data reported in this paper demonstrate that the use of instructional technology is not without implications for the resulting teaching and learning dynamic of a particular classroom. That is, the use of particular tool is not devoid of implications for student learning, but instead acts to shape a variety of instructional features including how the material is conveyed as well as the nature of the teacher-student interaction. For example, in our study, the use of chalkboards are strongly associated with the receive/memorize cognitive engagement and the lecturing teaching method for mathematicians and physicists. However, we do not suggest that the use of a particular tool will in all cases result in the same type of cognitive engagement. The chalkboard was also associated with the problem solving cognitive engagement and the working out problems teaching method for both of these disciplinary groups as well. These data echo the findings of Turpen and Finkelstein (2009) who demonstrated that clickers can be used by different instructors to achieve pedagogical interactions of varying quality, largely depending on how long the instructor allows students to answer the posed question and whether or not genuine discussion ensues. As Mazur (2009) argues, “It is not the technology but the pedagogy that matters” (p. 51).

Implications for policy and pedagogical reform

Calls to transform the college classroom by using instructional technology may only succeed if faculty are supported in defining and accessing tools that are germane to local circumstances (Meltzer and Manivannan 2002). In departing from “generic solutions [to technology integration that] do not value the individual teacher—their experience, teaching style, and philosophy—by assuming that all teachers teach the same way and hence would use technology the same way” (Mishra and Koehler 2006, p. 1032), it becomes possible to tailor interventions to local needs in ways that may enhance their adoption (see also Venkatesh and Bala 2008). As a result, policymakers and education administrators should pay close attention to local practices, as these situated behaviors constitute the grounds upon which an innovation will be introduced and ultimately adopted, adapted, or rejected (Clark 2009; Fishman 2005). Indeed, what may look like resistance to change or pedagogical improvement may in fact be partly a response to interventions that are viewed as inimical to the traditional practices of a discipline (Piderit 2000), a phenomenon that was reported by mathematics instructors in this study regarding efforts to encourage the adoption of clickers.

As a result, we argue that technology-based pedagogical reforms should not attempt to levy global or institution-wide solutions on all faculty at a given institution, but instead should “work within disciplinary clusters and focus on pedagogical techniques that are most effective for the outcomes most closely related to the specific goals of the respective disciplinary clusters and the nature of the content to be taught” (Smart and Ethington 1995, p. 56). With this in mind, we propose that the approach described in this paper can serve as a “diagnostic frame” that can inform the design and implementation of technology-based interventions. This approach can provide a catalogue of concrete classroom situations, identify specific leverage points for instructional decision-making, and highlight key discipline-specific practices that could be incorporated into program design. The resulting accounts of the subtle features that underlay faculty use of technology can then be used to ensure that new policies or interventions resonate in some fashion with local conditions, traditions, and practices.

Conclusions

This study presents an initial effort at describing faculty use of instructional technology from a practice-based perspective. Future research in this area should examine the role of social influences on technology use, and consider comprehensive analyses of faculty technology use that encompass the classroom, laboratories and recitations, and online venues. In addition, the influence of department- and institution-specific factors on perceived affordances, as well as the potential for instructional decision-making to be a largely automatized process, should be examined in the future. Finally, the notion of an instructional system-of-practice must necessarily be extended to include students as critical actors within the teaching and learning dynamics of a classroom. Thus, research that builds upon the framework introduced in this paper to include student perceptions and experiences regarding technology use in the classroom would provide a valuable contribution to the literature. As technology continues to be introduced into classrooms at both the K-12 and postsecondary level, particularly in the form of social media and educational games, the integration of instructional technology into pedagogical reforms will likely increase in the near future (Collins and Halverson 2009; Gee 2007), and so the need to understand how and why instructors adopt and utilize these tools in the classroom will continue to grow.

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