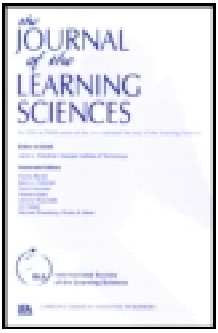

Journal of the Learning Sciences

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hlns20

Instructional Systems of Practice: A Multidimensional Analysis of Math and Science Undergraduate Course Planning and Classroom Teaching

Matthew Tadashi Hora [a] & Joseph J. Ferrare [a]

[a] Wisconsin Center for Education Research University of Wisconsin-Madison

Accepted author version posted online: 24 Sep 2012.Version of record first published: 19 Nov 2012.

To cite this article: Matthew Tadashi Hora & Joseph J. Ferrare (2012): Instructional Systems of Practice: A Multidimensional Analysis of Math and Science Undergraduate Course Planning and Classroom Teaching, Journal of the Learning Sciences, DOI:10.1080/10508406.2012.729767

To link to this article: http://dx.doi.org/10.1080/10508406.2012.729767

THE JOURNAL OF THE LEARNING SCIENCES, 1–46, 2012

ISSN: 1050-8406 print / 1532-7809 online
DOI: 10.1080/10508406.2012.729767

Routledge
Taylor & Francis Group

Instructional Systems of Practice: A Multidimensional Analysis of Math and Science Undergraduate Course Planning and Classroom Teaching

Matthew Tadashi Hora and Joseph J. Ferrare
Wisconsin Center for Education Research
University of Wisconsin–Madison

Descriptions of faculty practice that illuminate nuances of how course planning and classroom instruction occur in specific contexts are important to inform pedagogical interventions. The study reported in this article draws on systems-of-practice theory to focus on the dynamic interplay among actors, artifacts, and tasks that constrains activities such as course planning and constitutes other activities, such as classroom instruction. This qualitative case study of faculty teaching in math and science disciplines at 3 research universities is based on interview and classroom observation data ($n = 57$ instructors) that are analyzed using causal network and social network analysis techniques. Results indicate that course syllabi are important organizational artifacts that are created by curriculum committees, inherited from previous instructors, and shaped by consideration of the sequential acquisition of knowledge. Faculty perceived that although course syllabi delimit the type and temporal sequencing of material for faculty, they are generally free to teach how they like. Observation data reveal discipline-specific configurations in frequently used teaching methods, cognitive engagements, and the use of instructional technology. These results also demonstrate that conceptualizing teaching solely as the use of particular methods (e.g., lecture) obscures subtle features of practice. Using the approach outlined in this article, instructional designers can obtain insights into meanings and practices that can be used to design and implement locally attuned reform initiatives.

Correspondence should be addressed to Matthew Tadashi Hora, Wisconsin Center for Education Research, University of Wisconsin–Madison, 1025 West Johnson Street, Madison, WI 53706. E-mail: hora@wisc.edu

In recent decades a growing number of critics have assailed colleges and universities in the United States for providing inadequately rigorous and engaging instruction to undergraduate students (Arum & Roksa, 2011; Bok, 2005; Boyer, 1990). In particular, although math and science fields produce a prodigious amount of cutting-edge research, policymakers and educators are increasingly expressing concerns that these fields are failing to offer meaningful educational experiences to students (Momsen, Long, Wyse, & Ebert-May, 2010; President's Council of Advisors on Science and Technology, 2012). Additional concerns about the underrepresentation of women and students of color, the number of students entering these disciplines from high school and persisting until graduation, and the quality of learning taking place at the undergraduate level contribute to a rising chorus of critiques of how these disciplines are taught (National Research Council, 2010). These critiques are centered on the persistence of the "sage on the stage" model of instruction, where faculty[1] primarily present facts, concepts, and/or procedural knowledge in a way that relegates the student to a passive observer (Handelsman et al., 2004). Thus, reform efforts tend to focus on encouraging faculty to reduce the time they spend lecturing (i.e., providing verbal discourses to an audience; Merriam-Webster, 2011) and to engage students more directly in the learning process by adopting methods such as problem-based learning (Hmelo-Silver, 2004), peer learning (Mazur, 1997), and digital technologies (Garrison & Akyol, 2009).

Despite these efforts, evidence suggests that faculty are slow to adopt these research-based teaching methods and that the considerable investments made in pedagogical reform are having marginal impacts (Fairweather, 2008; National Research Council, 2003). Possible reasons for this state of affairs include organizational structures that are slow or difficult to change, entrenched cultural norms that run counter to these innovations, or recalcitrant faculty who resist changing their teaching practices (Henderson & Dancy, 2007; Kezar, 2001; Woodbury & Gess-Newsome, 2002). Another explanation is the nature of reform itself—research indicates that the mismatch between new tools or innovations and the realities of practice within the local settings in which they are introduced is a common reason for unsuccessful reforms (Fishman, 2005).[2]

Regardless of the reason for the slow rate of curricular and pedagogical change in higher education, policymakers, instructional designers, and other agents advocating change can benefit from detailed descriptions of the specific practices

[1] By *faculty,* we mean all people who hold undergraduate teaching positions—whether full or part time, tenured or untenured—in postsecondary institutions.

[2] This is also a basic premise in fields long involved in behavior change efforts, such as public health. A key problem is the misalignment between the sociocultural context of the target population and the underlying assumptions regarding behavior that inform particular interventions (Helman, 2007; Rogers, 1995).

that teachers use in order to design, manage, and implement behavior change initiatives (Cobb, Zhao, & Dean, 2009). Once identified, the situated practices of a group can be used as a foundation for designing new interventions that are more closely aligned with the realities and constraints of existing practice or as a road map for identifying specific factors that can be maintained or altered to change task performance (Halverson, 2003). Given recent research outlining the deleterious effects of top-down pedagogical reforms that fail to engage faculty in the actual design and implementation of new curriculum, developing more locally attuned interventions has become a national priority (Henderson & Dancy, 2008).

Two particular practices are central to the instructional practice of postsecondary faculty: course planning and classroom instruction. When engaged in these activities faculty do not operate in isolation but instead function within distinct cultural and organizational contexts at the institutional, departmental, and classroom levels (Umbach, 2007). In particular, the discipline acts as a significant factor in shaping academic communities of practice, in which epistemological frameworks, technical jargon, and instructional practices develop and are reproduced from generation to generation (Lave & Wenger, 1991; Neumann, Parry, & Becher, 2002). When planning courses within these unique structural and sociocultural situations, faculty will read their environments and determine how local policies, procedures, and the curriculum afford or constrain particular pedagogical choices (Hora, 2012; Lattuca & Stark, 2009). Similarly, classroom instruction can be viewed as a multifaceted practice that encompasses the teacher, students, and features of the instructional task (Cohen & Ball, 1999) instead of the common practice of focusing solely on oft-used pedagogical techniques (e.g., lecturing, small-group work). Thus, the multidimensional nature of teaching requires a view of both planning and classroom instruction that accounts for the subtle dynamics among actors and features of their organizational contexts.

Toward this end, we draw on research from distributed leadership studies to situate faculty practice within networks of artifacts (i.e., policies, procedures, and tools) called systems of practice, whose unique local configurations act to demarcate possible behaviors and mediate activity (Halverson, 2003). According to this view, an organization's context is not simply the backdrop to task performance, but instead activity is conceptualized as being distributed among individual actors, artifacts, and features of the situation (Spillane, Halverson, & Diamond, 2001). This framework is also useful in highlighting which artifacts could conceivably be altered by local leaders to support particular teaching practices and which represent deeply entrenched cultural practices for a particular group that may resist change. In this article we extend this framework to study how the interactions among actors, artifacts, and situations are implicated in faculty practice in two ways: first, by informing and constraining the sense-making processes regarding course planning, and second, by actually constituting the features of classroom instruction itself. Taken together, the *instructional systems-of-practice* framework provides a way to conceptualize these two instructional behaviors that accounts for the distributed nature of teaching practice. In this article, we focus on the following questions:

1. What are the sense-making processes related to course planning, and how do particular artifacts influence this process?
2. What are the different configurations of teaching practices used by faculty, and how do these configurations vary by disciplinary group?

To investigate these questions we developed an approach to study instructional systems of practice for five math and science disciplines at three large research universities in the United States. This approach includes two distinct yet interrelated modes of data collection and analysis. First, analyses of interview data reveal that perceived affordances related to course syllabi strongly influence course planning. Second, classroom observations using a newly developed instrument—the Teaching Dimensions Observation Protocol (TDOP)—capture the dynamics among *teaching methods* (e.g., lecture, small-group discussion), use of *instructional technology* (e.g., clickers, PowerPoint), and students' *cognitive engagement* (i.e., the types of student thinking evoked by the instruction). Using social network analysis techniques it becomes empirically possible to analyze configurations within and between these dimensions of classroom instruction to identify "repertoires of practice" (Gutierrez & Rogoff, 2003) at the group and individual levels. We suggest that, taken together, the resulting data provide comprehensive accounts of teaching practice that offer insights into the situated nature of course planning and classroom instruction.

RESEARCH ON COURSE PLANNING AND CLASSROOM INSTRUCTION AT THE POSTSECONDARY LEVEL

In this section we provide a review of the literature on course planning and classroom instruction in postsecondary institutions. Then research on educational practice that utilizes situated and distributed perspectives is discussed as an introduction to the instructional systems-of-practice framework.

Course Planning

A course curriculum can be thought of in terms of an academic plan that entails considerations of the type and sequencing of course material, learning goals and activities for students, and methods of evaluating student performance. A substantial body of research exists on curricular design at the postsecondary level

(Conrad & Pratt, 1983; Lattuca & Stark, 2009; Mayhew & Ford, 1971), some of which was instigated by a national push in the 1980s to improve teaching and learning at the undergraduate level by encouraging a more structured and "coherent" curriculum (Stark & Lowther, 1986). This was a salient problem given the evidence that previously unexamined features of the college curriculum, such as the arrangement of content and the articulation of clear goals for student learning, were closely related to learning. This led researchers to question whether courses were designed in ways to facilitate learning and the degree to which faculty were intentional when they planned their courses (Stark, Lowther, Ryan, & Genthon, 1988).

A prescient feature of the research program of Joan Stark and colleagues was the attention paid to the influence of preexisting faculty beliefs and features of the organizational context on faculty decision making. Stark (2000) hypothesized that faculty beliefs and assumptions about education drove decisions about the structure and content of a course and that these beliefs were in turn influenced by characteristics of the discipline and contextual factors such as student characteristics and goals, external influences (e.g., accreditation agencies), departmental goals, and facilities and resources. Based on this line of inquiry, Stark developed the contextual filters model as a way to explain how structural, sociocultural, and psychological features of academic life influence course planning and classroom instruction. Although this model details specific features of instructional decision making, it has not been empirically tested beyond survey validation studies. Consequently, the precise relationships among components of the model have not yet been explored. As Stark explained, "Our work fell short of exploring in depth the actual decisions teachers make about course plans and curriculum, and only used information about how teachers prefer to arrange content and monitor student progress" (p. 435).

A promising line of inquiry that addresses this gap in the literature focuses on the sense-making processes whereby faculty negotiate the complex social and organizational features of academic institutions while making instructional decisions. A sense-making perspective highlights how, when faced with a task or problem, organizational actors extract or notice cues from their environment that are then compared to existing interpretive frameworks or schema in order to identify appropriate solutions or responses (Coburn, 2001; Weick, 1995). Over time, perceptions of how the environment either constrains or affords particular tasks can themselves become internalized as cognitive schema (Greeno, 1998). Of particular salience to the present study, Henderson and Dancy (2007) found that physics faculty teaching introductory courses reported that certain "situational constraints," including student attitudes toward school, lack of time, and departmental norms, kept them from adopting new approaches to course design and classroom instruction. As researchers continue to articulate the specific factors that faculty perceive as constraining and affording their teaching practices and how they shape curricular decision making (Hora, 2012; Lattuca & Stark, 2009), the field of higher education is developing new insights into how cognitive, cultural, and contextual factors shape how faculty plan their courses.

Classroom Instruction

An abundant literature also exists on classroom instruction at the postsecondary level, with many scholars focusing on topics such as student assessment, the use of specific teaching strategies, and discipline-based approaches, to name but a few (see Menges & Austin, 2001, for a review). However, relatively little is known about the instructional behaviors that faculty actually exhibit in the classroom, particularly in the math and science disciplines. Contributing to this situation is the dominant view of teaching as being composed primarily of the pedagogical methods or techniques used by the faculty member during instruction. For example, researchers have focused on specific teaching methods such as lecturing (Dancy & Henderson, 2010; Deslauriers, Schelew, & Wieman, 2011) or designed curricula or techniques such as Peer Instruction (Mazur, 1997).

This view of teaching is partially an artifact of the instruments researchers commonly use to study faculty teaching. Although a variety of measures exist for studying teaching, including self-report data, student ratings, peer ratings, videotapes of classroom practice, observations, and student outcomes (Berk, 2005), the study of faculty teaching is frequently conducted using questionnaires of self-reported practice that necessarily must reduce teaching behaviors to individual items. For example, the widely used national surveys of faculty such as the Higher Education Research Institute Faculty Survey (e.g., DeAngelo, Hurtado, Pryor, Kelly, & Santos, 2009) and the Faculty Survey of Student Engagement (Indiana University, 2010) conceptualize and measure teaching as a collection of discrete methods used by faculty. In the case of the Faculty Survey of Student Engagement, teaching practice is operationalized as the percentage of class time allocated to particular methods.

Although these accounts of teaching have provided some important insights into the different types of teaching methods used by faculty, this perspective necessarily results in one-dimensional accounts of teaching that are limited in three important ways. First, self-reported data elicited in surveys have been critiqued on various grounds, including their limited internal and ecological validity (Desimone, Smith, & Frisvold, 2009; Mayer, 1999) and the fact that self-reported data capture *espoused theories* but not the *theories in use* that are actually enacted in the classroom (Argyris & Schön, 1974; Kane, Sandretto, & Heath, 2002). Second, the technique commonly called “lecture” is particularly subject to this reductionist approach, as what is generally meant by the term—a discourse given before an audience—actually masks a myriad of specific pedagogical behaviors such as distinct rhetorical strategies and the use of different instructional technologies (e.g., Hativa, 1995). Furthermore, the lecture method is often assumed by researchers to be less pedagogically effective than other techniques, yet as Saroyan and Snell (1997) argued, "A lecture can be as effective as any other instructional strategy so long as it is appropriately suited to the intended learning outcomes and is pedagogically planned and delivered" (p. 102). Third, a significant amount of research has demonstrated that teaching is a multidimensional practice that encompasses behaviors beyond the use of particular teaching methods, such as instructor enthusiasm, clarity, preparation, and organization, each of which have been empirically demonstrated to be components of instruction linked to student learning (Feldman, 1989; Murray, 1983; Perry, 1997).[3] Without taking the multiplicity of instructional behaviors into account as they occur in specific, observable situations, it is difficult to obtain robust and multidimensional portrayals of faculty teaching.

An alternative to self-reports obtained through surveys is firsthand observations of classroom practice, and many researchers in both K–12 and postsecondary settings advocate for the use of observations for purposes as varied as teacher evaluation, self-assessment, and empirical research (Murray, 2007; Pianta & Hamre, 2009). Observation instruments used in postsecondary classrooms include the Teachers Behavior Inventory, which requires analysts to rate instructors on 124 items after the conclusion of an observed class (Murray, 1983). Another widely used instrument is the Reformed Teaching Observation Protocol, which aims to capture the degree to which instructors are using "reformed" teaching practices (MacIssac & Falconer, 2002). Because the Reformed Teaching Observation Protocol is based on underlying scales of instructional practice (e.g., classroom culture) and a priori determinations of instructional quality, however, the resulting data do not provide descriptive accounts of teaching but instead prejudge which practices are effective and which are not. Given findings that research-based techniques can be implemented poorly and traditional lectures delivered in a pedagogically rich manner (Saroyan & Snell, 1997; Turpen & Finkelstein, 2009), such judgments call into question the validity of instruments that determine instructional quality prior to actually observing an instructor's practice. Despite these limitations, observation-based approaches represent an advance in the empirical analysis of postsecondary instruction, as they typically capture multiple dimensions of practice as opposed to focusing solely on the self-reported use of particular teaching methods.

[3]This body of research provides perhaps the most robust and detailed descriptive accounts of classroom instruction at the postsecondary level.

TOWARD A DISTRIBUTED ACCOUNT OF TEACHING: INSTRUCTIONAL SYSTEMS OF PRACTICE

Obtaining robust accounts of faculty practice requires not only improved instruments but also conceptual frameworks with which to frame, interpret, and analyze the resulting data. We suggest that an analysis of faculty teaching should be based on the premise that practice itself is best viewed as situated in and distributed among features of particular settings. Indeed, a view of teaching as solely overt teaching behaviors is based on the principle that teaching is reducible to a decontextualized, single behavior of an individual—the lone hero premise of organizational practice that ignores critical features of the sociostructural underpinnings of work (Spillane, 2006). Instead, faculty operate in relation to the sociocultural and structural contexts of their departments and institutions, as they are "embedded in an organizational matrix" of influences, including their discipline, profession, and institution, and so the broader milieu of practice should be taken into account when one is examining faculty teaching practices (Umbach, 2007, p. 263).

Research on school leadership from a distributed perspective provides a way to conceptualize educational practice that accounts for both individual agency and the context of activity. According to this perspective, educational practice is best viewed as "distributed in the interactive web of actors, artifacts, and the situation" (Spillane et al., 2001, p. 23). Therefore, the appropriate unit of analysis for behavior is not the individual but the larger activity system that encompasses individuals, artifacts, and tasks in an integrated whole (Cole, 1996; Engeström, 1996). Thus, in order to adequately understand how faculty plan and teach their courses, it is necessary to consider how they interact with artifacts and other people within specific contexts of activity (Lave, 1988). It is important to note that artifacts[4] are not solely material objects or tools but also encompass entities such as social structures, policies, and classroom procedures. Faculty will draw on these resources while negotiating their organizational environments and performing tasks, such that no activity is truly autonomous (Wertsch, 1991). In addition, over time, groups will develop habits and normative expectations for particular activities, especially in the academic disciplines, in which a highly refined process exists for socializing students into the professions.[5] Building on these ideas,

[4]This use of the term *artifact* is preferred to *tools* because it draws attention to the role of designers in fashioning key elements of the world in which people work and live. In contrast, *tools* refers to found as well as designed objects that are navigated in the course of daily life. The emphasis on design is useful in highlighting both the created aspects of educational organizations and the potential for leaders or faculty to themselves create the conditions for task performance (R. Halverson, personal communication, July 24, 2011).

[5]In a conceptual analysis of the role of cultural tools in interdisciplinary work, Lattuca (2005) emphasized the well-known fact that each academic discipline has its own set of cultural tools, such as foundational concepts, disciplinary jargon, research methodologies, and teaching practices (see also

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 the study of two aspects of faculty practice: how systems inform and constrain course planning, and how they actually constitute classroom instruction.

In regard to course planning, local configurations of artifacts provide instructors with a finite set of options as regards tasks such as creating syllabi, selecting instructional technologies, or coordinating with other course components (e.g., lab or discussion sections). As actors interact with the designed features of their environments, their actions are necessarily mediated and transformed by the nature of local networks of artifacts (Wertsch, 1991). However, the process of mediation is not a passive one, as individuals will notice certain features of artifacts based on their personal experiences and social norms while also perceiving the properties of artifacts as affording particular uses (Gibson, 1979; Norman, 1988). Here the focus is on the interactions between individuals and the artifacts that make up their local task environments and how perceptions of these artifacts afford or constrain certain behaviors.

Classroom instruction can also be viewed in terms of participation in local networks or systems, which necessitates an account that moves beyond solely capturing the methods that teachers use in the classroom (Barab, Barnett, Yamagata-Lynch, Squire, & Keating, 2002; Halverson & Clifford, 2006). Instead, teaching itself is seen as a multifaceted practice that encompasses the teacher, students, and features of the instructional task (Cohen & Ball, 1999). Thus, classroom instruction includes not only the use of specific *teaching methods* by faculty (e.g., lecture, small-group discussion) but also the types of *cognitive engagement* that students experience in class and the use of *instructional technology* (e.g., clicker response systems, chalkboards).[6,7] Each of these categories represents the core actors (i.e., teachers and students) and artifacts that make up instructional systems of practice within the classroom.

The configurations that form through the collective use of these teaching methods, cognitive engagements, and technologies represent repertoires of practice for individual instructors, departments, disciplines, and even institutions (Gutierrez &

Becher & Trowler, 2001; Bourdieu, 1990). When faculty from other disciplines borrow these tools, a process of transformation occurs as the disciplinary assumptions and practices of the new users necessarily alter how the tool is used. This process is particularly salient for pedagogical change in math and science, as faculty must appropriate some cultural tools from education research or the learning sciences, which results in the tool undergoing a certain degree of reinterpretation and quite possibly being used in new and unforeseen ways.

[6]This conceptualization is specific to our target sample for the study reported here, which consists primarily of large undergraduate courses in science and mathematics at three research universities. Other teaching contexts (e.g., a high school math course) will likely include different activities.

[7]We use the terms *chalkboard* and *blackboard* interchangeably in reference to the writing surface on walls at the front of classrooms, and not the learning software or its parent company.

Rogoff, 2003). In the analysis here we focus specifically on these configurations at the disciplinary level, as disciplines play a considerable role in shaping faculty identities, institutional structures, and approaches to teaching and learning. These configurations can be empirically discerned through techniques from social network analysis, which are increasingly being used to study complex interactions and affiliations in educational contexts (see, e.g., Daly, 2010; Shaffer et al., 2009; Zhang, Scardamalia, Reeve, & Messina, 2009). Given the relational assumptions of systems-of-practice theory, we argue that social network analysis is well suited to capturing the systemic nature of instructional practice.

METHODS

In this analysis we adopt a qualitative case study design, as it allows for an in-depth analysis of practice and the subtle processes by which individuals make decisions (Yin, 2008). The case focuses on 57 math and science instructors at three large research universities who taught undergraduate courses in the spring of 2010. Given our interests in both undergraduate education and pedagogical reform in math and science, we focused our attention on public research institutions with large undergraduate populations and active pedagogical reform initiatives under way at the time of the study. In combining the sites we are making the assumption that these faculty (and their disciplinary affiliates) operate in relatively homogenous environments. We recognize the limitation in this assumption. However, we selected the sites specifically because they share the following characteristics: They are (a) public research-intensive institutions as defined by the Carnegie Foundation for the Advancement of Teaching (2007); (b) institutions with undergraduate enrollments of similar size based on figures from Fall 2006; and (c) institutions with similar 4-year averages of National Science Foundation Division of Undergraduate Education funding, which suggests a high level of pedagogical reform activities at a given institution. Based on these criteria, we selected Institution A located on the West Coast, Institution B located in the Mountain West, and Institution C located in the Midwest. Although there are certainly additional differences that are meaningful, we do not believe that they are vital because we are not attempting to explain variance in the statistical sense. Rather, our goal is to understand the interrelationships among the different dimensions of practice, which does not necessarily require the homogeneity of sample units.

A variety of pedagogical reform initiatives were active during the time of data collection. At Institution A both the physics and biology departments had external support for faculty development and curricular reforms, and a campus-wide teaching and learning center offered workshops for students and faculty. At Institution B a major cross-disciplinary effort based out of the physics department involving curricular reform and targeted technical assistance was active, in addition to other campus-wide and departmental efforts. At Institution C a cross-disciplinary initiative focused on doctoral education provided workshops to students and faculty, along with other efforts, including a center focused on biology education. Finally, at each institution cross-disciplinary initiatives engaged faculty from mathematics, chemistry, and geology.

Sampling Procedures

The sampling frame for this study included 263 individuals listed in the Spring 2010 timetable as the instructor of record for undergraduate courses in the math, physics, chemistry, biology, and geology departments across the three institutions. The course component of interest for this study was the classroom component (i.e., the lecture) instead of discussion, laboratory, or tutorial sessions.[8] Because actual departments at each institution were named differently, these disciplinary groups were matched to the appropriate departments (e.g., zoology was placed in the biology category). Individuals were contacted up to two times via e-mail for participation in the study, and 137 (52%) faculty responded to these initial contacts. A smaller number of faculty had schedules that allowed for participation in the study and were actually teaching undergraduate courses that semester or quarter, resulting in a final study sample of 57 faculty (22% of the initial sampling frame).[9] Response rates were similar across institutions and disciplines. Given the self-selected nature of the sample, and the chance that respondents were limited to individuals with interest in teaching and learning issues, we collected information about prior participation in teaching programs in addition to other demographic information (see Table 1).

Data Collection

The evidence collected in this study included classroom observations and interviews with each respondent. A team of three researchers (i.e., the two authors and a graduate project assistant) conducted all data collection activities. One researcher observed two class periods of each participant, with interviews taking place immediately prior to or after an observed class.[10] The researchers varied

[8]Future research examining instructional systems of practice should take into account faculty activities in each of these separate venues and how, if at all, coordination among different course components influences planning and teaching.

[9]Although 57 faculty participated in this study, one respondent declined to be recorded. Thus, the study sample for the observation component of the study was 57, whereas the study sample for the interview component was 56.

[10]On a few occasions instructors were not immediately available before or after the class period. In those cases, we conducted the interviews as close to the observations as possible. All interviews were conducted within 2 days of the observations.

TABLE 1
Description of the Sample

Characteristic	*n*	%
Sex		
Female	22	39
Male	35	61
Discipline		
Math	18	32
Physics	11	19
Chemistry	9	16
Biology	11	19
Earth/space science	8	14
Level of course		
Lower division	39	68
Upper division	18	32
Size of course		
50 students or fewer	10	18
51–100 students	18	31
101–150 students	9	16
151 students or more	20	35
Participation in teaching program		
Yes	28	49
No	29	51
Position type		
Lecturer/instructor (non–tenure track)	29	51
Assistant professor	6	11
Associate professor	4	7
Professor	18	31

in their academic backgrounds (i.e., one was a social psychologist, one an educational sociologist, and one a cultural anthropologist) and prior coursework in math and science. The use of a semistructured protocol ensured that all researchers asked the same general questions during the interviews.

Observations. Given our interests in capturing dynamic features of instructional systems of practice, we required an instrument that would measure how actors (i.e., teachers and students) and artifacts interacted in real time. Although available observation protocols were limited by the use of preexisting scales that were not salient to our study or a prevalence of open-ended response items that would not allow for comparisons across observations, an instrument designed to study inquiry-based science instruction in middle schools did represent a viable starting point for the construction of a systems-of-practice-based protocol (see Osthoff, Clune, Ferrare, Kretchmar, & White, 2009). The core features of this instrument included four categories (teaching methods, student engagement, cognitive demand, and inquiry feature), with several codes describing specific instances of each category. The instrument allowed the researcher to circle a code when it was observed during the lesson at 5-min intervals, thereby resulting in a rich and temporally organized data set.

We adapted the substance of this instrument to develop the TDOP (see the Appendix).[11] The original protocol was changed by reducing the number of categories to include only teaching methods and cognitive demand, which would capture both faculty pedagogical behaviors and teacher–student interactions, and adding a category for instructional technology. We also included a section for open-ended notes to be taken about the specific activities taking place in the classroom. Several of the specific codes used in the original instrument suited more for a middle school classroom (e.g., reading work) were eliminated, whereas others relevant to a university setting (e.g., clicker response systems) were added. To identify the most appropriate codes for the entire instrument, as well as to ensure content validity, we informally surveyed education researchers active in math and science education and math and science faculty to review a proposed list of codes for each of the three categories in the fall of 2009. This group of faculty also confirmed that the list of codes included in the instrument was consistent with their own understanding of their teaching practice, thus providing face validity for the TDOP.

Prior to data collection the researchers participated in an extensive 3-day training process. During these sessions researchers verbalized their understanding of each code and then deliberated to reach mutual understanding. In order to test this mutual understanding and establish interrater reliability, the analysts coded three videotaped undergraduate classes (two in chemistry and one in mathematics). The results of the interrater reliability using Cohen's kappa are shown in Table 2.

The interrater reliability fluctuated according to the dimension of practice being observed. For this reason we provide the kappa scores in disaggregated form. Note that cognitive engagement had the lowest kappa scores overall, further suggesting

TABLE 2
Interrater Reliability Results From the Teaching Dimensions Observation Protocol Training

Raters	*Teaching Methods*	*Cognitive Engagement*	*Instructional Technology*
Analyst 1/Analyst 2	0.707	0.625	0.655
Analyst 1/Analyst 3	0.745	0.659	0.781
Analyst 2/Analyst 3	0.732	0.578	0.728

[11]The version of the TDOP included in the Appendix has been revised to include new dimensions of practice (e.g., pedagogical strategies such as organizational skills) and new codes for existing dimensions.

the highly inferential nature of assessing this dimension of practice. One possible explanation for the low reliability on the cognitive engagement dimension could be that the research team did not have disciplinary training in the observed classes. In an effort to increase reliability with this dimension, we conducted additional training prior to the data collection phase, though no data are available to assess the effectiveness of this additional training.

We describe each category and examples of the specific codes contained in the TDOP in greater detail next.

Teaching methods. The teaching methods category refers to overt and observable pedagogical techniques. The observed teaching techniques include both specific teaching methods and types of question-posing strategies. For examples of each code see Table 3.

Although these codes provide a fine-grained description of faculty members' classroom behaviors, they remain a relatively blunt measure of instruction. That is, each of these codes represents a middle range of specificity in regard to a particular pedagogical technique, such that many codes could be further broken down

TABLE 3
Teaching Dimensions Observation Protocol Codes for Teaching Methods

Teaching Methods	*Example*
Lecture (LEC)	Instructor verbally presents facts or concepts.
Illustration (IL)	Instructor uses a story or anecdote to describe a fact or concept.
Demonstration (DEM)	Instructor uses a physical demonstration of a phenomenon using experimental or other equipment.
Worked out problems (WP)	Instructor engages in the active solving of a numerical problem.
Small-group work (SGW)	Instructor directs students to work in pairs or small groups.
Desk work (DW)	Instructor directs students to work alone at their desks.
Case study (CS)	Instructor presents a case for detailed elaboration and analysis.
Online techniques (OT)	Instructor actively draws on the course website.
Rhetorical question (RQ)	Instructor poses a question as a figure of speech for illustrative or persuasive reasons.
Display conceptual questions (DCQ)*	Instructor poses a question to obtain information about student comprehension about concepts.
Display algorithmic questions (DAQ)*	Instructor poses a question to obtain information about student comprehension about algorithms or computations.
Comprehension question (CQ)	Instructor poses a question to assess students' generalized understanding of a previous topic.
Novel question (NQ)	Instructor poses a question to which he or she does not know the answer.
Whole-class discussion (CD)	Instructor and students engage in back-and-forth discussion.

*These types of questions are frequently posed using clicker response systems. As a result, each of these questions is also coded in conjunction with clickers (i.e., DCQ-CL and DAQ-CL).

into more nuanced subcodes. For example, working out problems or computations (WP) here simply refers to whether the faculty member is actively solving a numerical problem in front of the class, a measure that necessarily obscures subtleties of problem solving, such as specific types of problem-solving procedures. However, these details can be captured in analyst note taking if this level of nuance is desired.

Cognitive engagement. The cognitive engagement category refers to the types of cognitive activity that students *potentially* experience in the classroom. This category is based on research demonstrating that the type and degree of student cognitive engagement in the classroom is a key feature of learning (Blank, Porter, & Smithson, 2001; Blumenfeld, Kempler, & Krajcik, 2006; Porter, 2002). Measuring cognitive engagement is inherently difficult, and strategies include inferring student engagement from observations of student–teacher interactions or of student task performance (Fredricks, Blumenfeld, & Paris, 2004). For example, Nystrand and Gamoran (1991) distinguished between substantive (i.e., sustained and deep engagement with material) and procedural (i.e., compliance with classroom rules) types of cognitive engagement, which were inferred from the type and quality of classroom discourse. Despite challenges associated with inferring student cognitive engagement, we felt this was an important dimension of instructional practice to attempt to capture. To develop these codes, we adapted the category of cognitive demand from the Osthoff et al. (2009) instrument to fit the undergraduate classroom. For examples of each code see Table 4.

Because this category is what Murray (2007) would have called "high inference," this category received significant attention during the instrument training phase to ensure that all analysts coded cognitive engagement in a similar fashion. Toward this end, we developed coding rules that could be followed during data collection. For example, the "connecting to the real world" code was only applied

TABLE 4
Teaching Dimensions Observation Protocol Codes for Cognitive Engagement

Cognitive Engagement	*Example*
Receive/memorize information (RM)	Students hear facts and information with expectations only that they will internalize and recall information.
Understanding problem solving (PS)	Students follow solution paths or other analytic processes.
Creating ideas (CR)	Students engage in brainstorming activity at their desks and report back to the class with their ideas.
Integrating ideas (IN)	Students actively reflect on prior knowledge and its relationship to new information.
Connecting to the real world (CN)	Students relate course material to common experiences or aspects of their daily lives.

when the instructor linked the course material to events, places, objects or persons associated with popular culture or the state or city where the institution was located through anecdotes or extended illustrations. Another example involves the problem-solving category, which was applied in cases when instructors verbally directed students to participate in a computation or other problem-solving activity, usually at their own desks or in small groups.

Instructional technology. Finally, the technology dimension refers to instructional materials or technologies used by the instructor (see Table 5). As the observations are necessarily limited to what is directly observable in the classroom, many critical artifacts related to instructional decision making and classroom practice, such as the course syllabus, textbooks, departmental policies governing teaching, and so on, are not captured by the TDOP. This point applies particularly to the role of textbooks, as it is not possible to discern whether an instructor is following the book's organization or using text-based problems in class based solely on an observation. Instead, textbook use was only coded when the instructor explicitly referred to or physically picked up and used a book during the class, which likely underestimates this pedagogical resource.[12]

TABLE 5
Teaching Dimensions Observation Protocol Codes for Instructional Technology

Instructional Technology	*Example*
Demonstration equipment (D)	A ball suspended from the ceiling, or laboratory equipment such as beakers.
Laptop and slides (LC)	A laptop computer connected to a digital projector that displays slides on a screen.
Posters (PO)	Posters on the wall, such as the Periodic Table.
Book (B)	A textbook or other book physically used by the faculty member.
Pointers (P)	Laser pointers used to shine a focused light on a screen.
Clicker response systems (CL)	Handheld devices with which students indicate answers to multiple-choice questions projected onto a screen.
Overhead projector (OP)	A projector that displays images or writing on transparent sheets of plastic.
Digital tablet (T)	A computer that displays images or writing directly onto a screen.
Blackboard/whiteboard (BB)	A blackboard or whiteboard (i.e., dry-erase board) hung on walls at the front of a classroom.
Miscellaneous object (OB)	A miscellaneous instructional artifact not captured by other codes.

[12]Given the limitations of observation-based data in discerning pedagogical intentions or instructional decision making that may be informing classroom behaviors, it is especially important to pair observations with interviews with instructors. This is particularly important in regard to the role

The technology codes included in the TDOP were identified first by a review of the disciplinary literature in math and physics and then through a pilot study in the fall of 2009, and the actual materials and technologies used by respondents were included in the final instrument. The instructional technology category is limited to those materials or technologies used by teachers alone, such that any student-based technology (e.g., a laptop used for taking notes) is not recorded. The only exception is clicker response systems, which typically involve instructors generating and posing questions while students answer them using a handheld device.

Interviews. We also conducted semistructured interviews, which took approximately 30–45 min to conduct (but often extended up to an hour or more). The interview was 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. The interview protocol consisted of 17 open-ended questions and a series of probes that focused on eliciting the underlying features of instructional decision making. Thus, although each respondent was asked all of the questions in the protocol, the length and depth of answers varied considerably.

The key questions in the interview salient to course planning included "How much leeway do you have in determining how the course is taught?" "What goals do you have for students in your course?" and "What specific teaching techniques are you planning to use in your next class, and why?" In addition, an open-ended introductory question that started the interview ("Can you tell me about the course I'll be observing?"), or what Spradley (1979) called a "grand tour" question, also elicited important information about course planning. The instructors were interviewed in their offices or conference rooms. These interviews were audiotaped and later transcribed for further analysis.

Data Analysis

The analytic techniques used for this study include social network analysis for the classroom observation data and thematic and causal network analysis for the interview data.

Social Network Analysis of Observation Data. We used techniques from social network analysis to analyze the observation data, as this type of analysis is well suited to capturing configurations within and between dimensions of practice—which is at the heart of systems-of-practice theory. The raw data for this

of artifacts in systems of practice, as task analysis on its own will not illuminate all of the artifacts (and their features) that inform practice.

TABLE 6
Example of Initial Two-Mode Matrix Showing Instructor Interval (Mode 1) by Instructional Code (Mode 2)

Instructor	*5-min Interval*	*Code 1*	*Code 2*	*Code 3*	*Code 4*	*Code 5*	*Code 6*	*Code 7*
1	1	1	0	0	1	0	0	1
1	2	0	1	0	1	0	0	1
1	3	1	0	1	0	1	0	0
1	4	0	0	0	0	1	1	1
1	5	1	0	1	1	0	0	0

analysis were in the form of a two-mode (or "affiliation") matrix that consisted of instructors' 5-min intervals as rows (Mode 1) and TDOP codes as columns (Mode 2).[13] As Table 6 illustrates, a 1 denoted that the particular TDOP code was present in the interval, and a 0 denoted that the code was not present in that interval.

Using UCINET (Borgatti, Everett, & Freeman, 2002), we transformed the two-mode data matrix into a one-mode (code-by-code) matrix through matrix multiplication. This transformation results in a valued co-occurrence matrix in which each cell corresponded to the number of intervals for which TDOP code *i* was affiliated with code *j*. For example, the intersection of Code 1 (e.g., small-group work) and Code 3 (e.g., problem solving) could have a value of 3, which means these two dimensions of instruction were co-coded in three 5-min intervals across all instructors in the matrix. Next, the program Netdraw (Borgatti, 2002) was used to graph the co-occurrences between each pair of codes across all instructor intervals. The lines connecting the codes denoted a co-occurrence (i.e., codes that were co-coded in the same interval), and the line thickness indicated the relative strength of the co-occurrence (i.e., the number of intervals in which each pair co-occurred relative to the total number of intervals). Thus, thicker lines corresponded to stronger co-occurrences, which could be interpreted as more frequently co-coded in the same 5-min interval (than those lines that were thinner).

Configurations of co-occurring codes within each graph were used to identify *repertoires of practice*. In this article we focus on repertoires of practice at the disciplinary level. That is, we constructed code-by-code co-occurrence (or affiliation) graphs in order to identify the TDOP codes that most frequently co-occurred (i.e., were coded in the same 5-min interval) in each discipline. Within the systems-of-practice framework, capturing the co-occurrence of teaching methods, cognitive engagement, and instructional technology provides a direct measure of the configurations within and between the different dimensions of the activity system.

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

Next we used the concept of graph density (Δ) to measure the breadth of each discipline's repertoire. The density describes the proportion of ties in a graph relative to all possible ties. In the context of this study, the density refers to the proportion of co-occurrences between TDOP codes relative to all possible co-occurrences. Thus, in calculating the density we temporarily ignore the strength of the co-occurrences by dichotomizing the matrix. In this case a 1 indicates that code i and j appear in the same 5-min interval at least once, and a 0 indicates that the codes never co-occur. The density of a graph can be calculated as follows:

$$\Delta = \frac{L}{g(g-1)/2} = \frac{2L}{g(g-1),} \tag{1}$$

where L is the total number of lines (or 1's in the matrix) and g refers to the total number of nodes (i.e., TDOP codes). The result is a value ranging from 0 (if there are no lines present in the graph [$L = 0$]) up to 1, in which all possible lines are present ($L = g(g-1)/2$; see Wasserman & Faust, 1994). In graph-theoretic terms, a 0 corresponds to a null (or empty) graph and a 1 corresponds to a complete graph.

Finally, using the raw (two-mode) data set 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–laptop/slides" was observed in 50.7% of the 5-min 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 laptop/slides (e.g., PowerPoint) in the same 5-min interval. We report some of the most common triads for each discipline in order to provide snapshots of how the three dimensions of instruction co-occurred within each disciplinary repertoire of practice. In addition, we report those triads that were observed less frequently overall but were nonetheless distinctive of a particular group's graph. For example, the "small-group work–problem solving–laptop/slides" triad was only observed in 7.1% of biologists' intervals, but this exceeded all of the other disciplines.

Thematic and Causal Network Analysis of Interview Data. All interviews were transcribed and entered into NVivo qualitative analysis software. The first step in the analysis involved two analysts (i.e., the first author and a graduate project assistant) developing a coding scheme in order to segment the data into manageable and thematically coherent units (Chi, 1997). The coding scheme was created using an inductive coding process in which codes were created based on an open-coding process in which terms, phrases, or ideas from the text were

TABLE 7
Major Code Categories in Final Coding Scheme

Code Category	*Examples of Specific Codes*
Organizational characteristics	Colleagues, personnel policies
Course characteristics	Syllabi, content, administration
Faculty characteristics	Status, personal experience
Student characteristics	Degree trajectory, engagement with course
Teaching practices	Assessments, question posing
Instructional goals	Conceptual understanding
Instructional technology	Clickers, blackboard
Pedagogical reform	Participation, critiques

used to name a new code. To develop the initial list of codes the analysts carefully reviewed five randomly selected transcripts and independently created a list of codes (e.g., course syllabus, clickers, lecturing). In developing the initial code list, the analysts compared each successive instance of the code to previous instances in order to confirm or alter the code and its definition (i.e., the constant comparative method; Glaser & Strauss, 1967). After creating the initial code list, the analysts met to discuss the coding scheme and then analyzed another five randomly selected transcripts. After two additional meetings to revise and refine the codes, a final coding scheme composed of 10 categories and 135 individual codes was developed (see Table 7).

The next step in the data segmentation process was to ascertain intercoder reliability, and as part of this process the analysts applied the coding scheme to five newly selected transcripts. The unit of analysis for this application of codes to the interview transcripts was an utterance, which we defined as a series of sentences or phrases pertaining to a specific subject (e.g., the course syllabus). It is important to note that the coding of utterances often included surrounding text with references to topics related to the primary code (e.g., how the course syllabus is designed). For example, the following passage was coded as "course syllabus," but it also includes references to other codes in the coding scheme (e.g., "curricular committees"):

> There's a pretty well defined syllabus for this course. There are particular topics that are absolutely required and those were come up with the Math Department consulting with these other departments that are sending students to take this class. (Mathematics faculty, Institution A, Lines 42–45)

In this case, the code "curricular committee" was also applied to the utterance. After the analysts applied the coding scheme to the five transcripts, interrater reliability was assessed by calculating the percentage of agreement between the analysts in applying the codes. The proportion of instances in which both analysts coded the same code relative to all coded instances was 89%. The analysts then applied the coding scheme to all 56 transcripts, which resulted in an extensive NVivo library of coded text.

The second step in the analysis involved the first author, who conducted a causal network analysis of all text that had been coded as "course syllabus." Causal network analysis is a structured approach for identifying relationships between concepts or events in a graphic and time-ordered fashion (Miles & Huberman, 1994) and is similar to the verbal analysis method of Chi (1997). For this analysis we decided to focus on the role of course syllabi in course planning, given the frequency with which this topic was referenced in the data. The data for this analysis were obtained by first running a report in NVivo for all utterances that had been coded as "course syllabus." Thus, a significant amount of data coded during the segmentation process was not used for this analysis. The text was then analyzed to identify relationships between course syllabi and planning activities, which were identified primarily through explicit statements about relationships between variables. For example, in the quote above the mathematician links the development of course syllabi with a process of consulting with faculty from other departments. In cases such as this, the associated codes were noted in a table of what Miles and Huberman (1994) called "causal fragments." This process of identifying causal fragments was repeated for all data coded as course syllabi, such that multiple instances of code–code relationships were used to indicate causality between two codes. The code pairs that were built from these different sources were ultimately put into a graphic display depicting relationships between codes.

It is important to note that the resulting displays represent the accounts of a relatively small number of respondents from our study and should not be extrapolated to entire departments or institutions within the study sample or viewed as definitive accounts of action and behavior within these administrative units. Despite these limitations, causal network analysis and related methods such as verbal analysis (Chi, 1997) are valuable techniques for identifying relationships between concepts and visually depicting them in a structured manner. Furthermore, in using this technique we adopt a position that discerning causal relationships is not the sole province of experimental methodologies and/or quantitative analyses of large datasets but that field-based research can provide illustrative accounts of what Miles and Huberman (1994, p. 132) called "local causality"—or the "actual events and processes that led to specific outcomes" (see also Maxwell, 2004).

RESULTS

We now present the findings pertaining to each research question in two sections. First, we describe the sense-making processes regarding course planning in regard to a single curricular artifact—the course syllabus. Second, we report different dimensions of teaching practices used by instructors and the repertoires of practice for different disciplinary groups.

Examining Course Planning: How Faculty Perceive Affordances Related to the Syllabus

A core feature of systems-of-practice theory is the agency of individual actors as they actively negotiate the local configuration of artifacts within their environment, noticing certain features of artifacts and making decisions accordingly (Halverson, 2003).[14] Data related to this point were most often provided in response to the questions "How much leeway do you have in shaping your course?" and "What instructional techniques do you plan to use in your class we're observing?" as well as follow-up probes focused on eliciting which factors influenced both course planning and classroom instruction. The most frequently reported artifacts directly related to these behaviors were course syllabi (n = 41, 73% respondents directly referencing the artifact), textbooks (37, 66%), and instructional technology (37, 66%). Additional artifacts reported by respondents that exerted a more distal influence on course planning and classroom instruction included personnel policies (37, 66%) and coordination with other instructors (29, 52%). For this article we focus on course syllabi given their prominence in the data and the direct role syllabi play in shaping the classes we subsequently observed.

Examining the Artifact: What Is a Course Syllabus and How Is It Created? Lowther, Stark, and Martens (1989) defined a *syllabus* as a "planning device to organize the course and to provide students with information about course content, the instructor's expectations, the method of instruction and evaluation, and the overall course rationale" (p. vi). A syllabus can also be viewed as a contract between the instructor and student that can be referred to throughout the duration of the course and that includes a list of required textbooks and legal language regarding accessibility, academic dishonesty, complaints, and so on (Altman, 1999). The central focus of this particular analysis is how the course syllabus demarcates the type and sequencing of content for a particular course and the origins of this influential artifact (see Figure 1).

The most commonly reported origin of course syllabi, particularly among faculty teaching lower division courses, was the curriculum committee (n = 30, 54% respondents).[15] As many of the courses taught by the faculty in our

[14] There is also a tacit or unconscious element to this process, as artifacts and the networks in which they are embedded embody particular values and behavioral expectations that are often not perceived as such by users (Greeno, 1998; Pea, 1993). However, we do not explore this aspect of the process in this article.

[15] Other respondents either did not discuss the origins of their syllabi or referenced other influences.

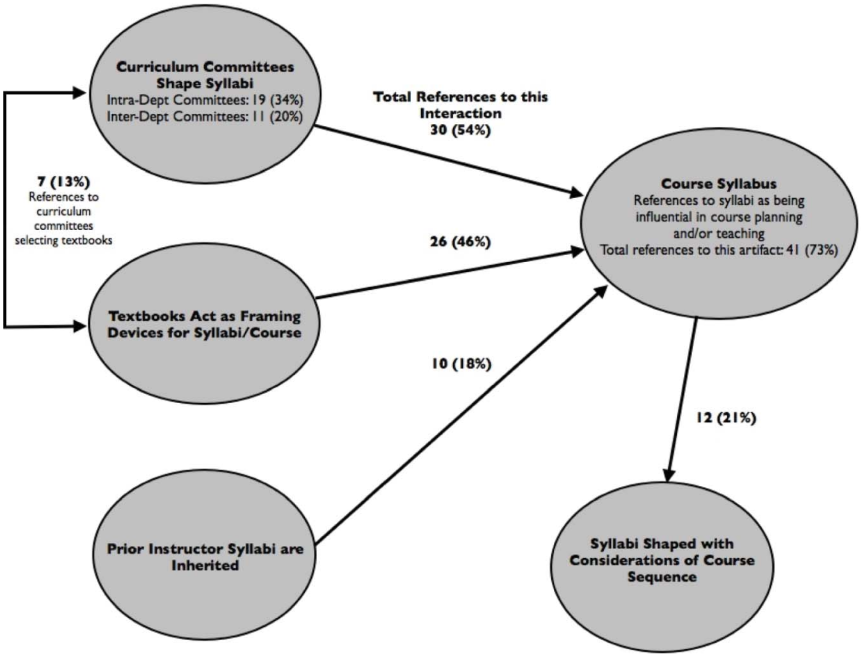

FIGURE 1 Causal network of factors related to syllabus design. The number of respondents and percentage of the total sample ($n = 56$) reporting each relationship are included in the figure. Intra-Dept = intradepartmental; Inter-Dept = interdepartmental.

sample were lower division courses that played key roles in degree programs, most departments had committees or a team of faculty who determined what content should be covered and in what order. In some cases, an internal departmental committee made curricular decisions (19, 34% respondents). In other cases, for courses that served large numbers of students from other colleges (e.g., calculus sequences), faculty from other departments or colleges often played a significant role in determining what content was included in the syllabus (11, 20% respondents). For example, 5 (9%) respondents reported that faculty from the College of Engineering participated in regular course redesign procedures in their departments (i.e., math and physics), and 2 (4%) respondents characterized this redesign process as a "negotiation" between departments, in which expectations about the requisite skills and knowledge for undergraduates are debated and departmental needs for degree requirements considered while shaping the course.

The result of these committee meetings is generally a list of topics that the committee feels are important for students to be taught and the sequence in which they should be presented. These committees also frequently select textbooks for the course, which was the case for 7 (13%) respondents. A larger number of respondents ($n = 26$, 46%) reported that the textbook itself is an artifact that strongly influences the structure of the course syllabus and that textbooks act as the primary point of departure for creating a syllabus, as some syllabi are designed in accordance with the chapters in a specific book. Thus, the textbook acts as another artifact that influences course planning, particularly through the features of content selection and sequencing. This highlights the nested or interconnected nature of artifacts and how they frequently operate in practice as parts of larger networks or configurations (Halverson, 2003).

Faculty also acquire course syllabi and other curricular materials by inheriting them from faculty who previously taught the course or from more senior faculty considered to be more experienced teachers ($n = 10$, 18% respondents). One respondent noted that upon being assigned the course, she simply went to the faculty member who had been teaching the course for years and said, "Look, you know what to do—show me your syllabus." Four (7%) respondents also noted that as new hires or junior faculty, they felt obliged to follow these inherited artifacts:

> The course has been around a long time. I inherited it from the [ex-department chair] so I have to follow his structure to some extent. That's the structure that was laid down with some wisdom and some consensus among the different departments. (Math faculty, Institution A, Lines 23–24)

Another respondent spoke about not having "the right" to change the structure of the course or assigned readings. This points to the resiliency of artifacts as cultural objects, and how newcomers to a group will respect them as embodiments of group wisdom and accumulated practice. It is also worth noting that by adopting preexisting curricular materials, faculty end up saving a substantial amount of time that otherwise would have been spent developing syllabi, preparing course materials (e.g., PowerPoint slides), and creating exams. At institutions like the research universities included in this study, where research activities (e.g., running a lab, writing manuscripts, acquiring external funding) generally take precedence over teaching, ready-made curricula are particularly attractive to some faculty.

Another frequently cited factor influencing the structure and content of course syllabi involves considerations of how course sequences build upon knowledge from prior courses ($n = 12$, 21% respondents). Given that many undergraduate sequences address foundational concepts for a discipline, there tends to be a canon that faculty expect students to be exposed to at the beginning stages of their postsecondary education. Thus, the nature of the sequence necessitates that particular topics be taught in a particular order—a decision that becomes instantiated in the syllabus. It is interesting that these course sequences have a built-in punitive mechanism that increases the likelihood that faculty teaching courses lower in the sequence will strictly adhere to the syllabus. Seven (13%) respondents noted that instructors in more advanced courses expected that incoming students would have a solid grasp of the foundational concepts in the field, and one respondent even observed that if these students lacked this foundation then “there would be trouble.”

How the Syllabus Influences Practice. Next we turn to an examination of how the syllabus influences classroom practice, with a focus on how faculty perceive certain features of artifacts as constraining or affording particular instructional behaviors. As previously noted, a key element of the interface between mind and environment entails individual perception of affordances (e.g., a piece of chalk is for writing), because this perception will then set the parameters for subsequent decision making (Pea, 1993). Thus, in our analysis we focus on how faculty perceived course syllabi as constraining or affording their teaching practice and how they ultimately negotiated the environment around them to make course decisions (see Figure 2).

The most frequently reported feature of syllabi perceived by respondents was how it demarcates a list of topics and the sequence in which they should be presented on a class-by-class basis. For 26 (46%) respondents, this feature effectively constrains their autonomy as instructors in terms of selecting the content featured in their course. For this group of faculty the syllabus acts as an organizing device

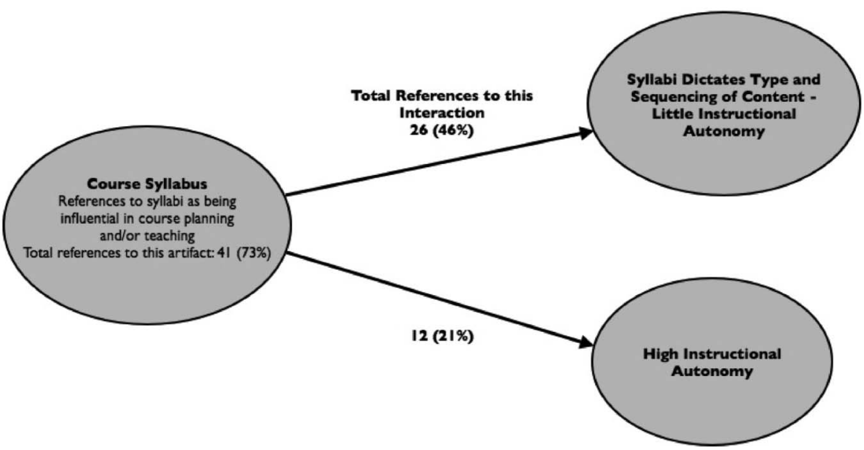

FIGURE 2 Causal network depicting how course syllabi mediate teaching practice. The number of respondents and percentage of the total sample ($n = 56$) reporting each relationship are included in the figure.

that determines what they will teach on a given day. As one biology faculty noted, "It's pretty much determined what I'll do every day—basically I'll follow the syllabus and that will fill up most days of the course." One of the factors that may be associated with this sentiment is the level of the course, as some respondents suggested that upper division courses allow faculty far more autonomy in selecting course content. Of the 26 faculty reporting limited autonomy, 17 were teaching lower division courses and 9 were teaching upper division courses at the time of data collection. In addition, 12 (21%) respondents reported complete autonomy in their course, 7 who were teaching lower division courses and 5 who were teaching upper division courses.

Two important caveats apply to the findings regarding constrained instructional autonomy. First, even within the restrictions of the tightly scheduled course, 13 (23%) respondents felt that the syllabus provided a certain degree of wiggle room such that once the prescribed topics were covered, they could design a few classes based on their own research interests. For example, a syllabus may demarcate class topics for 10 weeks of a 13-week semester, thus making the content for the first 10 weeks nonnegotiable, but for the final 3 there exists an opportunity for the instructor to be more creative. Second, 12 (21%) respondents observed that these restrictions apply to *what* is taught in the course but that *how* they teach is completely up to them:

> Everybody has the same syllabus. Everybody teaches the same section on the same day. Everybody assigns the same homework. We give the same tests. We're supposed to give the same lecture on the same day now. But, my lecture is way different from [another instructor], which is way different from somebody else's. So the way that I present the material might be a lot different form the material [instructor's name] will be presenting in her class. (Physics faculty, Institution B, Lines 204–208)

In another case, a faculty member had to teach about harmonic oscillators in the physics class observed as part of this study, and she noted that it was up to her to decide precisely how to treat the subject. For this individual, the decisions she had to make centered on how much detail to go into and how much mathematics to use when discussing the topic. Thus, although the content of a course was largely prescribed for 26 respondents, the actual teaching methods used in a given class appeared to be up to the individual.

However, features of the syllabus may represent affordances for particular types of instruction. In 4 (7%) cases, the syllabus specified learning goals for the course that were explicitly linked to course assessments and expectations about the type of instruction to be used in the course (i.e., interactive teaching methods). In other situations, the sheer amount of content included in the syllabus suggested to faculty that they had to teach in the most efficient manner possible, which for

4 (7%) respondents meant using traditional oral presentation (i.e., lecture).[16] Of course, examinations of the determinants of classroom instruction also need to consider factors such as faculty experience (i.e., as an instructor and researcher), departmental norms for teaching, and the role of instructional technology, to name but a few.

One of the more important antecedents to instruction identified in the postsecondary literature is instructional goals faculty have for a particular course (Angelo & Cross, 1993; Stark, 2000). Although we do not examine the role of goals in this article, it is important to consider the degree to which an artifact enables the instructor to enact his or her goals in the classroom. Indeed, goals play an important role in systems of practice, as the process of mediation entails the transformation of goal-directed activity as it interacts with artifacts in the organizational environment. For example, one chemist who taught a course mostly taken by premedical students had a goal of getting his students to "see the bigger picture" of how physics is related to health science, and consequently he strove to make his classes relevant to a future medical professional. Although the faculty member followed a predetermined syllabus and textbook, he felt a high degree of autonomy in how to teach his course, which was grounded in the sentiment that in his department there was little to no pressure regarding how to teach. In addition, because the course was the second in a yearlong sequence, the focus was less on grasping foundational concepts and more on application. As a result, instead of using the traditional oral presentation and board-work approach, he used small-group discussions and problem-based learning that drew on content-rich examples and anecdotes salient to medicine. In this case, although the syllabus specified the content of each class, the faculty member was able to realize his instructional goals because of the type of course and the nonrestrictive social milieu in which he operated.

Examining Classroom Instruction: Interactions Among Multiple Dimensions of Practice

Next we turn to an examination of classroom instruction. A systems-of-practice approach to classroom instruction seeks to identify the configurations of teaching methods, cognitive engagements, and instructional technologies that are enacted during a class period. In this section we report these configurations in the form of network affiliation graphs, which provide a representation of the repertoires of practice for each of the disciplines in this study. Although each individual faculty

[16]The volume of content included in a syllabus also may have implications for student learning, as one physicist noted that "the course is very difficult just because we're covering so much so fast." In his view, although the content itself was challenging to learn, it was the volume of content and the lack of time spent on each topic that represented the most difficult part of the course for students.

member has his or her own repertoire (i.e., his or her own configuration of teaching methods, cognitive engagements, and instructional technologies), the graphs presented in this section suggest that disciplines constitute an important context through which individual-level repertoires are constructed. The data presented in this section represent relationships between two or more codes and thus represent a central feature of instructional systems of practice (i.e., affiliations among system components).

Math Instructors. The graph[17] in Figure 3 reveals a repertoire of practice with a dense central core and a relatively limited set of teaching practices overall. The limited breadth of the mathematicians' repertoire is also detected in the relatively low density (Δ) of the dichotomous graph (0.335), which reveals that 33.5% of all possible co-occurrences between codes are present in this graph.[18] As a group, the mathematicians demonstrated a repertoire of practice that frequently

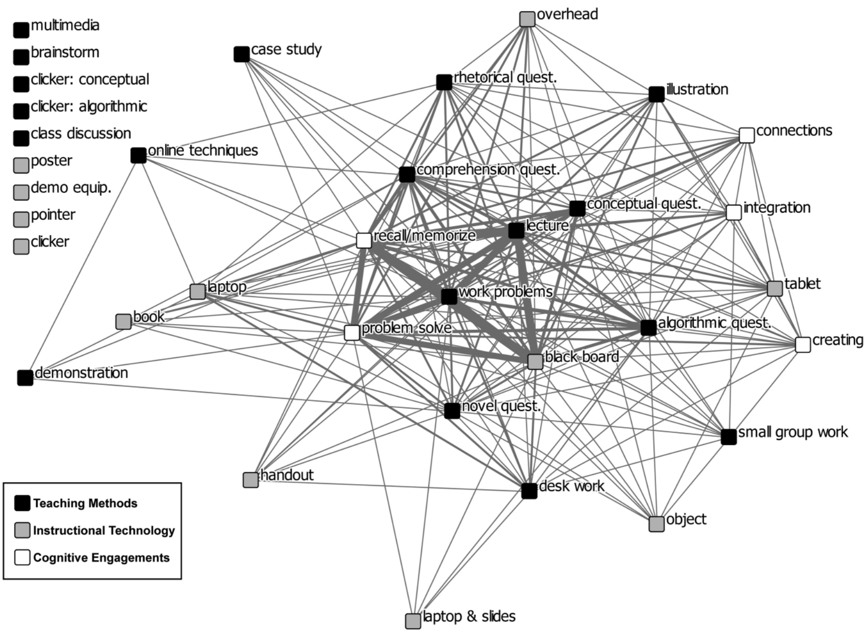

FIGURE 3 Co-occurrence network of observed codes for math instructors (381 intervals; $n = 18$). equip = equipment; quest. = question.

[17]Note that the codes arranged vertically along the upper left side of the graph are those that were not observed in any class and are thus disconnected from the graph.

[18]In practice it is not likely to be possible that a complete graph (density = 1.000) would be observed in this context, because some techniques cannot feasibly be used together.

required students to problem-solve and receive/memorize information by working out problems and lecturing at the chalkboard. For instance, at times an instructor simply would write an equation on the chalkboard, accompanied by a verbal description of the equation (lecture–memorize–chalkboard). At other times, however, the writing of equations was accompanied by computational questions posed to the students (lecture–problem solving–chalkboard) and example applications in which the instructor clearly guided students through the problem-solving process (working through problems–problem solving–chalkboard). These mathematicians used different combinations of teaching methods (working through problems and lecturing) and cognitive engagement (problem solving and memorization), but the technology medium (i.e., chalkboard) remained constant.

Selected triads further illustrate the different combinations of teaching methods, cognitive engagements, and instructional technologies within this activity system. More than half of all observed 5-min intervals included the "lecture–receive/memorize–chalkboard" triad (60%), and 39% included the "worked out problems–problem solving–chalkboard" triad. These core practices were supplemented with a range of question styles, including comprehension questions (21% of intervals), display conceptual questions (21%), and display algorithmic questions (24%).

Physics Instructors. The graph for physics instructors (see Figure 4) shows a very different picture, revealing a more diffuse central core than in the graph for math instructors. In addition, the breadth of the physicists' repertoire is greater than that of the mathematicians.[19] That is, the density (Δ) of the physicists' graph (0.538) reveals that 53.8% of the total possible co-occurrences between codes were observed. This means that the physicists, as a group, combined a greater number of teaching methods, cognitive engagements, and instructional technologies than the mathematicians. The physicists' repertoire frequently required students to problem-solve and make connections through the use of demonstrations and to receive/memorize information while lecturing at the chalkboard and using PowerPoint slides with pointers. The physicists' repertoire was also frequently supplemented with the use of clickers, multimedia, display conceptual questions, and illustrations. Thus, these physicists' repertoire delivered the course material through lecturing and demonstrations—supplemented by instructional technology—that were coupled with a wide range of cognitive engagements.

It is important to note that there is a difference between problem solving through demonstrations and problem solving through the application of equations at the chalkboard. Although the latter form of problem solving did

[19] In this context "greater" should not be equated with "better." We are not making any evaluative judgments here but rather are seeking to make comparative descriptions and raising hypotheses about the nature of the cross-disciplinary variations.

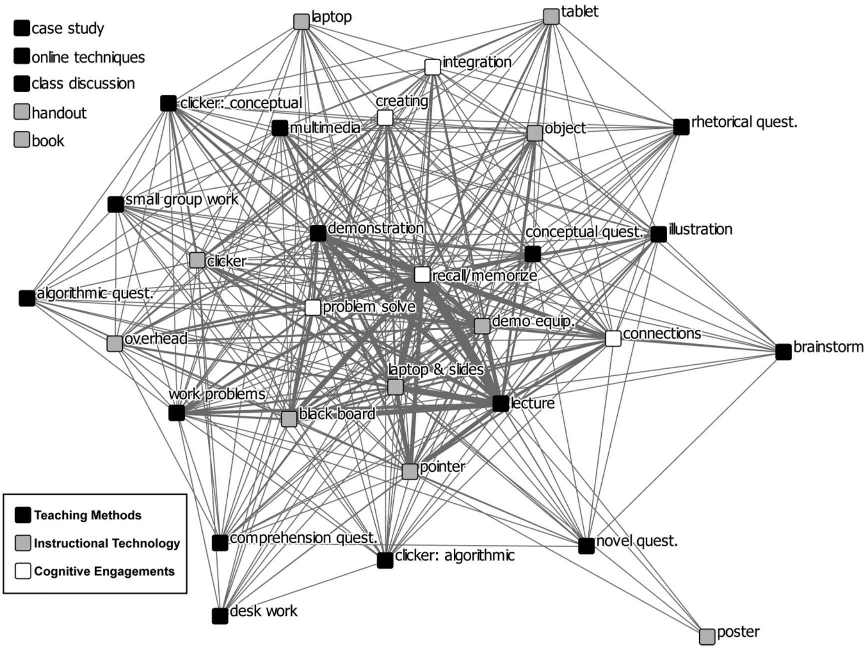

FIGURE 4 Co-occurrence network of observed codes for physics instructors (219 intervals; $n = 11$). equip = equipment; quest. = question.

occur (12% of intervals), problem solving with the use of demonstration equipment provides a physical experience of the subject matter that reduces the level of abstraction found in equations alone. Among the eight relatively common triads observed across all disciplinary groups, the physicists exhibited some frequency of each one. Although the "lecture–receive/memorize–laptop/slides" and "lecture–receive/memorize–chalkboard" triads were the most common affiliations (51% and 46%, respectively), three additional triads were observed in more than 10% of all observed intervals: "worked out problems–receive/memorize–chalkboard" (16%), "worked out problems–problem solving–chalkboard" (12%), and "demonstrations–receive/memorize–demonstration equipment" (28%).

Chemistry Instructors. The chemists' graph (see Figure 5) reveals a core set of practices surrounded by a set of secondary practices, which suggests a multilayered repertoire. This repertoire contains a core set of practices that is similar to the graph of the physics instructors in Figure 4, although the density (Δ) of the graph is less (0.415).

The repertoire among chemists required students to receive/memorize information as the instructor lectured, posed conceptual questions, and used a laptop

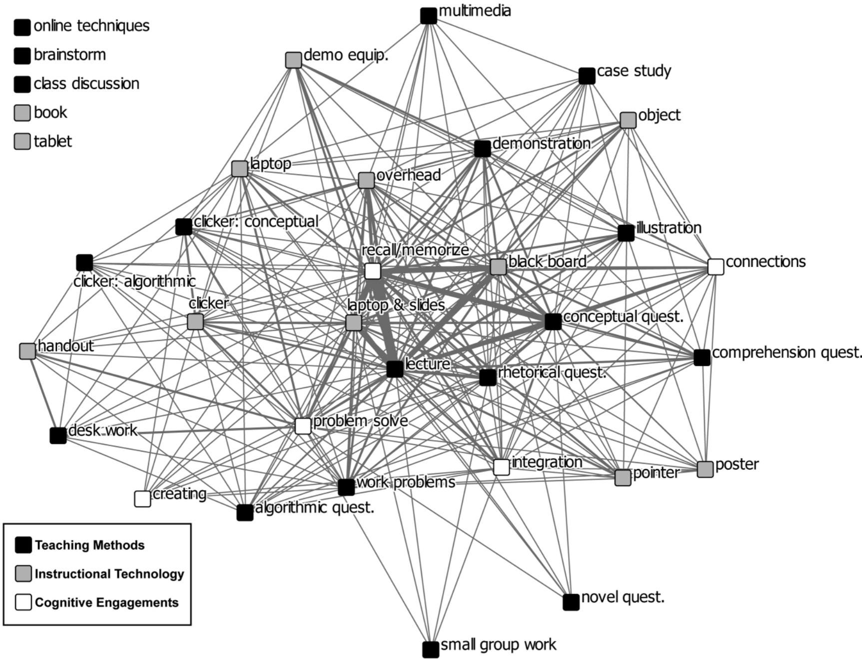

FIGURE 5 Co-occurrence network of observed codes for chemistry instructors (180 intervals; $n = 9$). equip = equipment; quest. = question.

computer or chalkboard. The core of this repertoire was supplemented by working out problems and asking students to engage in problem solving; posing comprehension questions; utilizing illustrations; and using instructional technology such as overheads, clickers, and demonstration equipment. Similar to the physicists, problem solving among these chemistry instructors involved both abstract formulas at the chalkboard as well as physical demonstrations using equipment (e.g., chemical experiments accompanied by problem-posing questions). At other times, however, equations or chemical bonds were presented at the chalkboard or through slides (PowerPoint or overhead projector), and no problem solving was required of the students (i.e., only memorization was required).

The most notable divergence, however, is the smaller number of observed triadic affiliations among the chemists relative to the physicists (though still more than among the mathematicians). In particular, chemists were less frequently observed using triads that involved small-group work and demonstrations. The most frequently observed triads were "lecture–receive/memorize–chalkboard" (40%), followed closely by "lecture–receive/memorize–laptop/slides" (36%).

The "worked out problems–receive/memorize–chalkboard" triad was observed in 10% of all intervals among chemistry instructors.

Biology Instructors. The biology instructors in our sample had a repertoire that frequently required students to receive/memorize facts, concepts, and procedures by lecturing with a laptop and slides (see Figure 6). The density (Δ) for the biologists' graph is 0.415, meaning that the proportion of all possible observed code co-occurrences is greater than mathematicians, identical to chemists, but less than physicists.

Unlike the mathematics, chemistry, and physics instructors observed, these biology instructors did not work out problems or present equations on the chalkboard. Rather, the biology instructors observed spent a significant amount of instructional time presenting conceptual information and definitions through the use of laptops and slides (i.e., PowerPoint). This is evident in the graph as well as the large percentage of intervals (69) in which the "lecture–receive/memorize–laptop/slides" triad was observed. When problem solving was asked of the students, it was often observed in the same intervals with small-group work and laptop/slides (8% of all intervals).

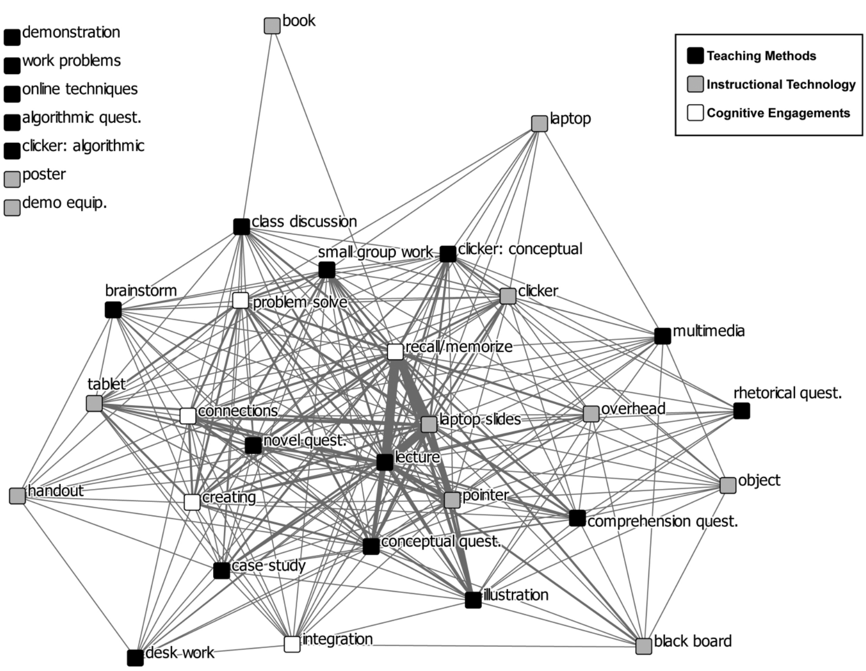

FIGURE 6 Co-occurrence network of observed codes for biology instructors (224 intervals; $n = 11$). equip = equipment; quest. = question.

The biologists also stand out in terms of their use of small-group work and whole-class discussion. For example, the "small-group work–problem solving–laptop/slides" triad was observed in 7% of all intervals, the greatest frequency among any discipline. On its own, "small-group discussion" appeared in 12% of all 5-min intervals among the biologists. These instructors also frequently supplemented their core repertoire with conceptual questions (23% of intervals) and whole-class discussion (11%). In fact, biologists were the only instructors observed to use whole-class discussion with any frequency. Biologists also frequently provided opportunities for creating (14%) and making connections to the daily lives of students (20%). The latter cognitive engagement was often observed in the same intervals as small-group work and laptop/slides (4% of all intervals).

Geology Instructors. The geology instructors exhibited the most limited repertoire among the instructors in our sample. As can be observed in Figure 7, this repertoire was almost exclusively composed of the "lecturing–receive/memorize–laptop/slides" triad (80% of all intervals). This latter triad often consisted of graphical depictions of geologic events or processes portrayed on PowerPoint slides. A graph density (Δ) of 0.269 reveals that 26.9% of the total

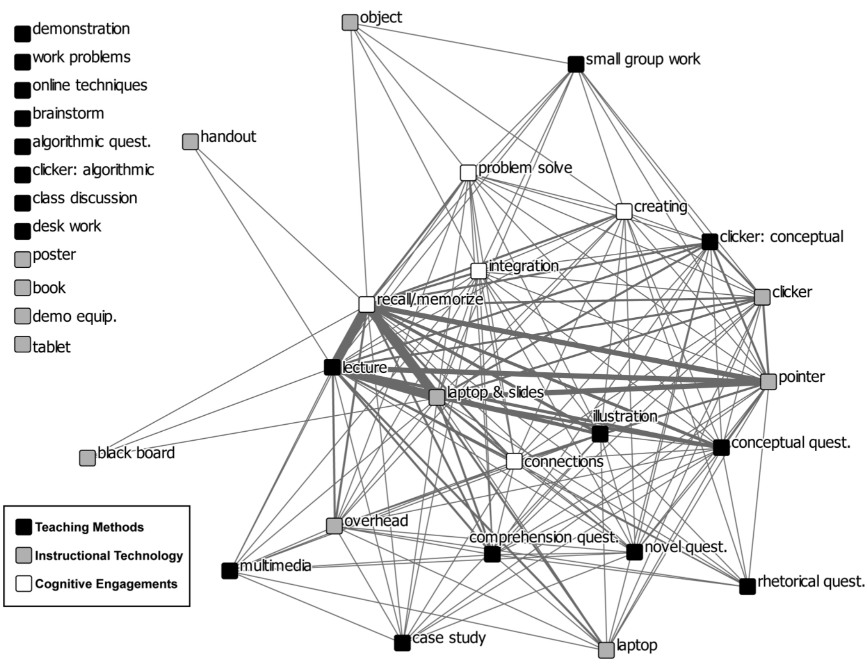

FIGURE 7 Co-occurrence network of observed codes for geology instructors (174 intervals; $n = 8$). equip = equipment; quest. = question.

number of possible code co-occurrences were observed, far lower than for mathematicians (0.335), biologists (0.415), chemists (0.415), and physicists (0.538). The relatively limited repertoire among these geologists is also evident in the relatively large number of teaching techniques and instructional technologies that are disconnected from the graph (aligned vertically along the upper left portion of Figure 7).

These geology instructors frequently supplemented their core repertoire with conceptual questions (24% of all intervals), often with the use of clickers (12%), and made use of illustrations (18%) with a greater frequency than any of the other observed disciplines. Although nearly every interval (97%) included the "receive/memorize" cognitive engagement, relative to the other disciplines geologists more often required that students integrate concepts from the course (9%).

DISCUSSION

In this article we have presented an approach to studying teaching at the postsecondary level that emphasizes the situated and multidimensional nature of instructional practice. The approach reported in this article also results in an account of both course planning and classroom instruction that offers analytic possibilities and applications for researchers and policymakers. In this section we discuss some of the key findings from the analysis and their implications for undergraduate education in general and for math and science education in particular.

Faculty Negotiation of Curricular Artifacts: A Focus on Course Syllabi

The thematic and causal network analyses shed light on how course syllabi influence faculty course-planning behaviors. The notion of the syllabus as an artifact is evident in early research on course planning that found that the syllabus acts as a "planning device" for faculty (Lowther et al., 1989, p. v). Viewing the syllabus as a device underscores the fact that it functions in ways similar to other more commonly studied artifacts such as instructional technology or departmental governance systems, in that it presents to the individual a constrained set of possibilities in regard to future practice (i.e., affordances). The implications of this view are twofold: first, that syllabi are artifacts created with specific intentions and goals in mind for users, and, second, that syllabi will act as important mediators between faculty members' intentions and their ultimate classroom practices.

In detailing the origins of course syllabi (i.e., departmental committees, inheritance, and course sequence requirements) it is clear that syllabi are cultural artifacts that embody group beliefs and goals regarding teaching and learning (Remillard, 2005). These beliefs and goals inform the design features of syllabi, including the content included, the sequencing of this content over the course of a semester, and the required texts for a course. Decisions about syllabus design are not made arbitrarily but are the result of careful deliberations by individual faculty or committees in which particular positions and interests are put forth and eventually instantiated into curricular policy. Once the syllabi and subsequent practices become routinized over time, they become part of the tacit fabric of a department's approach to curriculum and instruction. In this way, the syllabus not only establishes the content to be taught but also provides the grounds for student–teacher interactions by establishing student expectations for the course and through creating a regulative system through which disciplines constrain and enable particular students access to their group's knowledge (Afros & Schryer, 2009; Bernstein, 2000). As a result, by dictating course content and other key aspects of the learning process, syllabi are best viewed as particularly influential cultural artifacts in localized instructional systems of practice.

Once created, the syllabus shapes instructional practice by acting as a mediator between faculty members' intentions and how they ultimately choose to teach their course. Thus, the syllabus can be viewed as a "cognitive map" that serves as a plan for the instructor to set forth his or her intentions and planned direction for a given course (Matejka & Kurke, 1994). This is accomplished largely through two design features: the type of content included in a course and its order of presentation. For 26 (46%) respondents these features effectively constrained the range of possible practices available to them, especially if their class was connected to others such that multiple courses were required to teach the same content on the same day. For these faculty, their course-planning activities were effectively reduced to following the syllabus. In this way, an instructor's goals, pedagogical skills, or intentions for the course were altered or even subsumed by the larger needs of the course. As one physicist noted, "I cannot talk about cool scientific topics for 10 minutes in front of the class like I want to do but instead must get on to the next topic."

However, another design feature of syllabi described by respondents provides faculty with a high degree of autonomy, in which case the artifact may do little to shape the actual pedagogical practices used by faculty. With few exceptions course syllabi rarely detail how an instructor should teach his or her course, and instead what faculty notice and respond to most often is the demarcation and ordering of content ($n = 12$, 21% of respondents). Thus, the faculty member is left to determine how to best get this content across to students, in which case an individual's personal experience as a student and teacher, disciplinary tradition, and departmental resources play a role in shaping final decisions about classroom instruction. This freedom being acknowledged, the sheer amount of content included in some syllabi does require faculty to select the most time-efficient teaching methods available (i.e., lecturing), in which case the syllabus implicitly suggests to faculty particular ways to teach their classes (4, 7% respondents).

Toward a Multidimensional Perspective on Higher Education Teaching Practice

The data reported in this article demonstrate that the act of teaching involves participating in localized instructional systems of practice composed of actors (e.g., teachers and students), artifacts, and features of the task itself. Thus, focusing on a single component in isolation obscures the complexity of instruction and omits critical features of the teaching and learning dynamic (Cohen & Ball, 1999; Halverson, 2003).

The observation data also illustrate a substantial amount of disciplinary specificity in the way in which teaching methods, cognitive engagements, and instructional technologies are linked through pedagogic action. Thus, instructors utilize different configurations of these dimensions of teaching in the classroom. This is seen, for example, in the varying prevalence of practice triads across disciplines. In this way one might think of these configurations (or repertoires) as instantiated within—and sometimes between—disciplinary groups. Such a perspective does not require that one view these configurations as predetermined based on group affiliation. However, it does suggest that instructors perceive certain technologies, teaching methods, and cognitive engagements as being meant for each other and that these perceptions vary meaningfully across disciplinary contexts. Insights into the disciplinary variation of teaching shed light on the cultural practices and tools that are in use by each group, which may represent both entrenched behaviors that are challenging to alter as well as opportunities for future growth and development (Gutierrez & Rogoff, 2003; Lattuca, 2005).

Each disciplinary group exhibited certain practices in common as well. These include the role of course syllabi as influential instructional artifacts as well as the primacy of classroom practices such as lecturing, the receive/memorize cognitive engagement, and, with the exception of the mathematicians, frequent use of PowerPoint. However, even in cases in which the entire sample exhibited similarities, each group utilized practices in slightly different ways and in different configurations with other methods, types of cognitive engagement, and instructional technologies. For example, it is apparent that lecturing was a central feature of classroom instruction in the study sample, as the oral presentation of facts, concepts, and principles constituted a part of the central teaching core of each discipline in the study sample, being present in from 75% of the 5-min intervals for mathematics faculty to 93% of intervals for physics faculty. However, lecturing is often affiliated with other teaching methods, such as demonstrations, working out problems, rhetorical questions, and using illustrations or examples, such that to characterize a class period (or even portions of it) as just lecturing is inaccurate. A mathematician in our study, for instance, quickly switched between lecturing, working out problems, and posing questions while discussing direction fields. Other instructors observed in this study regularly interjected questions and illustrations during class periods when they were primarily lecturing, such that the lecture portion itself was used in conjunction with these other techniques.

Although lecturing most often co-occurred with the “receive/memorize” cognitive engagement (e.g., 90% for physics faculty), it also co-occurred with other cognitive engagements. Among physics faculty, for example, lecturing frequently co-occurred with problem solving (26% of intervals), connections to the real world (21% of intervals), and integration with prior knowledge (7% of intervals). This suggests that the lecture method can be used in different ways to engage students in varied cognitive states and that a lecture does not need to be synonymous with only asking learners to passively receive and memorize information. That being said, the high rate of co-occurrence between lecture and the “receive/memorize” cognitive engagement does indicate that this pairing was both common and widespread across the disciplinary groups in this study.

Lecturing was also consistently affiliated with instructional technologies such as chalkboards (e.g., 62% for mathematicians), PowerPoint slides (e.g., 73% for biologists), and demonstration equipment (e.g., 31% for physicists). Each of these artifacts acts to mediate the relationship between instructor and learner in different ways and provides different opportunities for learners to engage with the topic at hand. For example, the widespread use of PowerPoint slides shifts students’ attention from a sole focus on the instructor to the visual representation on the slide, which can vary in degrees of visual and pedagogical quality. In one case a geology faculty noted that he spends hours selecting meaningful and arresting images for his slides, in part because of the nature of geological knowledge as being highly visual and therefore amenable to the use of graphics as a learning tool. Thus, it is important to consider lecturing in relation to the role of instructional technology as well.

Finally, in all but four instances the lecture method was not used exclusively for an entire class period but instead was used for shorter periods (e.g., 5–10 min) and/or was interspersed with other teaching methods. In this way, collapsing a 60- or 90-min class into a single method, which most survey or questionnaire instruments require faculty to do when self-reporting regularly used teaching methods, obscures the temporal component of actual classroom instruction. Collectively, these findings suggest that faculty teaching is best viewed as a practice composed of multiple dimensions that interact with one another in varying ways throughout time.

Implications for Pedagogical Reform

Critiques of undergraduate education in general and the use of lecturing in math and science disciplines in particular are beginning to have substantial policy implications. For example, both the influential Association of American Universities (2011) and the White House (President’s Council of Advisors on Science and

Technology, 2012) have released reports that include specific recommendations for federal grant making and educational policy that focus on encouraging faculty to adopt interactive teaching methods and to reduce the amount of lecturing. Furthermore, policymakers are adopting the stance that the traditional lecture is a primary cause of a myriad of perceived problems with math and science education at the postsecondary level, including the underrepresentation of women and minority groups and high rates of attrition (e.g., President's Council of Advisors on Science and Technology, 2012). In addition, it is still common in the literature to see the lecture used as a counterpoint to teaching practices that are considered more effective, with experiments designed with control groups experiencing a lecture and experimental groups experiencing more interactive techniques.

Although we do not question the substantial evidence suggesting that a sole reliance on lecturing is less effective than other teaching practices, the data reported in this article indicate that teaching is invariably more complex than a single descriptor can convey. This complexity is evident in the co-occurrences between lecturing and other teaching methods, cognitive engagements, and instructional technologies. Another facet of lecturing that is often obscured is the planning processes that lead to classroom instruction and the situational constraints (e.g., class size, student abilities) that may be shaping a faculty member's decision to use particular teaching methods (Henderson & Dancy, 2007; Hora, 2012). In accordance with prior research that dispelled the notion of lecturing as a monolithic practice (e.g., Brown & Bakhtar, 1987; Saroyan & Snell, 1997), and recent analyses that have championed the lecture as a potentially rich pedagogical experience (Friesen, 2011), we argue that the reduction of a faculty member's instructional practice to a single method or label is insufficient to capture the complexity of observed practice.

Perhaps most important, such characterizations may be counterproductive, as evidence suggests that faculty resent being encouraged to adopt curriculum without any input into how it can be tailored to fit local conditions (Henderson & Dancy, 2008). This approach is evident in the research and development approach to pedagogical reform, in which innovations are designed in one setting and assumed to be transferable—with little or no adaptation—to other settings (Fairweather, 2008). The sentiment that educational researchers and policymakers are advocating a top-down approach is exacerbated by a longstanding view of some math and science faculty that educational researchers generally view them as bad teachers and consequently represent the primary barrier to educational improvement (Foertsch, Millar, Squire, & Gunter, 1997; Henderson & Dancy, 2008). Thus, the slow rate with which faculty seem to adopt interactive teaching may be understood as a lack of fit between particular reform initiatives and the actual working conditions and existing classroom practices of faculty. Indeed, reformers must consider why decades of investment in curricular reform and professional development have not led to a widespread adoption of research-based practices. In early research on the efficacy of National Science Foundation–sponsored pedagogical reform initiatives, Connelly and Clandinin (1988) found that many projects fail because curriculum developers failed to consider teacher experiences and classroom conditions and tailor their new materials to fit local settings. The issue of adaptability is particularly salient in light of the finding that different academic disciplines exhibit unique configurations of classroom instruction and that the cultural tools and traditions used by disciplinary groups represent an important feature of local practice.

With detailed insights into the nuances of teaching practice and decision making, instructional designers and researchers can develop initiatives that are responsive to the unique characteristics of local settings (Cobb et al., 2009). For example, two math faculty in our study used digital tablets to work out computations instead of the chalkboard in order to reduce the amount of time students spent taking notes. What is interesting is that the use of the digital tablets maintained the spirit of the dominant cultural tool for the discipline (i.e., the chalkboard) by allowing for the instructor to manually work out problems and maintain control over the pacing of the class but in a way that took advantage of the affordances provided by the tablets (e.g., posting lecture notes online). For a discipline that has generally had less participation in pedagogical reforms relative to other disciplinary groups (e.g., physics and biology), these practices could be used as a starting point for initiating conversations with local groups of math faculty or even as a technique that could be taught as part of faculty development workshops.

With this in mind, we propose that the systems-of-practice framework can serve as a diagnostic frame that can inform the design and implementation of pedagogical reform by providing a catalogue of concrete classroom situations, identifying specific leverage points for instructional decision making, and highlighting key discipline-specific practices that could be incorporated into program design. Such analyses of local practice also have the added benefit of illuminating teaching behaviors and innovations that could be built upon by instructional designers. Although conducting a study such as the one reported in this article is likely unfeasible for most instructional designers, we suggest that the overall conceptual framework and some aspects of our methodology can be adapted for small-scale diagnostic analyses of local settings.

CONCLUSIONS

A systems-of-practice analysis of teaching at the postsecondary level that views teaching as the interaction among individual actors, artifacts, and teaching tasks provides a more comprehensive account of instruction that also gives practitioners insights that can be directly applied in the field. Future research in this area should continue to explore the multiple dimensions of instructional practice in addition to those examined in this study, such as facets of student learning and how repertoires of practice vary between departments at different institutions and between different types of institutions (e.g., community colleges, secondary schools). With this point in mind, the TDOP instrument can be adapted for future research to capture additional dimensions of classroom instruction than those reported in this article and to explore in greater depth existing dimensions, such as cognitive engagement. Although the TDOP is not designed to measure the quality or efficacy of instruction, it may be possible to identify desired practices using combinations of codes. Doing this at the disciplinary level may be a particularly fruitful area of inquiry (Learning Mathematics for Teaching Project, 2011). Future studies should also examine patterns in instructional decision making to identify the key individual and contextual factors that shape faculty teaching plans, how these plans are related to actual classroom practice (see Schoenfeld, 2000), and the ways in which the specific substance of course content shapes these practices. Finally, additional techniques from social network analysis may allow researchers to directly compare the properties of the affiliation graphs to other data of interest (see Carrington, Scott, & Wasserman, 2005).

With the conceptual and methodological tools discussed in this study, it becomes possible for administrators, policymakers, and faculty to develop a grounded and nuanced understanding of practice in their local institutions. The strength of these tools is that they make it possible to see how actors, artifacts, and tasks interact to both constrain and constitute teaching practice from the perspective of the instructor. In the process, researchers gain access to the complexity of course planning and classroom instruction, which provides an opportunity to understand how each activity unfolds in specific institutional settings. This process often leads to unexpected events and decision points that can assist educators as they intervene in the practices of local settings. The tools and techniques described in this article, we believe, bring us a step closer to reaching this level of understanding.

REFERENCES

Afros, E., & Schryer, C. F. (2009). The genre of syllabus in higher education. *Journal of English for Academic Purposes*, *8*(3), 224–233.

Altman, H. B. (1999). Syllabus shares “what the teacher wants.” In M. Weimer & R. A. Neff (Eds.), *Teaching college: Collected readings for the new instructor* (pp. 45–46). Madison, WI: Magna.

Angelo, T. A., & Cross, K. P. (1993). *A handbook of classroom assessment techniques for college teachers*.San Francisco, CA: Jossey-Bass.

Argyris, C., & Schön, D. (1974). *Theory in practice: Increasing professional effectiveness*. San Francisco, CA: Jossey-Bass.

Arum, R., & Roksa, J. (2011). *Academically adrift: Limited learning on college campuses*. Chicago, IL: University of Chicago Press.

Association of American Universities. (2011). *Association of American Universities five-year initiative for improving undergraduate STEM education.* Retrieved from http://www.aau.edu

Barab, S. A., Barnett, M., Yamagata-Lynch, L., Squire, K., & Keating, T. (2002). Using activity theory to understand the systemic tensions characterizing a technology-rich introductory astronomy course. *Mind, Culture and Activity*, *9*(2), 76–107.

Becher, T., & Trowler, P. R. (2001). *Academic tribes and territories*. Buckingham, England: Open University Press.

Berk, R. A. (2005). Survey of 12 strategies to measure teaching effectiveness. *International Journal of Teaching and Learning in Higher Education*, *17*(1), 48–62.

Bernstein, B. B. (2000). *Pedagogy, symbolic control, and identity: Theory, research, critique* (Rev. ed.). London, England: Taylor & Francis.

Blank, R. K., Porter, A., & Smithson, J. (2001). *New tools for analyzing teaching, curriculum and standards in mathematics and science. Results from Survey of Enacted Curriculum Project*. Washington, DC: Council of Chief State School Officers.

Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2006). Motivation and cognitive engagement in learning environments. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 475–488). New York, NY: Cambridge University Press.

Bok, D. (2005). *Our underachieving colleges: A candid look at how much students learn and why they should be learning more*. Princeton, NJ: Princeton University Press.

Borgatti, S. P. (2002). *Netdraw network visualization*. Harvard, MA: Analytic Technologies.

Borgatti, S. P., Everett, M. G., & Freeman, L. C. (2002). *UCINET for Windows: Software for social network analysis*. Harvard, MA: Analytic Technologies.

Bourdieu, P. (1990). *Homo academicus*. Stanford, CA: Stanford University Press.

Boyer, E. (1990). *Scholarship reconsidered: Priorities of the professoriate*. Princeton, NJ: Carnegie Foundation for the Advancement of Teaching.

Brown, G., & Bakhtar, M. (1987). Styles of lecturing: A study and its implications. *Research Papers in Education*, *3*(2), 131–153.

Carnegie Foundation for the Advancement of Teaching. (2007). *The Carnegie classification of institutions of higher education.* Retrieved from http://www.carnegiefoundation.org/classifications

Carrington, P., Scott, J., & Wasserman, S. (Eds.). (2005). *Models and methods in social network analysis*. New York, NY: Cambridge University Press.

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences*, *6*, 271–315.

Cobb, P., Zhao, Q., & Dean, C. (2009). Conducting design experiments to support teachers' learning: A reflection from the field. *Journal of the Learning Sciences*, *18*, 165–199.

Coburn, C. (2001). Collective sensemaking about reading: How teachers mediate reading policy in their professional communities. *Educational Evaluation and Policy Analysis*, *23*(2), 145–170.

Cohen, D. K., & Ball, D. L. (1999). *Instruction, capacity, and improvement* (Consortium for Policy Research in Education Rep. No. RR-43). Philadelphia: University of Pennsylvania, Graduate School of Education.

Cole, M. (1996). *Cultural psychology: A once and future discipline*. Cambridge, MA: Harvard University Press.

Connelly, F. M., & Clandinin, F. M. (1988). *Teachers as curriculum planners: Narratives of experience*. New York, NY: Teachers College Press.

Conrad, C. F., & Pratt, A. M. (1983). Making decisions about the curriculum: From metaphor to model. *Journal of Higher Education*, *54*(1), 16–30.

Daly, A. J. (2010). *Social network theory and educational change*. Cambridge, MA: Harvard Educational Press.

Dancy, M., & Henderson, C. (2010). Pedagogical practices and instructional change of physics faculty. *American Journal of Physics*, *78*, 1056–1063.

DeAngelo, L., Hurtado, S., Pryor, J. H., Kelly, K. R., & Santos, J. L. (2009). *The American college teacher: National norms for the 2007–2008 HERI faculty survey*. Los Angeles: University of California at Los Angeles, Higher Education Research Institute.

Desimone, L. M., Smith, T. M., & Frisvold, D. E. (2009). Survey measures of classroom instruction: Comparing student and teacher reports. *Educational Policy*, *24*(2), 267–329.

Deslauriers, L., Schelew, E., & Wieman, C. (2011, May 13). Improved learning in a large-enrollment physics class. *Science*, *332*, 862–864.

Engeström, Y. (1996). Interobjectivity, ideality, and dialectics. *Mind, Culture and Activity*, *3*, 259–265.

Fairweather, J. (2008). *Linking evidence and promising practices in science, technology, engineering, and mathematics (STEM) undergraduate education: A status report for the National Academies Research Council Board of Science Education.* Retrieved from http://www7.nationalacademies.org/bose/Fairweather_CommissionedPaper.pdf

Feldman, K. A. (1989). Association between student ratings of specific instructional dimensions and student achievement: Refining and extending the synthesis of data from multisection validity studies. *Research in Higher Education*, *30*, 583–645.

Fishman, B. (2005). Adapting innovations to particular contexts of use: A collaborative framework. In C. Dede, J. Honan, & L. Peters (Eds.), *Scaling up success: Lessons learned from technology-based educational innovation* (pp. 48–66). New York, NY: Jossey-Bass.

Foertsch, J., Millar, S. B., Squire, L., & Gunter, R. (1997). *Persuading professors: A study of the dissemination of educational reform in research institutions*. Madison: University of Wisconsin–Madison, LEAD Center.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*(1), 59–109.

Friesen, N. (2011). The lecture as a transmedial pedagogical form: A historical analysis. *Educational Researcher*, *40*(3), 95–102.

Garrison, D., & Akyol, Z. (2009). Role of instructional technology in the transformation of higher education. *Journal of Computing in Higher Education*, *21*(1), 19–30.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Mahwah, NJ: Erlbaum.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. New Brunswick, NJ: Aldine Transaction.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist*, *53*, 5–26.

Gutierrez, K. D., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. *Educational Researcher*, *32*(5), 19–25.

Halverson, R. (2003). Systems of practice: How leaders use artifacts to create professional community in schools. *Educational Policy Analysis Archives*, *11*(37), 1–35.

Halverson, R. R., & Clifford, M. A. (2006). Evaluation in the wild: A distributed cognition perspective on teacher assessment. *Educational Administration Quarterly*, *42*, 578–619.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., & Wood, W. B. (2004, April 23). Scientific teaching. *Science*, *304*, 521–522.

Hativa, N. (1995). What is taught in an undergraduate lecture? Differences between a matched pair of pure and applied disciplines. *New Directions for Teaching and Learning*, *64*, 19–27.

Helman, C. G. (2007). *Culture, health and illness* (5th ed.). London, England: Hodder Arnold.

Henderson, C., & Dancy, M. H. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics—Physics Education Research*, *3*(2), 020102-1–020102-14.

Henderson, C., & Dancy, M. H. (2008). Physics faculty and educational researchers: Divergent expectations as barriers to the diffusion of innovations. *American Journal of Physics*, *76*, 79–91.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, *16*, 235–266.

Hora, M. T. (2012). Organizational factors and instructional decision-making: A cognitive perspective. *Review of Higher Education*, *35*(2), 207–235.

Indiana University. (2010). *Faculty survey of student engagement.* Retrieved from http://fsse.iub.edu

Kane, R., Sandretto, S., & Heath, C. (2002). Telling half the story: A critical review of research on the teaching beliefs and practices of university academics. *Review of Educational Research*, *72*(2), 177–228.

Kezar, A. (2001). *Understanding and facilitating organizational change in the 21st century: Recent research and conceptualizations*. Washington, DC: ASHE-ERIC Higher Education Reports.

Lattuca, L. R. (2005). Faculty work as learning: Insights from theories of cognition. *New Directions for Teaching and Learning*, *102*, 13–21.

Lattuca, L. R., & Stark, J. S. (2009). *Shaping the college curriculum: Academic plans in context* (2nd ed.). San Francisco, CA: Jossey-Bass.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge, England: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, England: Cambridge University Press.

Learning Mathematics for Teaching Project. (2011). Measuring the mathematical quality of instruction. *Journal of Mathematics Teacher Education*, *14*, 25–47.

Lowther, M. A., Stark, J. S., & Martens, G. G. (1989). *Preparing course syllabi for improved communication*. Ann Arbor: University of Michigan, National Center for Research to Improve Postsecondary Teaching and Learning.

MacIsaac, D., & Falconer, K. (2002). Reforming physics instruction via RTOP. *The Physics Teacher*, *40*, 479–485.

Matejka, K., & Kurke, L. B. (1994). Designing a great syllabus. *College Teaching*, *42*(3), 115–117.

Maxwell, J. A. (2004). Using qualitative methods for causal explanations. *Field Methods*, *16*(3), 243–264.

Mayer, D. P. (1999). Measuring instructional practice: Can policymakers trust survey data? *Educational Evaluation and Policy Analysis*, *21*(1), 29–45.

Mayhew, L. B., & Ford, J. (1971). *Changing the curriculum*. San Francisco, CA: Jossey-Bass.

Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall.

Menges, R. J., & Austin, A. E. (2001). Teaching in higher education. In V. Richardson (Ed.), *Handbook of research on teaching* (4th ed., (pp. 1122–1156). Washington, DC: American Educational Research Association.

Merriam-Webster. (2011). *Lecture.* Retrieved from http://www.merriam-webster.com

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis* (2nd ed.). Thousand Oaks, CA: Sage.

Momsen, J. L., Long, T. M., Wyse, S., & Ebert-May, D. (2010). Just the facts? Introductory undergraduate biology courses focus on low-level cognitive skills. *CBE Life Sciences Education*, *9*, 435–440.

Murray, H. G. (1983). Low-inference classroom teaching behaviors and student ratings of college teaching effectiveness. *Journal of Educational Psychology*, *75*, 138–149.

Murray, H. G. (2007). Low-inference teaching behaviors and college teaching effectiveness: Recent developments and controversies. In R. P. Perry & J. C. Smart (Eds.), *The scholarship of teaching and learning in higher education: An evidence-based perspective* (pp. 145–200). Dordrecht, The Netherlands: Springer.

National Research Council. (2003). *Improving undergraduate instruction in science, technology, engineering, and mathematics: Report of a workshop*. Washington, DC: National Academies Press.

National Research Council. (2010). *Rising above the gathering storm, revisited: Rapidly approaching category 5*. Washington, DC: National Academies Press.

Neumann, R., Parry, S., & Becher, T. (2002). Teaching and learning in their disciplinary contexts: A conceptual analysis. *Studies in Higher Education*, *27*, 405–417.

Norman, D. (1988). *The design of everyday things*. New York, NY: Basic Books.

Nystrand, M., & Gamoran, A. (1991). Instructional discourse, student engagement, and literature achievement. *Research in the Teaching of English*, *25*(3), 261–290.

Osthoff, E., Clune, W., Ferrare, J., Kretchmar, K., & White, P. (2009). *Implementing immersion: Design, professional development, classroom enactment and learning effects of an extended science inquiry unit in an urban district*. Madison: University of Wisconsin–Madison, Wisconsin Center for Educational Research.

Pea, R. D. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87). New York, NY: Cambridge University Press.

Perry, R. P. (1997). Perceived control in college students: Implications for instruction in higher education. In R. P. Perry & J. C. Smart (Eds.), *Effective teaching in higher education: Research and practice* (pp. 11–60). New York, NY: Agathon Press.

Pianta, R. C., & Hamre, B. K. (2009). Conceptualization, measurement, and improvement of classroom processes: Standardized observation can leverage capacity. *Educational Researcher*, *38*(2), 109–119.

Porter, A. C. (2002). Measuring the content of instruction: Uses in research and practice. *Educational Researcher*, *31*(7), 3–14.

President's Council of Advisors on Science and Technology. (2012). *Report to the President. Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering and mathematics*. Washington, DC: Executive Office of the President.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*(2), 211–246.

Rogers, E. M. (1995). *Diffusion of innovations* (4th ed.). New York, NY: Simon & Schuster.

Saroyan, A., & Snell, L. S. (1997). Variations in lecturing styles. *Higher Education*, *33*, 85–104.

Schoenfeld, A. H. (2000). Models of the teaching process. *Journal of Mathematical Behavior*, *18*(3), 243–261.

Shaffer, D. W., Hatfield, D., Svarovsky, G. N., Nash, P., Nulty, A., Bagley, E., . . . Mislevy, R. (2009). Epistemic network analysis: A prototype for 21st century assessment of learning. *International Journal of Learning and Media*, *1*(1), 1–21.

Spillane, J. (2006). *Distributed leadership*. San Francisco, CA: Jossey-Bass.

Spillane, J., Halverson, R., & Diamond, J. (2001). Towards a theory of school leadership practice: Implications of a distributed perspective. *Journal of Curriculum Studies*, *36*(1), 3–34.

Spradley, J. P. (1979). *The ethnographic interview*. New York, NY: Harcourt, Brace, Jovanovich.

Stark, J. S. (2000). Planning introductory college courses: Content, context, and form. *Instructional Science*, *28*, 413–438.

Stark, J. S., & Lowther, M. A. (1986). *Designing the learning plan: A review of research and theory related to college curricula*. Ann Arbor: University of Michigan, National Center for Research to Improve Postsecondary Teaching and Learning.

Stark, J. S., Lowther, M. A., Ryan, M. P., & Genthon, M. (1988). Faculty reflect on course planning. *Research in Higher Education*, *29*, 219–240.

Turpen, C., & Finkelstein, N. D. (2009). Not all interactive engagement is the same: Variations in physics professors' implementation of peer instruction. *Physical Review Special Topics—Physics Education Research*, *5*(2), 1–18.

Umbach, P. D. (2007). Faculty cultures and college teaching. In R. P. Perry & J. C. Smart (Eds.), *The scholarship of teaching and learning in higher education: An evidence-based perspective* (pp. 263–317). New York, NY: Springer.

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge, England: Cambridge University Press.

Weick, K. E. (1995). *Sensemaking in organizations*. Thousand Oaks, CA: Sage.

Wertsch, J. V. (1991). *Voices of the mind: A sociocultural approach to mediated action*. Cambridge, MA: Harvard University Press.

Woodbury, S., & Gess-Newsome, J. (2002). Overcoming the paradox of change without difference: A model of change in the arena of fundamental school reform. *Educational Policy*, *16*, 763–782.

Yin, R. (2008). *Case study research: Design and methods* (4th ed.). Thousand Oaks, CA: Sage.

Zhang, J., Scardamalia, M., Reeve, R., & Messina, R. (2009). Designs for collective cognitive responsibility in knowledge-building communities. *Journal of the Learning Sciences*, *18*, 7–44.

APPENDIX

Teaching Dimensions Observation Protocol (TDOP): Coding Section

*Use **pencil** to code the lesson in the categories.*

Minutes	0–4	5–9	10–14	15–19	20–24	25–29
Teaching Methods	LEC IL DEM SGW MM CS PS OT B RQ DCQ DAQ CQ NQ CL CD DW	LEC IL DEM SGW MM CS PS OT B RQ DCQ DAQ CQ NQ CL CD DW	LEC IL DEM SGW MM CS PS OT B RQ DCQ DAQ CQ NQ CL CD DW	LEC DEM IL SGW MM CS PS OT B RQ DCQ DAQ CQ NQ CL CD DW	LEC DEM IL SGW MM CS PS OT B RQ DCQ DAQ CQ NQ CL CD DW	LEC IL DEM SGW MM CS PS OT B RQ DCQ DAQ CQ NQ CL CD DW
Notes: Include brief description of what the instructor is actually doing here (e.g., content being discussed, sequence of argumentation, etc.)						
Cognitive Engagement	RM PS CR IN CN	RM PS CR IN CN	RM PS CR IN CN	RM PS CR IN CN	RM PS CR IN CN	RM PS CR IN CN
Notes:						
Instructional Technology	PO BB LC CL B OP D OB P T	PO BB LC CL B OP D OB P T	PO BB LC CL B OP D OB P T	PO BB LC CL B OP D OB P T	PO BB LC CL B OP D OB P T	PO BB LC CL B OP D OB P T
Notes:						