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Educational Reform, Personal Practical Theories, and Dissatisfaction: The Anatomy of Change in College Science Teaching

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The Teacher-Centered Systemic Reform model (TCSR) recognizes teaching context, teacher characteristics, teacher thinking, and their interactions as influential factors in attempts to implement classroom reform. Using the TCSR model, teachers' personal practical theories, and conceptual change as a framework, the authors of this article studied three college science faculty members as they designed and implemented an integrated, inquiry-based science course. The documentation and analysis of context, instructors' knowledge and beliefs, and teaching episodes allowed the authors to identify and study the interaction of factors, including grant support, that shape reform attempts. The results suggest that grant-supported mitigation of structural barriers is a necessary but insufficient precursor to change and that personal practical theories are the most powerful influence on instructional practice. The findings highlight the critical role of pedagogical and contextual dissatisfaction in creating a context for fundamental change.

Keywords: conceptual change, educational reform, teacher cognition, teaching context.

Calls for the reform of educational practice appear endemic in U.S. culture. Science education is no exception. Over the last 200 years, a multitude of revisions have been championed, but few, if any, have made any significant impact on the way that science is taught or learned (DeBoer, 1991). In light of the massive energy and finances devoted to science reforms in relation to the scant changes accomplished, we argue that reform efforts

in science education can be used as a specific contextual lens to help us understand the complexity of educational change.

In the 15 years since the release of documents intended to guide the latest round of science education reform, the most consistent message has been the call for the distillation of science content coverage to develop deep conceptual knowledge in students (American Association for the Advancement of Science, 1989, 1993; National Research Council [NRC], 1996). Conceptual development is linked to an increase in inquiry-based instruction that, the reformers argue, properly situates the learning of conceptual content within the necessary contexts of scientific processes and the nature of science (Mestre, 1994; NRC, 2000). These calls for change "challenge the cultural traditions of schools" (Romberg & Price, 1983, p. 159) and require fundamental shifts in the structure and cultures of schools, teacher thinking, and classroom practice.

Cuban (1988) noted that reforms that seek to change the fundamental structures, cultures, and pedagogies in schools are inherently difficult to implement and sustain. This difficulty prompted science education reformers to view change within the larger educational system, calling on faculty from colleges of education and science to act as partners in reform. As noted by Siebert and McIntosh (2001) in a book relating the goals of the National

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Science Education Standards (NRC, 1996) to college and university science faculty,

> University and college professors of science are an integral part of this educational system because it is, in very large part, from our courses that society will learn its science. . . . The responsibility of science faculty members is to develop not only the science knowledge of our students, but also their understanding of the nature of science, their ability to understand and use scientific ways of thinking, and their ability to make connections and apply what they know to the world outside the classroom. (p. ix)

Many university faculty have accepted this challenge, creating position statements that urge the integration of the principles in the National Science Education Standards into the college classroom and developing new science courses and programs (see, for example, National Science Teachers Association, 2000). Many of these projects received significant levels of initial funding from the National Science Foundation Division of Undergraduate Education and the U.S. Department of Education's Fund for the Improvement of Postsecondary Education. Other projects, such as Project Kaleidoscope (*www.pkal.org*) and Science Education for New Civic Engagements and Responsibilities *(www.aacu-edu.org/SENCER)*, invested directly in the professional development of faculty involved in undergraduate science, mathematics, engineering, and technology teaching.

Reform efforts are generally associated with large expenditures of time, effort, and money devoted to addressing three contexts of reform: the background of the teacher, the cultural and structural contexts of instruction, and teacher thinking. But, despite substantial work and investment, rarely do reform efforts at either the K–12 or the college level result in sustained, fundamental changes in classroom practice. Why? Woodbury and Gess-Newsome (2002) propose three potential explanations for the paradox of "change without difference":

1. *Structural and cultural contexts.* A variety of interconnected structural and cultural components of school systems must change to support and sustain instructional changes.
2. *Purposes of reform.* Many reforms are not intended to alter common pedagogies, leaving teachers' and students' roles untouched.
3. *Teacher thinking.* Teachers' knowledge and beliefs mediate reform proposals. Because reforms seldom alter important aspects of teacher thinking, reform enactment remains remarkably traditional.

This study is a close description of the enactment of reform in the context of a liberal arts college science course (as opposed to the report of an intervention). The research provides a useful context in which to explore the three proposed explanations for the limited impact of reform efforts. The course, *The Natural World: Explorations in Science*, was developed around

the central tenets of science education reform (American Association for the Advancement of Science, 1989, 1993; NRC, 1996) and was partially supported by a National Science Foundation grant.[1] As described by the course instructors,

> *The Natural World: Explorations in Science* (Biology 102 and Physics 104)—an introductory, integrated science course for non-science and elementary education majors—is laboratory based and experientially driven. It is designed around four major concepts—matter and energy, change and constancy, diversity and order, and interactions—with the following goals: To provide broad, integrated science knowledge; To foster the development of effective process learning skills in science; To create a continuing interest in science. [Teaching] methods include extensive writing, guided discovery laboratory experiences, reading in the history of science and popular journals, collaborative teams, library/internet research, quantifying phenomena, computer modeling, problem solving, and critical thinking skills. (Project summary in course syllabus)

The Natural World, by design, challenged a number of the cultural norms and expectations of a college science course: team teaching, integrated science content, an emphasis on process skills and inquiry learning, and the use of writing to learn science. As a result of these challenges, successful course enactment required both alterations of typical beliefs and practices (as supported by the instructors) and elimination of specific structural barriers as they related to college science teaching and learning (as supported by the grant). In this context, we attempted through our research to understand the reform efforts of three science professors, the variation that occurred in curriculum enactment, and the reasons for that variation. By documenting and analyzing the context, the instructors' knowledge and beliefs, and particular teaching episodes, we tried to identify and study the interaction among the general factors that shape fundamental changes in teaching practice.

Although we recognize that the national science education reforms do not represent an unquestioned singular portrait of "good teaching," in this study we use the aspects of the science reforms portrayed in the course in a normative fashion, based on the collaborative selection of course goals, the enthusiastic participation of the teaching team, and the purposeful design of the course. The consistencies or discrepancies between the beliefs of the course instructors, the stated goals of the reform-based course, and the enactment of the curriculum provided the metric by which we gauged successful implementation of the reform effort and sought the factors that influenced the reform effort.

Theoretical Framework

The Teacher-Centered Systemic Reform Model (TCSR), developed by Woodbury and Gess-Newsome (2002), guides our research. The model, based on

an extensive review and synthesis of the literature, simultaneously recognizes the influence and interaction of the teaching context (both structural and cultural), teacher personal characteristics, and teacher thinking as a means to understand classroom practices that change (or fail to change) as a result of reform initiatives. Since reform efforts often invest time, money, and energy attempting to mitigate one or more of these factors, the TCSR model (see Figure 1) acted as a framework by which we were able to determine which contextual elements that surrounded the development and teaching of *The Natural World* were neutralized and which presented opportunities to further explore the conditions through which reform efforts succeed or fail. Each of the categories of influence on reform efforts is discussed as it affects the study.

The structural and cultural contexts within which teachers work are often the targets of reform efforts. *Structural contexts* of teaching include the physical, temporal, and psychological characteristics of a setting, such as the arrangement of buildings, space, and furniture (Doyle, 1986); schedules, subject area, grade level, and/or teacher team organization and physical space (Cuban, 1993; Grossman & Stodolsky, 1995; Hargreaves, 1994; Little, 1995; Siskin, 1991); textbooks, tests, and teaching materials (Ball, 1990; Remillard, 1999; Shulman, 1987); and students (McLaughlin & Talbert, 1993; McNeil, 1988; Metz, 1993). All of these factors have been shown to shape the culture of a setting and thus influence teachers' thinking as well as their pedagogical and curricular choices.

Teaching culture—consisting of taken-as-shared patterns of thoughts and behavior—is defined by the "beliefs, values, habits, and assumed ways of doing things among communities of teachers" (Hargreaves, 1994, p. 165). Several particular features of the *cultural contexts* of teaching have been empirically identified as playing significant roles in influencing educational reform. These features include faculty collaboration (Fullan, 1991; Hargreaves, 1994); professional development experiences (Ball, 1994; Little, 1993); the perception and definition of group goals (Hargreaves, 1994; Talbert & Perry, 1994); and the influence of administrative leaders such as the principal (Berman & McLaughlin, 1978; Fullan, 1991; Leithwood, 1992; National Council of Teachers of Mathematics, 1991) and the department chair (Siskin, 1991).

Using a modification of the TCSR model, altered to better reflect the structure of a college or university classroom,[2] we argue that our study context is unique in that it represents a "best-case scenario" for reform: The faculty who were involved possessed vast content knowledge; the informal leader of the group had extensive experience in the development of reform-based curricula; and the monetary support provided by the National Science Foundation (NSF) ameliorated many of the structural constraints often thought to impede reform efforts. Specifically, there were institutional, financial, and instructional modifications that supported and increased collaborative instructor planning, and changes in the course content and experiential expectations (see Table 1). In addition, the prestige associated with the grant

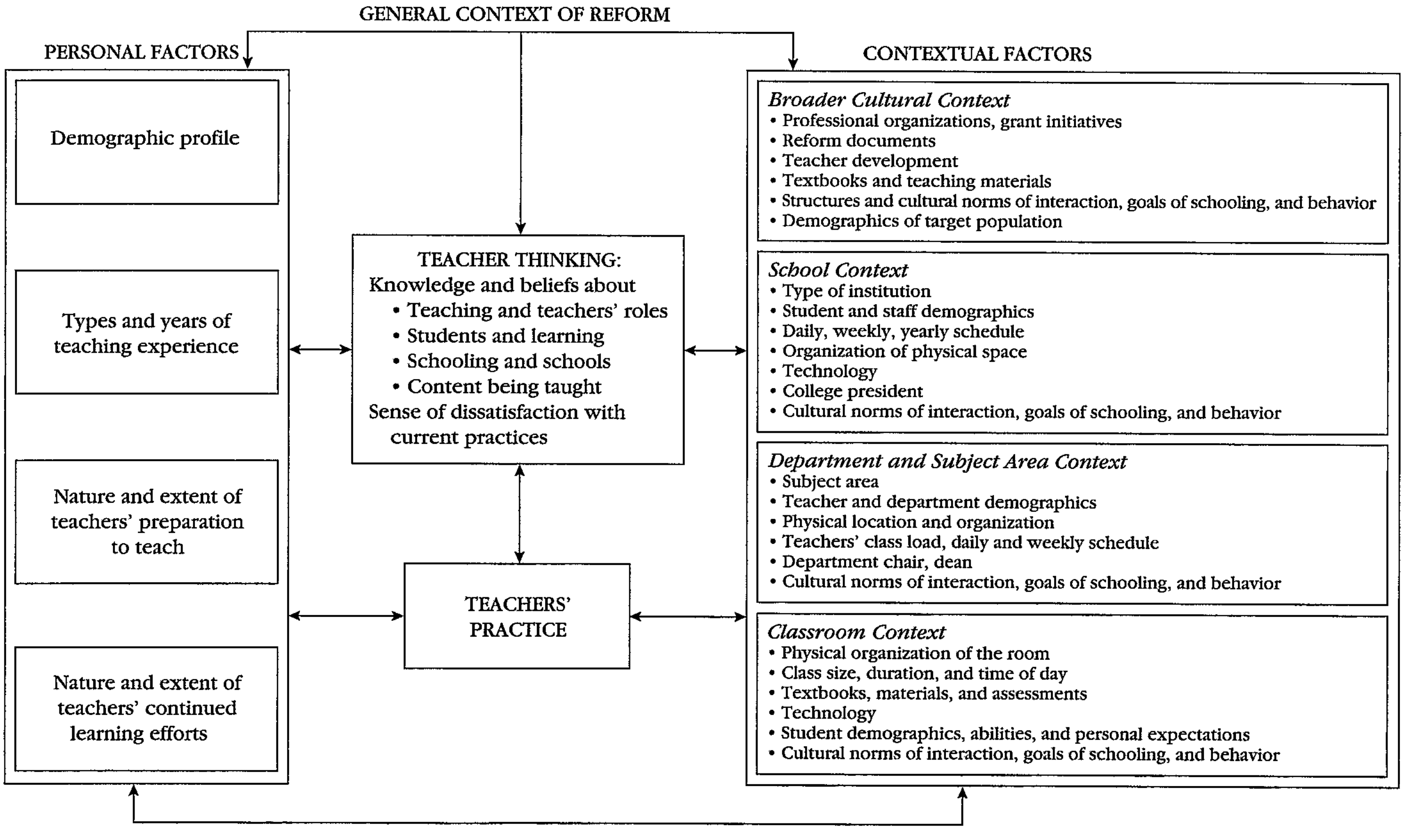

Figure 1. **The TCSR model for a college classroom.**

Table 1
Contextual Modifications for Course (Common Across Instructors)

Structural change	Manifestation	Impact on instruction
Institutional	Reduced content expectations	Time for experimental and inquiry teaching
	Faculty release from normal course loads	Opportunity for team teaching
	Administrative support	Countering student reservations about course instruction and requirements
Financial	Prolonged, supported period of planning	Grappling with ideas of reform and structuring curriculum around those ideas
	Enhanced laboratory equipment	Emphasis on experiential, inquiry-based learning
Instructional	Multidisciplinary expertise	Integrated curriculum and enactment
	Encouragement to engage in pedagogical experimentation	Use of journals, student-centered instruction, student research, extended field trips, etc.
	Program evaluation	Formative feedback on course implementation

served to minimize many of the cultural constraints to reform, at least those constraints typically imposed or supported by high-level administrators.

Of the three explanations for the paradox of "change without difference" (listed in the preceding section), the first and second can be discounted. The elements associated with the first explanation (structural and cultural contexts) were diminished through the presence of the grant; and the second explanation (purposes of reform) can be eliminated because the instructors involved with *The Natural World* did attempt to change the pedagogical methods for the class. Thus we focused on the third explanation, teacher thinking. With many of the contextual aspects of the TCSR model held constant in our study, a comparison of patterns of curricular enactment used by the three instructors allowed for an in-depth analysis of the personal factors affecting the enactment of reform.

Research on teachers' thinking provides evidence of its robust link with teachers' inclination and ability to teach differently (Cohen & Ball, 1990; Cooney & Shealy, 1997; Gess-Newsome, 1999; Putnam, Heaton, Prawat, & Remillard, 1992; Shulman, 1987; Smylie, 1989; Thompson, 1992). We define *teacher thinking* as teachers' knowledge and beliefs concerning teaching, teachers, learning, learners, schools, schooling, and subject matter. Teachers' thinking and practice are shaped by professional and life experience, the nature and extent of teacher preparation, and continued professional learn-

ing (Ball, 1994; Fullan, 1991; Fullan & Hargreaves, 1996; Smith, 2002). In the TCSR model, these are labeled *personal factors* influencing teachers' thinking and practice.

Using this model, Woodbury (2003) examined reform efforts in mathematics teaching. Of the three areas of influence, teacher personal factors and teacher thinking provided the most insightful explanations for understanding classroom practice, the most salient elements being teachers' abilities and inclination to learn and relearn conceptions of content, learning, and teaching (Ball, 1994; Sarason, 1982). If "unlearning" is required to change one's conceptions (Woodbury, 2003), then conceptual change theories offer a lens for the examination of teacher thinking and practice as influenced by reform efforts.

Of the current models of conceptual change (Feldman, 2000; Dole & Sinatra, 1998; Pintrich, Marx, & Boyle, 1993; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992), Feldman's theoretical construct of personal practical theories is perhaps the most useful because of its direct derivation from studies of teacher thinking. Personal practical theories are complex constellations of beliefs that have a powerful and constraining impact on instructional practice. According to Feldman, personal practical theories are not contextually bound, are applied on the basis of contextual cues, act as authorities against which to make decisions, and arise from life histories such as personal and professional experiences, the stories of others, and reflection.

Like other current theorists of conceptual change, Feldman (2000) recognizes the importance of the learners' dissatisfaction with their existing understanding as a precursor to change. As described by Posner and his colleagues, "an individual must have collected a store of unsolved puzzles or anomalies and lost faith in the capacity of his current concepts to solve these problems" (1982, p. 214). Woodbury (2003), Sarason (1982), Smith (2002), and Feldman all suggest that if teachers are not dissatisfied with the curriculum that they are teaching, they have little motivation to engage in reform and have little investment in making reform "work." We suggest that a consideration of teacher change as conceptual change provides another perspective on patterns of reform enactment. We must focus on teachers' dissatisfaction with their current practices and their degree of engagement with existing reforms if we are to understand the manner in which they enact reforms.

Methods

Context and Participants

The Natural World was offered at Bingham College, a private, independent, 4-year college noted for its small class size and low student–teacher ratio. Bingham enrolled approximately 2,000 undergraduate students and 500 graduate students and employed 100 full-time teaching faculty. The college offered professional and liberal arts courses, majors in 23 disciplines, and a limited number of graduate programs.

The 19 students enrolled in *The Natural World* reflected the ethnic, age, and academic composition of the campus student population. Seventeen of the students were of European ancestry and 2 were African American. There were equal numbers of freshmen and upper-level students, and of men and women. Eleven of the students were pursuing their college education full time, 8 had full-time employment in addition to their school duties, and 3 were second-career students. Two students planned to major in science; another was pursuing a secondary education certificate. Of the 17 non–science majors, four were majoring in elementary education.

Three science faculty members at Bingham were involved in the planning and enactment of the course: Albert, Brian, and Randall. Each member of the team brought a different type of pedagogical and content expertise to the course. With extensive knowledge of, and commitment to, the reform efforts in science education, Albert, a physicist and chemist, was the instigator and major motivating force behind the conceptualization of the course and the subsequent grant application. Randall, a biologist, had been engaged in conversations with Albert about such a course for a number of years, leading to Albert's development efforts. Brian, a physicist, was a novice faculty member searching for ways to improve his teaching and so volunteered to participate in the project. Other individuals who were involved included a writing specialist, an outside advisor, and guest speakers.

Two of the authors acted as members of the grant evaluation team. The first author was involved in the early stages of grant planning and interviewed the course instructors. The second author was a participant observer (Ely, Anzul, Friedman, & Garner, 1998) and collected data in all class sessions, attended instructors' debriefing sessions, and collected student data. The third author was involved in data management and organization. All four authors contributed to data analysis.

The research team had a varied history in education in general and in relation to reform in particular. All of the members had experience as high school science or mathematics teachers, taught science or mathematics at the postsecondary level, or worked as science or mathematics educators. Within these contexts, our work often revolved around helping current and future teachers (K–20) understand, critique, and begin to implement aspects of the national mathematics and science reform documents. Given this background, it is evident that each member of the research team, while recognizing the limitations of the current reforms, was supportive of these efforts and was personally challenged to implement the goals of the reforms into current university teaching. Each of us, in our teaching situations, found the guidelines of reform valuable yet difficult to implement, each experiencing structural, cultural, or personal limitations in our reform efforts.

Based on our experiences with reform-based teaching, understanding the mechanisms available to foster reform was personally and professionally important. With the strong local reputation of two of the course instructors, the evident enthusiasm and commitment of the teaching team, and the potential that outside funding would eliminate many of the structural barriers to

reform, we approached the evaluation of this project with high hopes of documenting a successful reform effort. We expected to see a strong translation of teaching goals into classroom practice while we uncovered minor barriers to implementation. These assumptions were revealed to us when one member of the team called attention to our simplistic interpretation of Albert's teaching case, noting teaching practices that were contradictory to our expectations. This discrepancy between course goals and instructional practices forced us to reexamine our data and the analytical frames that we used to determine and explain the antecedents of reform.

Data Collection and Analysis

How do teachers' knowledge and beliefs mediate reform efforts? To answer that question, we generated case studies for each of the participants. Examining the factors identified as important in the TCSR model, and in accordance with case study methodologies (Miles & Huberman, 1994), we collected, synthesized, and analyzed data on instructors' personal characteristics, their course goals, and their knowledge and beliefs about teaching, learners, learning, and content. (The role of content knowledge and beliefs in reform-based teaching are explored more thoroughly in Southerland, Gess-Newsome, & Johnston, 2003.) These data were compared against descriptions of curriculum enactment and the cultural and structural elements of the teaching context. Finally, using both the TCSR model and conceptual change theory, we performed within-case and cross-case analyses, which allowed for a detailed examination of the effects of cultural and structural factors and teachers' knowledge and beliefs within the context of reform.

Data Sources

As described by McDiarmid (1992), the use of direct measures alone can be misleading because they can trigger socially acceptable responses and fail to elicit participants' true conceptions. As a result, we used both direct and indirect measures to elicit knowledge and beliefs, to triangulate findings, and to increase the faithfulness of the case studies. Data sources for this study included

1. Course planning sessions [P] (recorded and transcribed). Seventeen 1–2-hour sessions were held the summer before instruction, and 10 sessions for both planning and course debriefing were held during the semester of instruction.
2. Instructor interviews [I] (recorded and transcribed). Sample inquiries included the following: *When did you first think about teaching science? Characterize your first teaching experiences. How would you describe your teaching now? What past experiences have most affected the manner in which you teach? What aspects of your content and of your students influence your teaching? How? What are*

your goals for The Natural World? Each interview lasted approximately 2 hours.

3. Class sessions (including participant observer field notes [FN] and class transcripts [CT] from recordings of each day of instruction). The class met for 2 hours, twice each week for the 15-week semester.
4. Classroom artifacts such as syllabuses, handouts, and student work.

Instructor Case Studies

Instructor interviews and course planning sessions were used to describe the instructors' backgrounds and conceptions of and attitudes toward teaching, learning, students, science content, and science education reform. The interview transcripts, a direct measure of these constructs, were triangulated against comments made in the planning sessions, which acted as indirect measures. Such comparisons allowed us to describe the manner in which the instructors stated definitions and how their attitudes were reflected, omitted, or contradicted in the less structured course-planning sessions.

We used three stages of data coding in the analysis of the instructor case studies: open, axial, and selective coding (Creswell, 1998; Strauss & Corbin, 1998). Open coding of the instructor interviews and planning sessions by two authors allowed for the identification and peer checking of themes. Emergent themes were then triangulated across datasets to ascertain robustness. For example, Randall's rejection of anthropocentrism was identified in both of the separate analyses of interview and planning sessions. After tentative themes were identified, both datasets were analyzed for negative instances of potential themes (Ely et al., 1998; Miles & Huberman, 1994). Themes were then revised on the basis of their ability to account for or explain the negative instances; those that could not explain the negative instances were abandoned. Data clips that addressed each theme were grouped, and the themes were arranged into broader categories in a process of axial coding. To extend the data analysis example, Randall's rejection of anthropocentrism was subsumed under his conception of the ecological relevance of scientific knowledge. This theme of ecological relevance—with the underlying rejection of anthropocentrism—was then placed under his definition of science. During selective coding, concept maps were constructed to organize the broad theme categories and their constituents and to make interconnections explicit. Returning to our example, Randall's conception of ecological relevance was linked to his emphasis on the complexity of scientific knowledge as well as to his need to take control of teaching through telling a story. Narratives for each instructor's views were written on the basis of the concept maps and were reviewed by the entire writing team.

Curricular Enactment

After a careful analysis of the content and teaching of each unit in the course, three units of instruction were purposefully selected for case study analysis and presentation (Creswell, 1998; Patton, 1989). Even though all the units

were team taught, we specifically selected episodes that were planned and enacted primarily by one instructor and that were representative of that instructor's teaching throughout the course. This selection process provided the best opportunity to describe how individual instructors' personal characteristics affected curricular enactment. In addition, because this liberal education course was free from formal curricular demands, the nature of the content selected and its pedagogical presentation provided insight into each instructor's understanding of the course goals. A unit was not considered for selection if the nature of instruction could be attributed to other obvious circumstances (such as significant time constraints or a holiday season) or if the unit represented such an amalgam of instructors' efforts that it was difficult to attribute the influences on the teaching observed. The teaching units selected included Microscopy (highlighting Randall), The Moon (highlighting Brian), and The Nature of Science (highlighting Albert).

Classroom transcripts, field notes, and class artifacts such as the syllabus, related handouts, homework assignments, and transcripts of the planning sessions for the unit were identified and analyzed. We read data clips from all sources for meaning, and we used a rubric (which focused on various aspects of instructional goals, roles of teachers and students, and the nature of the instructional delivery) to interrogate the data for each unit, allowing us to generate a narrative for each instructional episode.

Within-Case and Cross-Case Analysis

Each of the four authors conducted a within-case analysis (including instructor profile and curriculum enactment) for each of the three instructors; we then synthesized the analyses. The essential features of each instructor were characterized and organized in Table 2; and, on the basis of the factors in the TCSR model (Figure 1), we generated hypotheses about the impact of personal and contextual characteristics on teacher thinking and curricular enactment. As the important role of teacher thinking became clear, we applied elements of conceptual change theory to test their value in explaining the results of the cross-case comparisons. Throughout the process, we actively sought negative instances to assure the rigor of the analysis and to enhance confidence in our conclusions.

Results and Within-Case Analysis

In this section we will describe each of the three instructors in terms of their personal backgrounds, their curricular enactment, and our attempts to reconcile the consistency or discrepancy between the course goals and their instructional practices. The cases of Randall and Brian are presented first because these two analyses are relatively straightforward, although in different ways. Albert's case is presented last, as his case required the most effort to reconcile his background, knowledge, and beliefs with his enactment of the curriculum. Each case is followed by a within-case analysis detail-

Table 2
Personal Factors, Teacher Thinking, Content Factors, and Curricular Enactment in Three Instructors

Variable	Randall	Brian	Albert
Personal factor			
Knowledge of reform	Limited	Developing	Highly developed
Pedagogical content knowledge for topic	Limited, traditional	Developing, inquiry-based	Limited, non-traditional
Dissatisfaction with teaching	Not present	Acute and current	Present in past
Knowledge of content	Sophisticated	Sophisticated	Sophisticated
Teacher thinking			
View of teaching	Accomplished through narratives	Science process to support content learning	Science process to learn nature of science
View of learners	Ill-prepared, incapable	Capable, motivated	Capable, motivated
View of learning	Instantaneous	Difficult process of construction	Difficult process of construction
View of content	Products of science	Processes of science	Processes of science
View of content learning	Complex	Understandable	Complex but understandable
Content factors			
Unit topic	Microscopy	The Moon	Nature of Science
Content complexity	High	Low	High
Nature of content	Concrete and abstract	Concrete	Abstract
Content derivation	Empirical	Empirical	Philosophical
Curricular enactment			
Instructional goal	Relationship between observations and cell structure and function	Relationship between observations and generation of explanations of moon phases	Epistemological basis of science and generation of hypotheses
Nature of teaching	Didactic, factual	Inquiry, conceptual	Didactic, factual
Match between goal and instruction	Low	High	Low and high
Implementation of ideals of science reforms	Low	High	Low and high

ing the most important influences on the enactment of reform for each of the instructors.

Randall: The Storyteller

Portrait of Randall's Background

Randall was a well-known figure in community environmental education circles and regularly ran teacher development workshops, advised student environmental groups, and gave pubic lectures on local environmental issues. In both public and private interactions, Randall spoke in a soft, musical voice, pausing frequently to stroke his beard and carefully select a phrase or emphasize a point. As one listened to Randall, one was struck by how tenaciously he followed a point and relished the spotlight.

Randall's research background was in physiological ecology; before coming to Bingham he had occupied research and teaching positions at two universities. In those positions he was confronted by the difficulties of balancing research and teaching and was disappointed to see how both endeavors took his time and attention away from his central passion—environmental issues. According to Randall, it was not until he learned to integrate environmental issues into his teaching that he became satisfied in his work. Environmentalism served as a focal point for all his professional activities.

Randall's environmental focus played a major role in shaping his three most prominent conceptions of the nature of science: science as a cosmology to rival anthropocentric views, an emphasis on the products of science over the processes, and the importance of knowledge integration through environmental topics. Randall was passionate in his quest to "change [students'] worldview with an appreciation of the natural world" (I 14) and to "lead the students to a new cosmology" (P 6/1, 2)[3] that replaced human-centered, anthropocentric concerns with a scientific appreciation of the complexities and interactions of the living environment. To reach his goal, he felt it was imperative that students master a wealth of scientific information in a manner that highlighted the elegance and complexity of the world around them. As will be seen, his conceptions of science were affected by his views of students and influenced his preference for, and selection of, certain teaching strategies and curriculum topics.

Like many scientists with little formal preparation for teaching, Randall was comfortable using the teaching practices and curriculums that he had experienced as a student until he saw the impact of discussions and field trips devoted to understanding environmental issues. When given the opportunity to teach environmental biology classes at Bingham, he "saw how excited students could be when a knowledgeable leader could show them [scientific concepts] firsthand" (I 13). Because of the complexity of science and the ecological importance of "getting it right," Randall believed that the responsibility for knowledge organization must remain with the teacher: "I think we should gravitate toward stories that tell [students] why things are" (P 6/27, 11), resulting in teaching through well-crafted narratives and interesting illustrations.

Randall had very little previous experience with curricular reform, whether formal or informal. In planning sessions he occasionally commented to Albert that he was unfamiliar and uncomfortable with planning a course around instructional goals and objectives rather than around specific activities. Also in these planning sessions, Randall opposed Albert's advocacy of process-oriented approaches to teaching science, skeptical that adequate conceptual understanding could occur through inquiry-oriented methods: "We don't have time with this hands-on approach to convey that [concept]" (P 6/27, 4). Instead, Randall understood science to be so inherently complex that it was difficult for students to grasp: "It's really hard to teach natural history to naive people who don't know it" (P 6/18, 6). Thus, during the planning sessions, Randall continually argued that scientific conceptions must be *told* to students if they are to come to a deep understanding: "The two [content] stories that I just mentioned can be told by story—not by scientific logic and deduction" (P 6/27, 2).

This didactic notion of teaching, although in contrast to the course goals, was compatible with Randall's ideas about learning. For Randall, learning was direct and rapid process: "[In the outdoor workshop] I was able to change the way [the students] saw the physical environment in just a few hours. Because we talked about it, we saw it. . . . If it's done in the right way, you can almost instantaneously change the way in which people think" (P 7/23, 8). This instantaneous view of learning reinforced Randall's reliance on well-crafted narratives as a preferred vehicle for teaching. The usefulness of this teaching strategy, however, was limited to upper-division classes, because lower-division students possessed insufficient background knowledge ("Students always seem to come to you so poorly prepared" [I 9]) and a low motivation to learn ("[T]he learning is so intensive, it's unpalatable" [I 21]). Randall's dim view of student preparation and motivation must be contrasted with his high expectations for student understanding. That combination resulted in his recognition of content deficiencies in his students that he did not know how to address.

For Randall, the scientific worldview was complex, integrated, and centered on nature. Teaching science required that a knowledgeable professor craft an interesting and informative narrative. It was the science teacher's role to provide poorly prepared students with a glimpse into the magnificence and intricacies of the world of nature and the powerful explanatory power provided by science. "They're naive, . . . they won't get it. . . . You have to tell them that you want them to know" (P 7/23, 7). In Randall's view, if a story is told well and students work hard to attend to its message, learning will occur.

Portrait of Randall's Teaching: Microscopy

The Microscopy unit had a promising beginning. In the week preceding the unit, Randall admitted, "This [inquiry approach to teaching] is such a stretch for me" (FN 11/7, 1). His admission prompted the researchers' anticipation

of witnessing reform-based practices such as those modeled elsewhere in the course. Randall's goals for a 3.5-day unit were ambitious. His explicit goals were to develop students' knowledge of cell structure, microscopy and its role in observation, photosynthesis and respiration, and mitosis (the last goal was eventually dropped). His secondary goal was to demonstrate the integration of Microscopy with the other topic units of the course. Implicit goals were related to an emphasis on the role of writing and record keeping in scientific knowledge production.

During each of the 3 days of activity-based instruction, Randall offered the directions, procedures, and content for the activities before the students moved to the microscopes. For each task, students made observations and detailed drawings during classic microscopic activities, such as making a wet mount of human cheek cells and onion epidermis, and exposing *Elodea* and human red blood cells to different salt solutions. In a classroom filled with microscopes, slides, samples, and the other paraphernalia of a biology class, student engagement at the outset of each session was obvious, as comments such as "Oh wow!" and "Come look at this!" filled the air. A community atmosphere existed as students assisted their neighbors in focusing the microscopes, finding assigned cell structures, and sharing particularly interesting finds. The instructors (often including Randall, Brian, and Albert) circulated around the room answering questions and offering technical assistance.

As students completed their drawings, Randall offered more detailed information to the group, largely through mini-lectures (typically 8 minutes long) augmented by drawings, overheads, and models. Sometimes, Randall (abbreviated "*R*" in the following dialogue) would "go over" the material in triadic dialogues (Lemke, 1990):

R: What's that line that bounds the cell?
Joe: Cell wall?
R: No, that's not it.
Ed: Cell membrane?
R: Yes, that's it. Remember, animal cells don't have cell walls. (FN 11/12, 7)

Often, attempts to engage small groups of students in dialogue dissolved into lecture when Randall failed to find volunteers for his direct and specific questions.

R: Why doesn't the slide cover come off when you flip the slide? Anyone? [A short pause follows.] Because of the adhesive properties of the water, you all remember that? (FN 11/12, 4)

Thus, although students were engaged with the microscopic observations, that level of engagement did not hold for the more detailed discussions.

Each new day of the unit brought with it an increasing level of complexity, detail, and speed. For instance, on the 2nd day in one 4-minute tri-

adic dialogue, Randall described in close detail palisade cells, stoma, chloroplasts, cell walls, cytoplasm, mitochondria, and vacuoles (FN 7/12, 9). The lecture was offered with such speed that many of the students put down their pencils in obvious frustration. Noticing this capitulation, Randall simply reminded the class, "This information is in your text" (FN 7/19, 8), as he continued his lecture. On the last day, Randall began reviewing the structure and function of leaf organelles. Early in the lecture he commented, "[Y]ou don't need to concern yourselves with the details of photosynthesis" (FN 7/19, 6); but moments later, he began a rapid but detailed discussion of the enzymatic pathways of photosynthesis and respiration. Again, prompted by the pace, many of the students put down their pencils and put their heads on their desks or returned their attention to their microscopes. Sensing the students' frustration during these lectures, Brian interjected questions designed to broaden and integrate the content. At one point he asked, "What is the efficiency [of energy transfer] moving up the food chain?" (FN 7/19, 6). Although Randall warmed to the ecological bent of Brian's questions, his mini-lecture quickly settled back into enzymatic pathways.

The students' activities during the unit fell into a pattern: Early engagement with the physical materials was followed by time spent in recording observations and hushed table-based discussions in which the students tried to make sense of what they were seeing. Randall, noticing that their record keeping was complete, then offered short, fast-paced lectures on the details of the material—during which he maintained the attention of two or three students while the rest turned their attention to the microscopes or simply rested. A review of the data revealed very few student questions during these presentations; virtually all student participation took the form of responses to Randall's triadic dialogues. The students' lab notebooks supported this pattern. Their notes concentrated on the details of the cells, with scant mention of the conceptual underpinnings of the material—concepts that Randall had attempted to portray in his mini-lectures.

It is clear from an analysis of the goals and enactment of this unit that, for Randall, the products of scientific knowledge were more important than ideas related to the nature of science. As in the other units that Randall taught, activities (such as the use of the microscope) were used as backdrop for content presentation, and the instructional goals for the unit were foiled by the pedagogical methods used. The activities served as a mechanism to anchor student interest but not as a means of ensuring or building understanding. The combined speed, complexity, and volume of material that Randall felt compelled to introduce could be accomplished only through a didactic, teacher-centered approach. Despite efforts at reformed teaching practices, this unit remained intrinsically teacher-centered and isolated from other units in the course. Although this unit did allow for student familiarity with the microscope, an exposure to cell structure, and a more superficial recognition of cellular metabolism, the fast-paced, deductive content emphasis failed to support student construction of concepts and, instead, privileged the combined authorities of the teacher and text.

Understanding the Influences on Randall's Enactment of Reform

With few opportunities to learn about effective teaching, Randall used familiar strategies until he discovered a teaching method that pulled together the various aspects of his knowledge and beliefs about content, teaching, and learning: teaching as the telling of a well-articulated content tale (see Table 2). Based on his views of the nature of science, didactic instructional methods allowed him to acknowledge the complexity of interactions that occur in the natural environment and to maintain the primacy of content over process in both generating scientific knowledge and learning science. The historically and contextually bound nature of biological content has been noted by others (Mayr, 1988), lending credence to the didactic portrayal of ideas in final form. Unfortunately, such didactic instruction also supported Randall's belief that students were ill prepared and could not benefit from his sophisticated content knowledge. Thus he was compelled to "give" students knowledge quickly in an effort to adequately introduce them to an ecocentric worldview. In fact, Randall believed that learning could be accomplished quickly if an instructor-designed story was well-crafted and included field trips or activities to ensure student interest, and if students were prepared to hear its message.

The picture painted of Randall may be representative of many faculty in the natural sciences. With limited opportunities to learn about teaching, many faculty rely on transmittalist models of teaching that resemble their own learning experiences: Lecture and text act as dominant forms of knowledge transmission, and learning is assumed to immediately follow (Mestre, 1994). Unfortunately, the transmittalist model stands in direct contrast to the goals of the course and to current understandings about teaching and learning (NRC, 2000). Based on Randall's transmittalist views of teaching and learning, inquiry-based instruction could only be viewed as inefficient and unlikely to result in student learning.

Such a characterization, however, is not to be interpreted as disparaging. Randall had many reinforcements for his teaching practices. Throughout his notable teaching career, Randall honed his pedagogical skills to a fine edge and had ample evidence that his methods were effective—students enjoyed his classes and he was a favorite biology instructor on campus. When his instructional techniques resulted in student disengagement, he attributed its cause to a lack of student preparation or to low motivation to learn. Although Randall found little use for the course emphasis on student construction of concepts, he valued the efforts to teach from an integrative frame, something he had already begun to do and his reason for participating in the course. Thus, when asked if his experience in designing the curriculums for *The Natural World* had affected his other courses, Randall replied that it had not, although he did find that he was "just beginning" to revise the manner in which he used science journals (I 20). It is notable that Randall found the collaborative structure of the planning and teaching to be an "efficient," or work-conserving, approach to the demands of teaching, as

opposed to a challenge to the teaching practices that he used. As a result, Randall felt no need to change his teaching style as part of his participation in this reform-based effort.

Brian: Learning to Let Students Inquire

Portrait of Brian's Background

To see Brian in the classroom was to see him in his element. Before class he was a flurry of activity, arriving in the classroom early, gathering materials, putting notes on the board, and joking with students. He moved quickly and deliberately and seldom paused for interaction with the other instructors. Instead, he seemed focused on the task at hand—preparing to teach. Even though there were multiple instructors available at each class session, it was Brian who took charge—raising his normally quiet voice to get students' attention, describing the activities of the day, fielding student questions, and distributing materials. Brian's enthusiasm for teaching was apparent as he embraced the day-to-day activities of the classroom.

Unlike Randall, Brian always thought of himself as a teacher. Despite a lifetime of traditional classroom experiences, Brian questioned the efficacy of teacher-centered practices early in his career and sought alternatives. "[E]ven when I was in grade school, I remember looking at teachers and going, 'I'm not going to do it that way.' . . . [During a lecture I would think], there's got to be a better way to present this so that people feel like they can understand" (I 2). Although Brian was introduced to the instructor's role as a teaching assistant while pursing a PhD in physics, it was not until he came to Bingham for his first full-time teaching position that he formally examined his approach to teaching.

Brian's dual teaching focus, student learning and science content, was grounded in his own experience as a student: "I struggled [in school]. It was really hard for me, . . . and I didn't want my students to go through that, because [science] is a joyous exploration" (I 6). After coming to Bingham, Brian read the research by Laws (1997), McDermott (1984), and Arons (1990) on the use of inquiry-based methods in physics teaching. This fledgling interest was augmented by discussions with Albert. At the initiation of course planning, Brian understood the importance of allowing students to grapple with questions, to have concrete experiences with scientific phenomena, and to "bounce ideas off one another" (P 6/7, 4), although he could not envision classroom practices that implemented those ideals. As the planning sessions progressed, he became more and more vocal regarding the need to "get away from telling [the students] these things" and to let the students "discover a lot of this on their own" (P 6/7, 4). Indeed, in discussing how to teach The Moon, he began to argue with Randall about how to present the assignment. For example, at one point Randall said, "What you need to do is show them the arc of movement"; Brian responded, "No, I don't want to give them that information, it's a discovery activity" (P 8/6, 14). Brian continued to explain

that the purpose of the data collection activity was to support students in building their understanding of the movement of the earth, moon, and sun.

In a related manner, Brian's most prominent conceptions of science stressed the importance of scientific process and understanding science as a way of knowing. Brian believed that *The Natural World* should help students explore "how we know what we know"(P 6/7, 4) by having students "doing science" through observations, measurements, data collection, and keeping science journals (I 11). Such activities not only helped students to learn science but also fulfilled an enculturation role by having students "act" like scientists (P 6/7, 10). Brian also wanted students to appreciate science as a powerful human and cultural endeavor designed to understand the world, within boundaries, "Science doesn't have all the answers: it is not the end all" (P 6/7, 5).

Although Brian's emerging familiarity with inquiry-based, student-centered teaching meshed well with his conceptions of science, he struggled with the approach: "It [inquiry teaching] is hard, . . . [The students] need guidance still, and it is hard not to just do it for them or tell them what's going on instead of trying to draw it out of them so that they have ownership of it" (I 6). This excerpt demonstrates Brian's recognition that students have the responsibility to construct their own knowledge and that the teacher's role is to allow for, support, and help direct such constructions through the vehicle of inquiry learning. Although Brian recognized the difficulty of knowledge construction—"It's just so hard to see [the struggle] on their faces" (I 6)—it was this commitment to student learning that motivated his desire to reform his teaching practice.

Brian's participation in *The Natural World* was an extension of his initial efforts to examine and reform his teaching as an apprentice under a knowledgeable mentor, Albert. "I never felt like there was much I could contribute [to the course]. It was more that I'm going to learn a lot from Albert. It's going to really help me out in my teaching and my understanding of what's going on" (I 5). As a result, Brian had both motivation and support in implementing the visions of reform and changing his teaching practice.

Portrait of Brian's Teaching: The Moon

In teaching The Moon, Brian emphasized the scientific concept of light and the processes of scientific inquiry and observation through the study of the moon's phases. Specifically, his goal was to have students' link observations of phenomenon with the generation and testing of personal and scientific concepts. Before the 3-day unit, the students were required to look for, observe, and chart the motions and characteristics of the moon and its phases for 2 weeks. The observation assignment was scheduled for nine o'clock each night to coincide with phase changes from the first to third quarters and an observable lunar eclipse.

At the outset of the assignment, methods of observation were carefully described and practiced by the students, including the construction and use

of a simple altimeter. In recognition of the uniqueness of the activity, class time was devoted to making explicit all parts of the assignment: "You'll be taking [the horizon and sky overhead] and essentially mapping it out in two-dimensional drawing and drawing the landscape as you see it. . . . You want a place that's fairly open so you can see plenty of sky. . . . The very first day you may want to go out early . . . [and] just draw in some major landmarks so [you're] looking . . . south" (CT 10/8, 2). In a similar fashion, Brian described how the observations were to be recorded, how to compare views from one night to the next, and how measurements could be clearly documented.

The assignment emphasized the following:

1. Student notebooks were to be used as repositories of observations about the moon and the motions of stars in the sky. This assignment reinforced Brian's view that scientific journals were both learning and scientific tools.
2. Students were responsible for making personal observations and recording moon positions and appearances to construct an initial understanding of the scientific phenomena.
3. Final concept construction, guided by Brian, was a group process and included an in-class synthesis of the data. This synthesis provided students with the opportunity to assess their observational accuracy and to search collectively for patterns and explanations behind the data.

Before the unit, Brian collected and reviewed the student data, observations, and budding explanations. On the day the discussion began, Brian noted that their explanations were "skimpy, like you weren't quite sure of what you were doing. Let's work on that. Any questions?" (FN 10/8, 8). Brian listed student questions on the board while systematically addressing each. With initial questions resembling relatively simple queries, the questions became progressively more complex as the students warmed to the process: "What causes a harvest moon? What's up with a blue moon? Why would it [the moon] ever be a different color? I know that the earth rotates, but does the moon rotate too? Is it true we never see the backside of the moon? Why the circle [the arc]? Does the moon always move that way?" (CT 10/8, 8).

Through this process, Brian used student questions to model the use of data to answer questions about natural phenomenon. For example, in discussing the rotation of the earth, one student asked, "Does the moon rotate too?" Brian responded, "Good question. We'll try to answer it based on some of our own data and observations" (CT 10/18, 8). Brian then asked the students to consider the physical features they had observed on the surface of the moon. Through Brian's focused questions, notable wait-time, and interaction between students and their responses, patterns in the collected data were analyzed and confirmed. Brian then had one student stand in front of the class to represent the earth and he used himself to represent the moon. Brian then "orbited" the "earth" to develop the understanding that the moon *must*

rotate for the same face to be visible from the earth at all times. As commonly occurred, after constructing this explanation, Brian paused to ask, "How many people have I lost?" (CT 10/18, 9), followed by a long pause in which he looked over the classroom, calling on students who seemed perplexed. In this way, Brian used the questions, observations, and participation of his students to guide their construction of the target concept. Similar instructional strategies were used to describe the observed movement of the moon in the sky and the patterns visible in the phases of the moon and to produce causal explanations.

What is notable about Brian's teaching is that he deliberately planned the curriculum to facilitate a student-centered environment that would lead to concept construction. Brian selected a concept to teach that would allow him to mesh his views of the nature of science, student learning, and the goals of the course, resulting in a strong match between his goals and instructional practice. Student data collection acted as a basis for questions and explanations, which then became the grist for meaning making. As it became apparent that students were struggling to understand the movement of the moon, Brian did not simply "tell them" the answers but guided their thinking to consider their own data to generate explanations. Brian's use of tool construction, data collection, student-generated questions, and the application of problem-solving techniques to analyze the data allowed students to construct the scientific concepts that were identified as unit goals, provided students with ownership of their understandings, and allowed students to participate in the processes of science.

Understanding the Influences on Brian's Enactment of Reform

In contrast to Randall, Brian entered this project with a long-standing dissatisfaction with teacher-centered pedagogies. He viewed his participation in *The Natural World* as an opportunity to develop expertise in inquiry-based teaching strategies under the guidance of Albert. Although past teaching experiences did not provide Brian with a strong experiential basis for this new form of instructional practice, his underlying beliefs about science content, teaching, learners, and learning acted as an appropriate foundation for these efforts (see Table 2). For Brian, both science and learning were processes in which individuals must personally engage. The role of the instructor was first to provide students with well-designed experiences that would guide them in collecting data about natural phenomena and then to help them construct answers to self-generated questions. In Brian, we see a strong case of the enactment of fundamental pedagogical reforms as a result of participation in a curriculum development grant allowing for an almost seamless translation of his beliefs about teaching, learning, and content into his practice. Brian was an anxious learner of the new knowledge and skills that were gained as a participant in this project. When asked about the impact of his new teaching skills on his other courses, however, Brian indicated that he would "probably still [lecture] in my upper classes, . . . just because I haven't figured out

how to do it through active learning" (I 18). He was also the least experienced of the three members of the instructional team and therefore was able to adopt the inquiry-based strategies championed by the grant as a novice pedagogue. The ease of transfer, then, may have had less to do with the grant context than with Brian's limited number of alternative strategies.

Albert: Exploring Through His Teaching

Portrait of Albert's Background

Before class, Albert was usually involved in teasing out some complexity—working out the nuances of a particular laboratory instrument, talking intently to students about their laboratory notebooks, or refocusing the goals of the day's activities through a hurried discussion with another faculty member. Albert had little time for the small details involved in teaching or taking a course. For example, student questions regarding the format for a homework assignment were met with, "I don't care. Just show me that you've thought about [the content]" (FN 11/7, 3). In short, there were few superficial discussions with Albert—if Albert was involved in an activity, he was involved intensely. This intensity came through in Albert's classroom presentations, in which he was energetic and animated; he paced, he shouted, he used his entire body to gesture and emphasize a point. Albert frequently called on students and incorporated their ideas and questions into the fabric of the discussion.

Albert's teaching revealed his breadth of content knowledge as he drew examples from biology, physics, geology, history, and the arts. Albert's integrated approach to teaching was grounded in an academic background in chemistry, physics, and mathematics, evidence of Albert's personal pursuit of knowledge and his enthusiasm for the integration of knowledge. As Albert explained, "the world out there doesn't respect the boundaries we've constructed" (I 26). As a result, he believed that students must be able to access knowledge from several scientific disciplines to solve problems that they would encounter in their world.

Like Brian and Randall, Albert acquired much of his knowledge of teaching "on the fly." Although his academic career involved him in research, it was teaching that drew his interest and energy: "[As a graduate student] I had really started accumulating this huge catalog of ways of approaching things and ways of explaining things as teaching approaches, not just knowledge approaches" (I 7). His "trial by fire" crystallized in a high school science teaching position following his postdoctoral research. The immediacy of the needs of the high school students changed the way that Albert thought about and approached teaching and "was key to everything that I've done [at Bingham]" (I 18). As a result, he expanded his teaching strategies to include group work and peer tutoring, the active engagement of students with natural phenomena, and the use of student reactions to gauge his teaching effectiveness: "If you're experimental in the classroom, you have to be

reactive [to the students]. You've got to watch, you've got to ask them, . . . and, depending on the response, you've got to [re]structure where you're going" (I 23). Albert "explored" through his teaching and reflected deeply about the results. But these explorations were not random. Albert's willingness to investigate alternative teaching techniques (such as the use of popular culture in the form of readings or videos), his frequent use of student opinion polls, and his ability to revise or ignore the syllabus, were all purposeful efforts to improve the course and meet his ultimate goal for students: increased problem-solving ability. Even in a nonmajors' class, Albert expected students to use the course content to solve problems, "to deal with things in their lives" (P 7/9, 13). This emphasis was consistent with Albert's other beliefs: that learning is more than the rote acquisition of knowledge, that scientific knowledge can be and should be useful to everyone, and that students are capable of learning science and are willing to invest in the learning process. "They really tried to hang in there and work hard" (I 16).

Albert's instructional goals were intertwined with his commitments to the ideals expressed in the science education reforms and his view of science as a process of "problem solving from four different angles" (I 13). For students to "truly understand science" (P 6/27, 3), Albert believed that they must acquire process skills and be involved in the generation of scientific conceptions. This problem-solving emphasis permeated Albert's preference for curricular topics. For instance, he argued for the need to present theories of immunology simply because they were still under revision in the scientific community: "I think that it is a valuable thing for them [students] to come away with. . . . [W]e [scientists] thought we understood a lot but now we're finding out that we didn't understand it so well. . . . [T]here's an awful lot here that we don't understand yet—the tentative nature of science" (P 6/25, 12–13). Thus Albert's personal enthusiasm for teaching, his recognition of students' interests, his goals for problem solving, and a wealth of highly integrated content knowledge synergistically influenced his contributions and participation in *The Natural World.*

Portrait of Albert's Teaching: The Nature of Science

The Nature of Science unit was taught during three class periods spread over the first 2 weeks of class. Albert planned and took the lead in teaching the unit, which was interwoven with other teaching topics deemed critical to starting the course. The unit goals, ambitious in relation to the timeframe available, included student construction of a conceptual and philosophical understanding of the epistemological basis of science and the nature of knowledge generation, including subgoals for understanding the tentative nature of scientific knowledge, science as a culturally and historically embedded human activity, the structure and characteristics of the methods of science (as opposed to *the* scientific method), the distinction between laws and theories, and the goals of scientific understanding. The specific content and

sequence of the unit were extensively planned in the summer prior to the course with few changes in its implementation beyond the expansion of time to accommodate some of the student-centered activities.

The unit opened with the expectation that the students would read multiple creation stories and cosmologies collected from cultures around the world (e.g., Mesopotamia, Yorba, and Native American) and then write a personal cosmology. For Albert, this assignment allowed students to "think about where you're coming from and how you understand the world" (CT 9/5, 5), and highlighted the role of culture in worldviews such as science. This assignment was reinforced by a small-group activity of writing stage directions for plays about various cosmologies in class, followed by an elaborate lecture, delivered by Albert, on the history, geography, and scientific accomplishments of the groups portrayed.

The unit vacillated between short, teacher-centered presentations and student activities. Examples of the more didactic lessons included a lecture on the role of preconceptions in scientific methods, the cultural embeddedness of science, the distinction between laws and theories, and the tentativeness of scientific knowledge. Video clips from *Monty Python* and *Saturday Night Live* that offered comical but informative characterizations of the nature of science and scientific knowledge were viewed and discussed. During an activity, students were asked to form hypotheses to explain their difficulty in turning the handle of a generator. Through his questions and subsequent debriefing, Albert stressed the role of data in hypothesis generation, to the exclusion of hypotheses testing or verification.

The topics and activities presented in this unit were interesting, and the students were highly engaged—almost all of them took notes, laughed, or nodded their heads in response to discussions and occasionally asked questions of Albert or other students sitting nearby. However, these activities generally failed to place the responsibility for sense-making or organizing information with the students; instead, the control of the information remained with the instructor or the text. In fact, although there were roughly the same number of student-centered (4) and teacher-centered (6) activities in the unit, less than 20% of the total instructional time was spent in student-centered activities. Although many of the activities (both teacher- and student-centered) were novel, engaging, and nontraditional in form, the emphasis on teacher-centered activities was a direct contradiction to the teaching philosophy described by Albert, the course syllabus, and the instructional goals of the unit.

Understanding the Influences on Albert's Enactment of Reform

The Nature of Science unit seemed like the perfect context in which to spotlight Albert's goals for teaching: to convey the usefulness of science, the integration and embeddedness of science within culture and other disciplines, the role of problem solving, and the importance of knowledge generation through inquiry. Instead, what we observed in his curricular enactment was

a relatively didactic unit in which many concepts were covered in a teacher-centered, although innovative, manner (see Table 2). What accounts for the disjuncture between Albert's reform ideals, his goals for the class and the Nature of Science unit, and his enactment of curricula? Three explanations are possible: the characteristics of the students enrolled in the unit, the content selected, and Albert's pedagogical repertoire for this content.

Although students are known to greatly influence teachers' content and pedagogical selections (Gess-Newsome & Lederman, 1995), two facts dissuade us from using this explanation to understand Albert's practice. First, the unit was planned before the course and implemented with fidelity. Second, in the literature, most changes in instruction occur on the basis of poor response by students (Ball, 1994; McNeil, 1988). In this case, the students were highly engaged with the content of the lesson. Thus, as with the other instructors, we believe that Albert's selection of this content was purposeful and provided insight into his views of teaching and learning in this reform-based context.

A second explanation could be based on the nature of the content selected. It could be argued that concepts about the nature of science are inherently complex because of their abstract and philosophical nature and thus difficult to approach adequately through inquiry. These concepts are fundamentally different from those included in the Microscopy and Moon units, both of which could easily be approached through more empirical means. Thus the nature of the content combined with Albert's ambitious teaching goals may have prohibited the use of a more student-centered approach. Other studies, however, have demonstrated that there are a number of ways to make such a unit more inquiry-oriented (see Lederman & Abd-El-Khalick, 1998). Alternatively, Albert's extensive knowledge about the nature of science may have dominated his less centrally held beliefs about student learning. Dobey and Shafer (1984) noted a tendency of instructors to teach didactically when they have a rich knowledge base about the topic of instruction. As was the case with Randall, such a knowledge base and commitments to that knowledge base were certainly evident in Albert.

The third explanation, lack of pedagogical repertoire on the teacher's part, does not seem to apply in Albert's case. Albert was a vehement supporter of inquiry methods in all other aspects of the course, but in the planning and debriefing sessions for this unit he gave no sign of trepidation about his lack of student-centered or inquiry-based instruction. He chose the topic in spite of that limitation, indicating a primacy of content over pedagogy in his view of the unit.

At this point it is important to consider Albert's history. When Albert first began teaching, his dissatisfaction with traditional teaching methods motivated him to experiment with new strategies. But his sense of dissatisfaction was long past. Albert's current teaching, derived from early explorations, was generally in line with the teaching practices advocated by the national reforms. Albert's familiarity with the reforms and inquiry-based methods propelled him into the role of both teacher and pedagogical model for Brian

and Randall during the period of the grant. Perhaps this lead role suppressed any doubts or dissatisfaction that Albert may have had with his teaching. Or perhaps, because he assumed that his teaching practices were already consistent with the reform efforts and reinforced by positive student feedback, the course development opportunities were insufficient to engender in Albert a sense of disequilibrium with his current teaching practices. Whatever the reason, the mismatch between Albert's self-described allegiance to inquiry-based instruction and his didactic teaching practices in this unit offers an interesting point of contemplation.

Fleshing Out the Model of Reform: Cross-Case Analysis

As identified in the TCSR model (Woodbury & Gess-Newsome, 2002), we argue, many of the structural and cultural context factors that often derail attempts at educational reform were mediated by the grant context in which this course was developed. In the next section, we analyze these assumptions and use a conceptual change framework to explore the impact of teachers' knowledge and beliefs on the reform process through a cross-case analysis. In conclusion, we propose a tentative model of reform that synthesizes and extends our findings and the extant research.

Structural Change as a Necessary but Insufficient Condition for Reform

Table 1 lists the factors (institutional, financial, and instructional) that the NSF grant context eliminated in this study by modifying many of the structures that typically bar fundamental reform in science classrooms. We believe that without the grant and the change context that it engendered, it was unlikely that the four instructors would have engaged in the design and delivery of this reform-oriented course. In fact, Brian, the instructor who was the most consistent in his use of reform-based approaches, admitted the uncertainty of their use in his other classes.

On the basis of the potential explanations for the "paradox of change without difference" proposed by Woodbury and Gess-Newsome (2002), the removal of structural and cultural barriers might be predicted to improve the potential for reform implementation equally across instructors. Instead, what we observed was differential enactments of reform. Why? Certainly the content of instruction varied across instructors, bringing with it the potential of pedagogical approaches that were contradictory to the inquiry-based goals of the course. But, recognizing the freedom offered to the instructors in content selection, we argue that topic and pedagogical selection were more indicative of the different manners in which the instructors approached and defined reform than they were a consequence or a contextual constraint. We hypothesize that instructor differences were instead the result of the central impact of teachers' beliefs about content, teaching, learning, and learners, and the influence of teachers' dissatisfaction with their current teaching practices. Therefore, the easing of contextual barriers to facilitate reform is a necessary

but insufficient condition for fundamental educational reform. Similar observations were lamented in the report of the Boyer Commission on Educating Undergraduates in the Research Universities (1998, "Overview," p. 2):

> For the most part fundamental change has been shunned; universities have opted for cosmetic surgery, taking a nip here and a tuck there, when radical reconstruction is called for. Serious responses to complaints about undergraduate teaching have generated original and creative pedagogical and curricular experiments. But too often bold and promising efforts have vanished after external grant support disappeared, have withered on the fringes of the curriculum, or have been so compromised that their originality has been lost.

Indeed, in the next section we will argue that the predisposition of teachers to change their practice is central to the reform of teaching.

The Influence of Personal Practical Theories on Instructional Practice

Table 2 compares the personal factors, elements of teacher thinking, content factors, instructional goals, and curricular enactments of the three instructors. In all cases there is a degree of consistency between the beliefs of the instructor and the teaching practices used, although these are not necessarily consistent with the goals of the course or the stated unit goals of the instructor. The strongest consistency found was in the cases of Randall and Brian. This finding reinforces the previously noted strong translation of teachers' beliefs into their teaching practice (Cohen & Ball, 1990; Cooney & Shealy, 1997; Gess-Newsome, 1999). In only one case (Brian's), however, was movement seen toward instructional practices idealized by the course goals. Why?

Following Feldman (2000), we believe that the portraits of teacher thinking developed in this study describe the personal practical theories of teaching held by each of the instructors. Personal practical theories, formed through experience and reflection, include images of teaching and learning, the roles of teachers and students, and the purposes of and methods for content instruction. Personal practical theories both shape and constrain teachers' interactions with reform. For instance, the selection of course content and its related pedagogical structure is an outcome of a personal practice theory, providing insight into each teacher's views of teaching, learning, and the course goals.

Randall believed that an instructor best portrayed the complexity of science and the primacy of factual knowledge by teaching through a compelling narrative. This reliance on narrative was congruent with his view of students as ill prepared and incapable of learning complex information on their own. Viewing this constellation of beliefs as Randall's personal practical theory of teaching allows us to understand his resistance to the teaching practices advocated by the reforms.

Brian's instructional practice also mirrored his personal practical theories, although he was still a novice in inquiry-based teaching strategies. Brian

held strong beliefs about the importance of learner-centered instruction and the role of scientific processes in knowledge generation. He used the opportunities offered through the grant to solidify, hone, and bring into alignment his instructional goals and practices to develop "a better way to present this [content] so that people feel like they can understand" (I 2). Had Brian not had a chance to operationalize his personal practical theories under the guidance and assistance of Albert, we might have seen a mismatch between his stated philosophy and his teaching practice (Fulton & Licklider, 1998).

For Brian, the grant context may have allowed him to enter the "zone of enactment" described by Spillane (1999). Spillane suggests that reform efforts must include both (a) external teacher support for understanding the intent of the reform and how it will look in practice, and (b) internal support for adapting, reflecting on, and discussing individual practices—activities that enable teachers to take ownership of the personal process of change. Although the grant did not provide planned pedagogical interventions, Albert provided Brian with the internal and external support necessary to change his practice.

A somewhat similar story of consistency may be written for Albert, with one exception. Although Albert was firm in his beliefs about content knowledge, student learning, and appropriate instructional practices, it may be that the topic that he attempted to teach—the nature of science—and the depth at which he sought to teach it were either incongruent with inquiry-based teaching methods or beyond his degree of inquiry-based pedagogical content knowledge. Thus Albert used teaching practices that had served him well in the past and were proven to be successful with students: exploring instruction by using nontraditional teaching techniques and studying their impact on students. This application of his personal practical theories allowed Albert to maintain core values about students' understanding of the processes of science but forced him to compromise a less centrally held view about inquiry for a more firmly entrenched ideal—pedagogical exploration. In fact, in an analysis of Albert's teaching of a less abstract topic (as was seen in the structural unit offered toward the end of the semester), his enactment of reform remained incongruent with his personal theories. Thus we argue that this mismatch was due more to Albert's ambitious approach to topics and than to the fundamental nature of the topics themselves. Also, as the recognized pedagogue in the group, Albert had no one available to challenge the consistency of his teaching methods with his advocated teaching philosophy. Such challenges are recognized as instrumental in providing an impetus for reflection and potential change in instructional practice (Chism, 1998; Loucks-Horsley, Hewson, Love, & Stiles, 1998) and might have been well received by Albert.

The Nature and Role of Teacher Dissatisfaction

Within this study, we recognize two forms of dissatisfaction that affected the enactment of reform-based teaching: contextual dissatisfaction and pedagogical dissatisfaction. Albert was the only member of the team who expressed

a high degree of contextual dissatisfaction. Albert recognized that reform-based instruction would require time and a faculty team that had content expertise in various disciplines and was free enough from typical college course constraints to design and implement an integrated science course for nonmajors. As a result of these concerns, Albert initiated the writing of the grant that allowed for a number of structural and cultural changes to occur.

It is clear that both Randall and Albert were satisfied with their teaching beliefs and practices. As Feldman reminds us, however, "[i]f we want teachers to change their practice, which is what is called for in the current reform efforts, then they must accept new practical theories that are consonant with the reforms" (2000, p. 613). In Albert's case, although his practical theories were in line with the reforms, his limited pedagogical content knowledge for the Nature of Science unit may have been responsible for the disjuncture between his beliefs and teaching. Perhaps more important, he felt no need to problematize his instructional strategies. Had a more powerful intervention been embedded in the project, such as a critical friend who could highlight the mismatch between Albert's stated beliefs about teaching and his instructional practice, or an opportunity to reflect on student learning outcomes in comparison with stated learning goals, we might have seen a closer enactment of the values inherent in the science education reforms in Albert's teaching (Chism, 1998; Loucks-Horsley et al., 1998).

In contrast, Randall's personal practical theories were not consonant with the reforms. As Feldman states, "The practical conceptual change metaphor suggests that teachers need to be discontent, not only because their goals are not being met, but to also be discontent with their goals" (2000, p. 622). Randall held no dissatisfaction with his teaching goals or his practice and thus had no need to change. In the cases of both Albert and Randall, we see not pedagogical dissatisfaction but, rather, a degree of instructional complacency that was not challenged through the context of this project.

Brian was the only member of the team who entered the project with a sense of personal dissatisfaction with his current teaching practices and a strong motivation to study and attend to the message of reform—a message that closely resembled his beliefs about teaching, learners, learning, and content. Participation in the project offered Brian an opportunity to study and practice skills related to inquiry-based instruction under the direction of a knowledgeable mentor, Albert. This combination of factors contributed to his ability to make fundamental changes in his teaching practices for the course.

Barriers and Enablers of Reform: A Model

As a result of this analysis, we are convinced of the powerful role of dissatisfaction and agree with Feldman (2000) that dissatisfaction with both one's current teaching methods and one's goals is critical to the success of reform efforts in education. This research extends his findings by explicating the

multifaceted nature of dissatisfaction (contextual and pedagogical) and suggesting the role that dissatisfaction may play in the enactment of reform.

The analysis of these three cases allows for the derivation of a tentative model that combines the elements of the TCSR model with the precursors and enablers of conceptual change in the personal practical theories of the participants (see Figure 2). Although this model is more linear and hierarchical than portrayed in the richness of these cases, it captures the essence of our findings in a parsimonious fashion. In the steady state situation, an individual's personal practical theories and instructional practices are in concert, thus eliminating pedagogical dissatisfaction. As a result, instructional complacency can be anticipated, regardless of whether the instructional practices are in harmony with those advocated by the educational reforms, as we saw in the case of Randall.

We argue that for change in instructional practice to occur, pedagogical dissatisfaction must exist. Dissatisfaction may occur because of a long-term

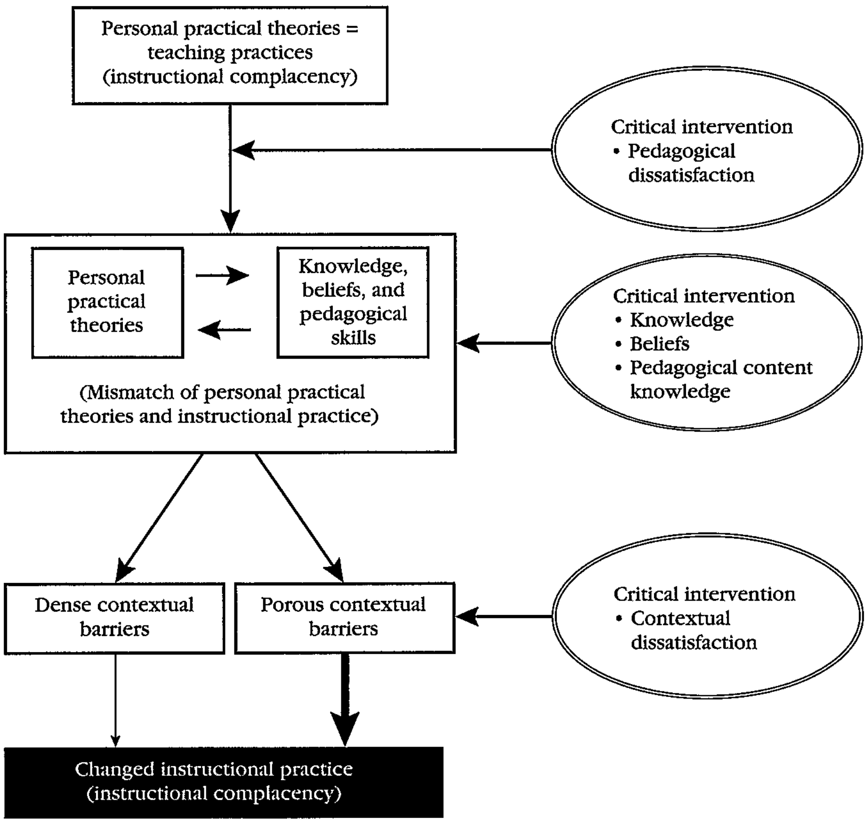

Figure 2. **Interventions, dissatisfaction, and changes in personal practical theories as influences on the enactment of reform.**

and recognized mismatch between personal beliefs and practices (as in Brian's case) or may be induced by some form of intervention, such as the critical friend who was hypothesized as a necessary element for change in Albert, or through other strategies recognized as effective in professional development (Loucks-Horsley et al., 1998). Pedagogical dissatisfaction results when one recognizes the mismatch between stated teaching beliefs, goals, instructional practices, and student learning outcomes (as represented in the second box in Figure 2). To reestablish balance from an unstable state, inputs are needed, such as additional content or pedagogical knowledge, or both; challenges to, and shifts in, beliefs about the nature of teaching, students, and learning; and additional pedagogical tools that allow one's beliefs to be operationalized in practice. An individual's dissatisfaction can lead to the development of new knowledge and beliefs, which, in turn, can lead to new levels of dissatisfaction (maintaining the instability and thus providing an opportunity for change), or may result in eventual consistency between beliefs and practices. These inputs were available to Brian, allowing for productive shifts in his practice.

Once new beliefs or practices are adopted, they can be planted in an environment that is supportive or hostile. In some cases, new practices do survive in situations that include dense and unmitigated contextual barriers, while others may perish in the same climate (Boyer Commission on Educating Undergraduates in the Research Universities, 1998). In other cases, the contextual barriers may be reduced, making them more permeable and thus more supportive of changed beliefs and teaching practices. Efforts to make contextual barriers more porous typically come from an outside source, perhaps a sympathetic administrator or a grant effort. In either case, to enter Spillane's (1999) "zone of enactment," both personal and external support are needed to assist a teacher in negotiating changes in pedagogy and curriculum. It can be hypothesized that, in the absence of other interventions, the newly adopted personal practical theories and instructional practices will once again reach a steady (although changed) state, allowing for the reestablishment of instructional complacency.

Implications

From our research and the extant literature, we derive three implications for educational reforms designed to encourage fundamental change. First, NSF and other granting agencies are correct in their attention to facilitating curriculum reform efforts and can be confident that many of the contextual barriers to change can be ameliorated with their support. Our tentative model of education reform, however, recognizes the removal of contextual barriers as a necessary but insufficient condition for change.

Second, to create and sustain fundamental change, there must be specific and concentrated attention to the personal practical theories of the faculty involved. Change in practice requires dissatisfaction with the teaching and learning goals established for students, beliefs about students and how they

learn, and beliefs about the effectiveness of instructional practices used to meet newly established goals. How do we create faculty discontent to facilitate change that cannot be addressed through cosmetic modifications of practice? Beyond the production of products such as revised curricula, grant agencies must also pay attention to the process of change and provide two key elements: time and facilitation. Time is needed to decrease the pressures of the academic year and to allow for reflection on, and group study of, the goals of reform and the mechanisms available to achieve those goals. Facilitation by a knowledgeable other is needed to provide the pedagogical interventions known to invoke change: asking questions that make explicit personal practical theories, providing resources to challenge or operationalize beliefs, and supporting individuals or groups who are ready to implement new beliefs and instructional practices (Chism, 1998; Loucks-Horsley et al., 1998).

Third, further validation is needed of our proposed model of change in personal practical theories. Evidence must be obtained through research using a variety of methodologies and data collection tools (such as quantitative measures in large-scale studies) and in a variety of contexts. As such work is undertaken, we encourage attention to other key factors, such as dissatisfaction, that can shed light on the process of reform as well as to the mechanisms needed to support change efforts. Questions such as the following need further exploration: Is dissatisfaction a binary condition, or are there gradations of dissatisfaction? How can an outside agent stimulate dissatisfaction? Does "stimulated dissatisfaction" lead to reform, and if so, for whom? What personal characteristics allow one to operate productively while dissatisfied? What characteristics make individuals and systems ready for reform? What critical support mechanisms are needed to influence teachers' knowledge and beliefs about content, pedagogy, and the nature and role of teaching and learning? How does pedagogical content knowledge enhance or constrain reform efforts? Which contextual barriers exist as insurmountable barriers and require outside interventions? Which contextual barriers can be mediated through other means?

Fundamental educational change is difficult, and repeated attempts at reform have resulted in the "paradox of change without difference" (Woodbury, 2003; Woodbury & Gess-Newsome, 2002). Among the potential explanations for this paradox, our study was able to focus closely on the role of teachers' knowledge and beliefs as mediators of reform. One thing is clear from our findings: The foundation of systemic change is individual change. Like Feldman (2000), we are convinced of the centrality of teachers' personal practical theories, and we argue that teachers' dissatisfaction with their instructional goals and teaching practices is a prerequisite to educational reform.

Notes

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[1]The grant provided funding for summer curriculum development by the course instructors, the purchase of data collection equipment and computer technology, support for team teaching that facilitated the integration of several scientific disciplines, and program evaluation.

[2]Examples of this study's modifications of Woodbury and Gess-Newsome's (2002) original model for the college classroom include the lack of high-stakes testing in college courses for nonmajors, the focus on change efforts prompted by government grant initiatives (as opposed to K–12 reform documents), and the role substitution of the college president or dean for the K–12 principal.

[3]Data notations indicate the type of data (P = planning session, I = interview, FN = field note, CT = classroom transcript), the month and day of data collection (when applicable), and the document page number. All data were collected in 1997. For the interview data, only page numbers are supplied.

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