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Inscriptional practices in undergraduate introductory science courses: a path toward improving prospective K-6 teachers' understanding and teaching of science

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Abstract: Inscriptions play a critical role in the creation and communication of scientific knowledge, yet are afforded little status in traditional science education research and practice. In the vast majority of science classrooms, K-12 and university alike, inscriptions are treated as transparent, unproblematic illustrations of the "content" rather than complex, nuanced renderings of natural phenomena that are part and parcel of the content itself. In an effort to better understand the science preparation of pre-service K-6 teachers, we observed lectures and labs in two introductory non-majors science courses, biology and geology, paying particular attention to instructors' inscriptional practices with an awareness of the constraints under which instructors in such classes do their teaching. Based on these observations as well as formal interviews and informal conversations with course instructors, we present four episodes from course instruction to illustrate both the nature of instructors' inscriptional practices in situ and how one might build on these practices in ways that would support the development of deeper understandings of what it means to do science. We argue that expanding the purview of the science lecture to include inscriptional practices (and other practices in which scientists regularly engage) will better prepare pre-service teachers to support their students development of deeper understandings of the scientific enterprise and more broadly contribute to increased scientific literacy in the general population.

Keywords: undergraduate science teaching, pre-service teachers, inscriptional practice, visual representations

I. Introduction.

To ensure that elementary teachers acquire an adequate foundation in mathematics and science content, state licensure requirements typically include at least two undergraduate courses in these domains. Yet, several decades of research suggests that the correlation between undergraduate coursework and teacher subject-matter knowledge is weak at best. Pre-service teachers emerge from undergraduate courses with "mechanical" or static views of the disciplines – able to recall facts or follow rules, but unable to explain underlying systems (McDiarmid, 1992; Floden and Meniketti, 2005).

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In science, the gap between ideal and real has been attributed to a gulf between a "reform" vision for K-12 science learning and instruction (cf. Gamoran et al., 2003; Lehrer and Schauble, 2004) and the views of the science disciplines communicated in undergraduate education. At the heart of the reform vision are teachers who possess flexible understandings of "big ideas" in science, understand how scientific knowledge is generated and revised, and who recognize scientific theories as responses to conceptual problems (Hewson et al., 1999). However, undergraduate science courses typically immerse students in a flood of detail, offering little sense of the conceptual connections or lines of inquiry – much less the norms of practice – in which such details gain significance (McDiarmid, 1992; Sunal et al., 2007).

This paper delves more deeply into the dynamics of undergraduate science courses typically taken by prospective teachers, exploring how disciplinary norms and practices are communicated to students. Drawing on data from a longitudinal study of elementary teachers' learning in mathematics and science, we focus on how one key disciplinary practice, inscription, is enacted in two introductory science courses, biology and geology. We use the term inscription to denote material, non-prose *externalizations* of scientific models, concepts, and phenomena ranging from near literal depictions such as photographs to data displays to mathematical equations to structured text (i.e., lists and outlines). The term representation is reserved to refer to *internal* or *mental* representations (Roth and McGinn, 1998). Following the lead of other researchers in the fields of the sociology of science and science education, we make this distinction both for the sake of clarity and to recognize these displays and their use as distinct components of scientific practice.

Probing the nature and use of inscriptions in these courses, we offer a set of observations that are consistent with prior research, but also point to opportunities to make this and other forms of disciplinary practice more explicit even in the confines of "traditional" introductory courses. The kinds of changes we propose are intended as a "first step" in broader institutional reform. Given the slow nature of such reform (and the many sources of institutional resistance), we believe it is useful to look carefully at what kinds of incremental shifts have the potential to affect students' understandings of scientific practice.

II. Background.

The primary goal of both K-12 and undergraduate science education, especially for non-science majors, is commonly considered to be the development of scientific literacy. While the term scientific literacy lacks a singular, broadly held definition (Baur, 1992; Laugksch, 2000; Lehrer and Schauble, 2006; McGinn and Roth, 1999; Roth and Barton, 2004; Shamos, 1995), in the corpus of scholarship on science education and philosophy of science, it is possible to identify a set of shared themes regarding what a person should know and be able to do as a citizen and as an individual. Chief among these are knowledge for personal wellness and understanding of the nature of science and scientific inquiry (Bybee, Powell, and Trowbridge, 2008).

Missing from this consensus, and indeed from the traditional definitions of both the nature of science and scientific inquiry, however, are insights provided by socio-cognitive and socio-cultural views of the scientific endeavor (Roth and Barton, 2004). These insights derive from studies of science in practice, which make evident the need for science education to provide opportunities for student engagement in "science-in-the-making" as opposed to student exposure to the "ready-made-science" (Latour, 1987) of textbooks, lectures, and traditional as well as many reform laboratory experiences.

An essential component of scientists' engagement in science-in-the-making are the myriad inscriptions they produce and use as reasoning tools and communicative devices. Research on the history and sociology of science (Lynch and Woolgar, 1990; McGinn and Roth, 1999; Kozma and Russell, 2005), analysis of scientific texts (Lemke, 1998; Pozzer and Roth, 2003), science teaching and learning (cf., Gilbert, Reiner, and Nakhleh, 2008; Kindfield, 1993/1994, 1999; Lehrer, Schauble, Carpenter, Penner, 2000), as well as compilations of interdisciplinary research (e.g.,Biannual International Conference on the Theory and Application of Diagrams, 2000-present) demonstrates that practice and communication in science rely on what Lemke (1998) calls "semiotic hybrids" or descriptions of phenomena that are "simultaneously and essentially verbal, mathematical, visual-graphical, and actional-operational." Lemke notes that "To do science, to talk science, to read and write science it is necessary to juggle and combine in various canonical ways verbal discourse, mathematical expression, graphical-visual representation, and motor operations in the world" (p. 87). Inscriptions[3] and inscriptional practices are critical to *doing* science, yet they are afforded little status in traditional science education practice and research. In the vast majority of instructional settings and materials, inscriptions of the *products* of science, such as a display of the DNA double helix, are used as illustrations to transmit "the content" as if they are transparent and unproblematic. Yet, in doing, talking, reading, and writing science, inscriptions are complex, nuanced tools that are integral to creating and communicating knowledge. As described in the literature cited above, in the lives of scientists, inscriptions serve as means of expressing research goals, reasoning tools, communicative devices within one's community of practice, boundary objects for communication across communities of practice, means of verifying research results, rhetorical devices to persuade the scientific community of the validity of created knowledge, and means of confirming membership in a community of practice.[4]

Using inscriptions in these ways requires certain kinds of competence. Two of the more obvious competencies are the ability to produce and interpret canonical inscriptions. More interesting are those which diSessa (2004) defines as "*meta*representational": competencies that go beyond production and interpretation. Among the *meta*representational competencies identified by diSessa and others are the abilities to invent or design new inscriptions; to critique and compare the adequacy of different inscriptions; to understand purposes for which, contexts in which, and ways in which inscriptions do work; to explain the inscription itself as well as connections across different inscriptions; and to engage with new inscriptions in meaningful ways.[5]

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[3] Of the four semiotic types delineated by Lemke, we identify mathematical expressions and graphical-visual forms as inscriptions.

[4] An example of this last purpose comes from our observations of undergraduate biology majors participating in a summer research immersion program at a Research I university. As part of the program, students attended a weekly journal club, which was dominated by the interpretation and explanation of complex figures in scientific research papers. Participants also spent significant time crafting professional talks on their research findings. Key to this work was optimizing inscriptions they had gathered or created during their tenure. One of the mentors in this program went so far as to say that a successful tenure for a summer intern was one that resulted in the production of a research-paper-worthy figure (unpublished data). Thus it appears that understanding inscriptions and inscriptional practices was considered a significant component of the participants' initiation into this community of practice.

[5] Returning to our undergraduate summer research example, what we likely were seeing at least in part was research community support of the development of metarepresentational competencies.

In the context of scientific practice, inscriptions are products of science-in-the-making, constructed and employed to accomplish the purposes delineated above. The referents of inscriptions are natural phenomena and means of capturing relevant data (e.g., a structured investigative protocol, a diagram of an experimental procedure, a photograph of a piece of equipment, etc.). Inscriptional competencies are the abilities that allow scientists to connect natural phenomena and descriptions of natural phenomena.

The profoundly complex relationships among the uses, inscriptional competencies (both simple and metarepresentational), and referents of inscriptional practice are exemplified in Bruno Latour's (1999) analysis of the work of a botanist, pedologist, and geomorphologist who seek to understand the dynamics of the savanna-forest border. In his essay "Circulating Reference," Latour addresses the inevitable trade-offs as one moves from phenomena to inscription and vice versa. As observable phenomena are transformed into inscriptions, certain aspects of the phenomena are reduced to a form that can be circulated among relevant parties regardless of their physical proximity. This reduction necessarily means that some irrelevant information is lost and relevant information is compacted into inscriptions that can be circulated. Recipients who are knowledgeable in the domain can use their specialized competencies to unpack these inscriptions and in a sense return to the phenomena. Those who lack such knowledge and competency have little, if any, capacity to understand the inscriptions beyond their surface features.

Lowe's (1994) work on the relative ability of professional meteorologists and college graduates unfamiliar with the discipline to work with weather maps exemplifies this point. Lowe describes diagrams as presenting "a highly selective view of the subject matter" (p. 468) that require domain-specific knowledge for their interpretation and use, a description borne out by the domain experts in his study being able to meaningfully interpret and extend a weather map while the novices in the study could not. The college graduates in Lowe's study were much like our target population, pre-service K-6 teachers, who come to their survey science courses with little substantive disciplinary knowledge. If prospective teachers are to become scientifically literate and able to support the development of scientific literacy among their future students, they must be provided experiences that promote the development of inscriptional and metarepresentational competence as an avenue to understanding disciplinary content and practices.

Yet, in typical undergraduate and K-12 science instruction, students are exposed to surface features rather than substantive practices of scientific inquiry. This superficial exposure combined with the obligatory lecture on the nature of science serves as the foundation on which students are to become scientifically literate. Consequently, students walk away from their science classes with little understanding of either general or discipline-specific features of authentic scientific work. Whereas there is broad recognition that these outcomes are problematic, the norms sustaining typical practice are deeply ingrained. Those who would even attempt to teach from a science-in-the-making perspective at any level confront a host of cultural and logistical constraints. As a result, we find ourselves in an entrenched cycle in which teachers from elementary school through college teach science as it was taught to them – giving content-jammed lectures driven by inscription-packed slides that are treated as unproblematic illustrations, and running labs that at best include contrived inquiry projects but more often than not follow a cookbook model.

There are some documented attempts to move in the direction of teaching undergraduates from a science-in-the-making perspective, particularly with regard to inscription. Lunsford et al. (2007) designed and implemented a biology laboratory course for prospective science teachers in which students have free access to the laboratory and inscriptional practices play a prominent role. Bowen and Roth (1998) have reported on the use of graphs in an introductory ecology lecture. Whereas both studies shed light on inscriptional practice in undergraduate science classes, the former focuses on supporting the development of inscriptional competence among a small number of students (N = 15) in the context of an inquiry-based lab and the latter provides a microanalysis of the use and interpretation of one type of inscription in the context of a science lecture course. Our study extends this work by considering a range of inscriptional types appearing in biology and geology lectures, and by delving into the relationship between instructors' dual identities as research scientists and teachers of introductory science and the problems and possibilities of inscriptional practice in these contexts.

Our understanding of the relationship between identity and inscriptional practice is informed by the work of Lave and Wenger (1991). In their view, identity is constituted in terms of one's membership within a social community; individuals construct identities with respect to their evolving participation the social practices of that community. As participants in multiple communities of practice, human identities are complex and multifaceted. While in universities the communities of research science and the introductory science lecture overlap in membership, their practices, roles, rules, and relationships remain distinct. Indeed, these communities of practice exist as unique "figured worlds" (Holland et al, 1998).[6] Periodically, however, the instructors in our study consciously or unconsciously blurred these boundaries of practice with varying results. In these occasions, we observed both trouble and opportunity.

The research presented here is part of an ongoing study of prospective K-6 teachers' developing understandings of learning in mathematics and science, the enactment of these understandings as they begin teaching, and the learning outcomes of their students. The objectives are to build models of teacher learning trajectories that might inform the design of teacher preparation programs, and to support the development of appropriate tools to assess the impact of teacher preparation program features on early childhood and elementary-school student learning. Toward our goal of documenting the development of teachers' science knowledge for teaching, in the first phase of our study we sought to understand the forms of inscriptional practice that prospective teachers encounter in their university science courses. Because elementary school teachers take only introductory-level science courses (to fulfill distribution requirements), we devoted our attention to the two courses most commonly taken by our undergraduate teacher education candidates. An overview of the courses and the instructors' impressions of the context in which they teach follows.

III. Courses, Context and Constraints.

We want to emphasize that our intent in what follows is not to critique individuals' instructional practice. Rather, we seek to document features of preservice teachers' encounters with inscriptional practices in order to understand the experiences they would bring to their science foundations and pedagogy courses. The framing offered by Bowen and Roth (1998) resonates for us: "As a member of a culture, the lecturer merely represents practices common in the enculturation of students to the discipline … and this analysis should not be viewed as any indictment of the particular lectures analyzed" (p. 78). This section is intended to orient the

[6] We elaborate on the work of Holland, Lachicotte, Skinner, and Cain (1998) in our discussion of the study context below.

reader to several key elements of the culture within which our focal instructors and prospective teachers were immersed.

Biology 100 (abbreviated below as BIOL 100) is a course for non-science majors that offers broad coverage of the biological sciences. Particular emphasis is placed on basic biological processes in cells and the relationships/interactions between organisms and their environment. The instructors further describe the course as offering a biological "way of thinking" and vocabulary for students to apply biological principles in their lives. Enrollment in this three one-hour lecture/one three-hour lab per week course ranges from 90 to 120 students (lab sections are capped at 24 students). At the time of our data collection, the fall and spring offerings of the course were taught by Professor Dillon and Professor Wiley[7] respectively using virtually the same lecture and lab syllabi. Both are senior lecturers and experienced research scientists.[8]

Geology 101 (abbreviated below as GEOL 101) is an introductory-level geology course, focusing on processes affecting the earth, relationships between these processes and products (earthquakes, minerals and rocks, mountains, ocean features), and the impact of these interactions on the earth and humans. Like BIOL 100, the course includes three one-hour lectures and one three-hour lab each week. Enrollment ranges between 120-130 students per semester. An overarching goal of the course is to help non-majors look at the physical world around them with greater appreciation of the natural forces at work, as well as to provide students with some knowledge that might position them to think critically about public policy on topics such as global warming or energy conservation. For example, during the semester we observed, students were required to attend a screening and panel discussion of *An Inconvenient Truth*.[9] Also like BIOL 100, GEOL 101 is offered during both the fall and spring semesters, and while taught by two different instructors, syllabi and assignments are virtually identical. During the semester that we observed most intensively (Spring 2007), the course was taught by a senior lecturer, Professor Brown, who had served as a petroleum geologist for a major oil company in addition to pursuing academic research at the university.

At the surface, our observations confirmed prior research characterizing undergraduate introductory-level science lectures. The courses met in large, theatre-style halls, with all seats facing a lectern at the front and a large screen hanging from the ceiling behind the instructor. Instructors stood at the lectern and talked for most of the period, projecting PowerPoint slides to support their presentations of content. While these slides included some prose, the vast majority of slides (over 70%) relied on other inscriptional forms to develop content. On average, biology lectures included 10-12 slides; geology lectures included closer to 20. Occasionally, the instructor used a board or overhead to elaborate or simplify one of the images projected.

The four instructors involved in prepping and teaching both BIOL 100 and GEOL 101 were personable, approachable and prepared for each class session. They enjoyed teaching these courses and were committed to providing opportunities for undergraduate learning. When asked about the kinds of constraints they perceived in teaching this type of course, instructors noted numbers of students,

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[7] Instructor and course names are pseudonyms.

[8] Whereas the senior lecturers teach the lecture portion of both BIOL 100 and GEOL 101, biology labs are primarily taught by senior undergraduate biology majors; geology labs by graduate students in geology. Lab TAs typically lecture for 10-15 minutes at the beginning of each lab and circulate during the remainder of the lab while students carry out the day's activities.

[9] BIOL 100 students also watched *An Inconvenient Truth* during one of their lab sessions for similar purposes especially as they related to ecological impact.

> Yeah, I think the institutional constraints more revolve more around the size of the class, you know the facilities that you have, you know. I've noticed that in the years that I've been doing this if you can have them in small groups every thing works out so much better but you can't do that when you have 120 students enrolled in the course. It's just not possible to give everyone individual attention every day…Even in the lab, you still have 24 students you still have to take care of and you have one TA to help, there's just no way you can get around to all of them and that's just the nature of how this works (Wiley interview, February 26, 2007) .[10]

the nature of the teaching space,

> You know this course could be probably a third as long as it is if we could teach it in the field. That would be the best way to teach this class. It's terrible to try to teach anything about the natural world in a lecture … in a lecture room that's below the ground surface even (Brown interview, March 29, 2007).

and lab access

Wiley:	Yeah I would change the lab in, what I'd like is to have more time … I would love to have lab day you know but I can't do that … You could do so many different things if you had either longer blocks of times or more variable blocks of time.
Interviewer:	Would you advocate … free access to the lab?
Wiley:	I would love to have that. Yeah. I mean I have thought about doing that in my genetics lab. But I keep being told there are liability issues … But yeah I would love to have free access to the lab (Wiley interview, February 26, 2007).

The instructor for the fall biology course, Professor Dillon, similarly expressed a desire to make labs more inquiry based but noted that it is difficult to manage the "realities" of real inquiry such as providing unscheduled lab access, overcoming an entrenched and inflexible university master schedule to allow for different configurations of meeting times, and protecting instructor time to "come up with a good plan" (Dillon interview, October 20, 2006).

As student numbers, lecture halls, lab access and the university master schedule posed institutional obstacles, so too did the available range of published instructional resources and the time (or lack thereof) available for curricular design. For example, typical introductory biology textbooks and ancillary materials present topics in a standard "levels of organization" sequence (i.e., from atoms and molecules to ecosystems) that most readily supports teaching introductory biology, both lectures and labs, according to this sequence. Deviating from this sequence would require time on the part of the instructor not to simply rearrange topics but to reconceptualize the course according to a new framework that is not supported by most available resources. Even if

[10] Throughout the paper, quotations from interviews for which we have transcripts are shown either in indented paragraphs or quotation marks. Close paraphrases from class sessions, based on observers scripted notes, are shown in italics.

an alternative resource were available, the instructor might not find it suitable as noted by one of our biology instructors,

> I've sort of experimented in past semesters, like the text up there, *Bio Inquiries*, … presents things in a different order starting with … DNA, genetics, then evolution and then coming back to cell biology and more biochemistry stuff at the end. I … actually like that sequence better, but it's hard to do with Campbell [and] I don't like the Pruitt text enough so … you got to pick and choose [supporting materials]… [A]s I said if I had my choice I would present things in a slightly different order … but the text sort of keeps you from doing that. The one year I did that [using the standard text], kids never knew where we were in the textbook (Wiley interview, February 26, 2007).

Beyond the constraints of time, space, and resources were the disciplinary and student norms for introductory science courses. As PhD scientists, the instructors approached their courses knowing how the pieces fit together in the larger context of the discipline and having a sense of what "should" be included. Their "should" list was informed by their experience as students, textbooks designed for such courses, syllabi from prior offerings of the course, and their respective perceptions of their disciplines. In addition, there were more general departmental criteria for what "should" be covered (though fewer than would exist for an introductory course for majors). This created a tension between covering all the "stuff" in a topic and keeping up with the syllabus that delineates a long list of topics. Different aspects of this tension were evidenced by our instructors in both interviews and informal conversations. One such conversation occurred between one of us (AK) and Professor Wiley after the March 21, 2007 biology lecture. With two slides left to go and one minute left in the lecture, Wiley covered both slides, contending with increasing noise from the students as he went overtime by about two minutes. In conversation after class, Wiley confessed that he knew he had gone past 10 a.m., but, with good intention: he just wanted to get the last two slides in because doing so made the lecture complete and would allow him to begin a new section of material that according to the syllabus should have started on March 19. In an interview, Wiley addressed a different aspect of "coverage":

> I would say probably the most challenging thing is not getting bogged down with the minutia, all the details, but still not simplifying it so far as to make it meaningless. I mean it is sometimes hard to decide what to leave out and what to put in. I mean today's lecture [about DNA replication] is a prime example. You know I wrote my thesis on how chloroplast DNA is replicated in algae. So I could go on and on about leading and lagging strands and all of these wonderful details but as soon as you do that you, you lose the points you want to make … to me that's the most difficult thing, figuring out what details to leave in so that you don't dilute it so much that it's meaningless versus how many details do you put in so [it] doesn't become overwhelming. Because I think that the vast majority of kids that are in this class are not interested in science because they think it is overwhelming and they think they are not going to be any good at it (Wiley interview, February 26, 2007).

Instructors also noted how student expectations confounded the pressure for coverage. Students wanted instructors to "stay on track": one of our instructors said that when she got one or two days behind, students complained mostly because it raised confusion about what would be on the test (Dillon interview, October 20, 2006). This remark highlights what often appears to be the overriding student concern in a large lecture: knowing and paying attention to what will be on the test. Students who come to class arrive with a model that this concern will be addressed by listening to the instructor talk while they take notes. They frequently remind instructors to indicate when material at hand will be on the test vs. when it is tangential—and in our observations, instructors typically complied. Finally students expect and prepare for test questions (and other assignments) that are fairly straightforward, with right or wrong answers.

> I think that's the nature of students especially at an institution like [this]. There's a right and wrong answer and darn it, I want to get the right answer. So yeah I think that's the biggest thing that we have to defeat is the mindset that there is a right and a wrong answer and you know and it's not whether it's right or wrong, it's whether your data can support your conclusions or not … I can feel good I think if I have 5 to 10 students who really have an answer where they're writing it down, it's their thoughts and their words and their sort of probing beyond where the level that I presented them rather than just the superficial answer which is the bulk of what I get (Brown interview, March 29, 2007).

> The lab is the place that they are supposed to put science into practice. So it's the place where they're supposed to form a hypothesis, test a hypothesis, and draw a conclusion based on the data that they have generated and decide whether their data supports or refutes their hypothesis. That's what's supposed to happen … I think they forget the hypothesis part. They're ready to generate whatever data they're going to generate, analyze it in whatever way we've asked them to analyze it, you know whether it's do a calculation or whatever, and then ask whether it's right or not … (Wiley interview, February 26, 2007).

The instructors' comments support the view that a variety of institutional constraints and cultural norms converge to shape the implementation of undergraduate introductory science courses, defining many aspects of what might be covered in these courses and how. These norms and constraints are formidable, enmeshed in ways that make significant change seem nearly impossible – especially change involving the incorporation of disciplinary practices as objects of instruction. In conceiving of what might be entailed in this change, we find it helpful to draw on the conceptualization of "figured worlds" by Holland, Lachicotte, Skinner, and Cain (1998). As defined by Holland and her colleagues, a figured world is "a socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others" (p. 52). As illustrated above, in undergraduate science lectures, instructors and students (actors) are understood to have particular roles and responsibilities, and are expected to carry these out in particular ways. Instructors are obliged to present information through both assigned readings and exercises and by talking through slides projected on a large screen. These activities are supposed to prepare students for tests. Officially, students are expected to attend, listen, take notes, read, and complete assignments in order to prepare for tests.

Within this figured world there exist distinct rules for discourse, for example negotiated times during which an instructor may pose a question to the class and other times when students may pose questions of the instructor. Violation of these norms by faculty may carry the consequences of low instructor ratings on course evaluations. The time frame of introductory science class is also clearly bounded. While most students were attentive to the instructor during lectures, toward the end of the hour all students packed up books and computers, letting instructors know it was time to wrap up the presentation.

Figured worlds are also distinguished by the ways in which artifacts are used and interpreted. For example, while the same *types* of inscriptions appear in both the figured world of science-in-the-making and the figured world of traditional introductory science (e.g., graphs, diagrams, maps, etc.), the inscriptions take on wholly different meanings. These meanings are shaped by the conventions for engaging with the inscription (*inscriptional practice*) and the use or *purpose* to which the inscriptions are put. In our study it was quickly evident in observations and interviews that for instructors, inscriptions were layered with meaning and purpose associated with the enterprise or figured world of scholarly science. It was equally evident that the undergraduates imputed very different meaning and sense of purpose to these same inscriptions, enacting the figured world of traditional introductory science.

Significantly, figured worlds are dynamic rather than static: change results from human improvisation as well as the appropriation and reshaping of practice. As we explained to the instructors when we sought permission to observe their lectures and labs, one of our hopes was to find "leverage points" – experiences in undergraduate science from which prospective teachers might build as they transform their knowledge of central scientific concepts into a pedagogy of elementary science. Thus, through our observations and analysis, we not only began to establish a picture of the forms of disciplinary practice our prospective teachers encountered in their Arts and Science courses, but also began to identify moments in which disciplinary practices from the figured world of scholarly science *could* become objects of instruction and appropriated into the figured world of undergraduate science.

IV. Episodes of Practice and Pedagogy.

In our analysis reported here we focused on ten lectures (six in biology, four in geology) for which we had the most robust sets of observer notes synced with the instructors' PowerPoint slides. The format, discourse patterns, and activity structures in this sub-sample strongly resembled the other lectures we observed in each course.

As a first step in examining inscriptional practice, we analyzed each slide that had appeared in the instructors' presentations. We characterized each slide along four dimensions: Type, Purpose, Practice, and Instructional Mode in order to get an overall sense of each display supporting the lecture. Categorization within dimensions was not mutually exclusive: a number of slides involved more than one type, purpose, practice, or mode. Our slide-by-slide examination made visible the episodic structure of each lecture. Episodes, constituted of one or more slides and the discourse and activity structure associated with them, thus became our unit of analysis for describing opportunities for making disciplinary inscriptional practice a more explicit component of introductory undergraduate science instruction.

Given the logistical and normative constraints within which instructors operated, as well as our familiarity with the traditions of university lecture courses, we were not terribly surprised by the broad patterns that emerged from our counts of *types* of inscriptions used in lecture and our coding of pedagogical purposes, inscriptional competencies, and instructional mode accompanying these inscriptions. Turning first to inscriptional types, Figure 1 shows that in geology, the large majority of inscriptions were diagrams, followed by maps and then slides with text only. In biology, photographs and diagrams dominated.

For each inscription or set of inscriptions that constituted an episode, we coded the instructor's apparent pedagogical intent(s) or *Purpose* for displaying the inscription(s) according to a set of purposes that emerged from our analysis. These purpose categories are defined in Table 1.

As shown in Figure 2, instructors generally drew on displayed inscriptions to explain or exemplify phenomena related to the lecture topic.

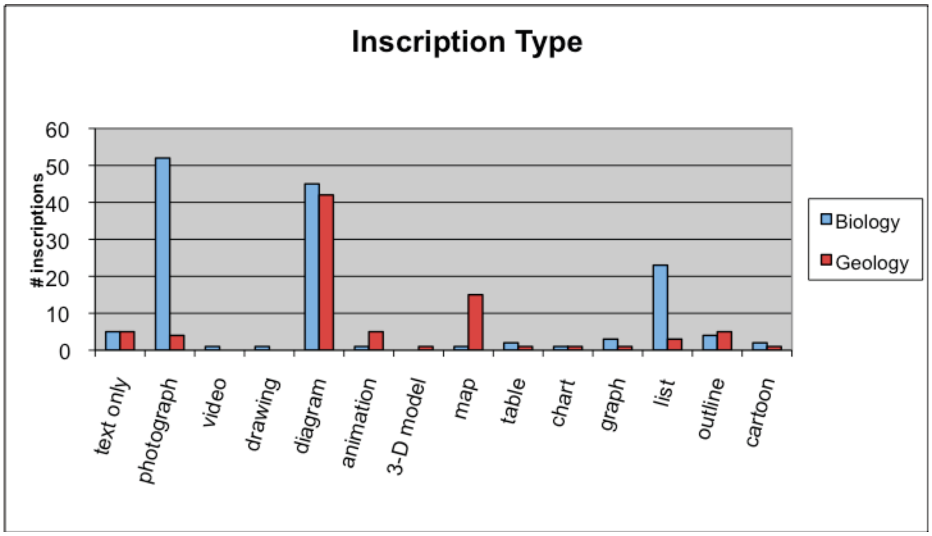

Figure 1. Types of inscriptions displayed in lecture.

Table 1. Descriptive categories for purpose.

Category	Description
None	No apparent purpose
Illustrate	Show what something looks like – offer a visual "definition".
Explain	Clarify some dimension of a phenomenon with a focus on what it is, what it consists of, or how or why it "works".
Exemplify	Offer a depiction as an instance of a broader class of phenomena ("This is what it *can* look like." or "Here's one.").
Provide Evidence	Provide evidence in support of a phenomenon or claim under discussion.
Other	Grab students' attention, change mood (e.g., with humor), etc.

Table 2. Descriptive categories for Inscriptional Competence.

Category	Description
Take as Given	Offer inscription as information – as if completely transparent. Treat the inscription as the phenomenon, not an inscription of the phenomenon.
Decode	Point out some aspects of the inscription for clarity; explain key conventions.
Interpret	Draw some scientific inference from the inscription.
Critique Superficially	Comment on how well an inscription represents a phenomenon although not to the point of comparing inscriptions or explicating affordances, etc.
Generate	Produce a "standard" inscription of a phenomenon.

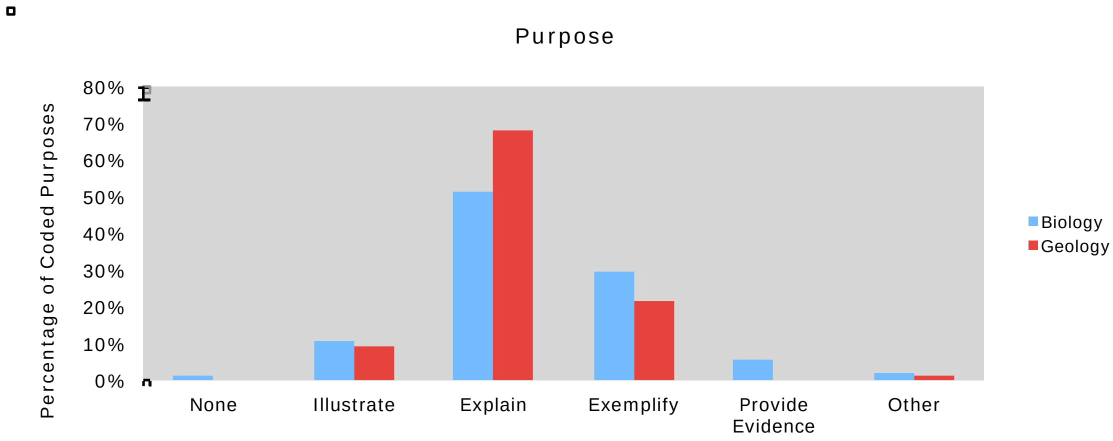

Figure 2. Purposes for which inscriptions were used in lecture.

For each inscription or set of inscriptions displayed we also developed categories of *Inscriptional Competence.* These categories were largely empirically derived but roughly correspond to basic representational competencies. They include: take as given, decode, interpret, critique superficially, and generate. Each category and its meaning is shown in Table 2. In the course of data analysis we also considered a set of potential metarepresentational competencies adapted from diSessa (2004). While we rarely observed these competencies, we found it useful to keep this level inscriptional competence in mind, as it helped us identify opportunities for instructors to utilize metarepresentational competencies to advance students' understandings of scientific ideas in the context of a large lecture.

In both courses, the dominant inscriptional competency was "take as given". By this we mean that the inscription was not treated as an object of instruction. However, in the geology course, the instructor did spend time helping students "read" the slides – decoding inscriptions (30% of coded instances), identifying what meaning he drew from the slide, and in a few instances, addressing the affordances of particular strategies for representing three-dimensional phenomena (see Figure 3). This attention to how an inscription made particular features visible was consistent with his interest in problems of visualization. As he noted during our interview: "Within geology I do something called structural geology. [You look at the] folding and faulting of rocks, the deforming of rocks in different ways… I've spent a lot of time looking at things in three dimensions in my research in academics and professionally as a petroleum geologist" (Brown interview, March 29, 2007).

Whereas in biology 75% of the inscriptional practices displayed were coded as "take as given" there were several instances of "decode," interpret," and "generate." Interestingly, instructors in biology were more apt to "interpret" (an action typically not made explicit by the instructor) than "decode" (an action made explicit by the instructor) with three of the four instances of decoding paired with interpreting. In other words, relatively speaking, there were a number of instances where the instructor clearly made an inference from an inscription (e.g., stated the meaning of a graph) without articulating how s/he "read" the inscription to arrive at the inference.

Finally, we considered the *Instructional Mode* or ways in which the instructor positioned her/himself and students in relation to content. While purpose and inscriptional competence are important primarily in relation to materials (i.e., the slides) presented by the instructor, the

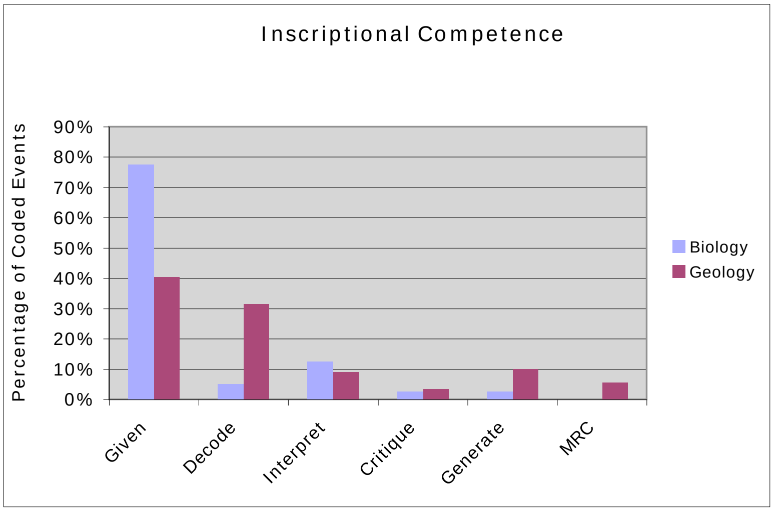

Figure 3. Inscriptional Competence displayed by instructors during lecture.

importance of the instructional mode dimension lies in its capturing instructor/student interactions. The categories along this dimension were largely empirically derived and include: tell facts, tell stories, tell reasoning, tell inscriptional conventions, model reasoning, model use of inscriptional conventions, invite to name facts, invite reasoning, and invite to practice using inscriptional conventions. Each category and its meaning is shown in Table 3.

In both courses, the dominant mode of instruction was coded as "tell facts" and to a lesser extent "tell reasoning" or "invite to name facts". In geology, however, we noted several examples of the instructor modeling reasoning, and even a few cases in which the instructor invited students to reason or practice conventions. While biology instructors did occasionally model reasoning as well as invite students to model or practice reasoning, we observed no instances of these instructors working directly with inscriptional conventions by telling, modeling, or inviting students to practice them (see Figure 4).

Although these patterns echo themes in earlier investigations of undergraduate science teaching, over the course of our observations we came to realize that there is more to be understood here. In the exceptions—represented on the further end of the continuum of inscriptional competence and instructional mode—something interesting was going on. While lectures were highly constrained, periodically they also became sites in which instructors revealed their identities as research scientists by appropriating not only artifacts but also practices from the figured world of scholarly science. As illustrated in the following episode (Geology Episode 1), such moments raised the question of how instructors might leverage their dual identities to bridge introductory level science with scientific practice.

A. Geology Episode 1: Revealing, but Marginalizing, Professional Inscriptional Competence (January 15, 2007).

Professor Brown opened the third lecture of the course by noting that he wanted to provide some clarification on the notion of physiographic provinces discussed in the prior lecture. During the earlier session, Brown had defined a physiographic province as

[A] region all parts of which are similar in geologic structure and climate, and which has consequently had a unified geomorphic history. A region whose pattern of relief, features, or landforms differs significantly from that of adjacent regions (Brown lecture slide, January 12, 2007).

Table 3. Descriptive categories for Instructional Mode.

Category	Description
Tell Facts	Provide end-product knowledge (the "facts").
Tell Stories	Present "disciplinary lore"—canonical stories about findings, progress in the field, etc.
Tell Reasoning	Describe how scientists in the discipline (including self) think about particular problems or phenomena.
Tell Inscriptional Conventions	Note the meaning of different components of an inscription.
Model Reasoning	Demonstrate how scientists in the discipline think about particular problems or phenomena by "thinking aloud".
Model Use of Inscriptional Conventions	Explicitly apply conventions for representing a phenomenon or reading an inscription.
Invite to Name Facts	Ask students to recall information (from a previous lecture or elsewhere) typically using IRE.
Invite Reasoning	Ask students to think about a problem or phenomenon from the perspective of a scientist. When invitations are "successful", students are visibly engaged in reasoning about a scientific idea or problem.
Invite to Practice Using Inscriptional Conventions	Ask students to try/apply conventions for inscribing a phenomenon or reading an inscription. When the invitation is "successful", students connect directly with content by reading or making an inscription.

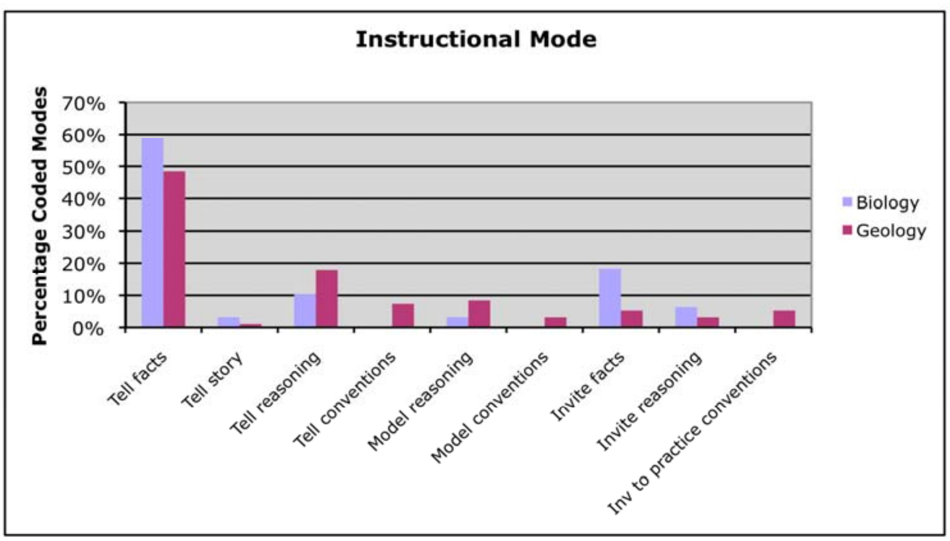

Figure 4. Instructional Mode when displaying/using inscriptions in lecture.

He had then begun to outline major divisions of the continents (students had a handout that characterized these divisions, as well as divisions of the oceans). Now Brown projected and decoded a shaded relief map of the United States, saying: *All of the bumps, that means* *something. If you look you can begin to see defining features. The Mississippi River runs through here and it's ultra flat; in contrast note the Appalachian Mountains here. Those broad definitions are physiographic provinces.* Over the next few minutes, Brown projected several more topographical maps for different physiographic provinces around the world.

Then he announced: "I'm going to diverge a little. I want to talk about the connection between the landscape and plate tectonics." The next slide he projected was a magnetic map featuring the eastern portion of North America with the title: "Who Cares? A tangent into Brown's world – Amazonia in Appalachia" (see Figure 5).

> Brown: *This is a magnetic map of the US. It is derived from people flying low in airplanes and doing measurements with magnetometers. Then all of the data are compiled in a map. It looks maybe to you like nonsense, but in the colors there seem to be patterns. Note the line from Alabama to New York. A line that exists in covered shield* [points out lines in the covered shield indicated by magnetometry readings].
> Brown: *This is what is really cool. We - I - just found out over the summer that in those rocks, way below the surface, there are places where two pieces of continental crust are glued together. If you go on the other side of this line* [points to reddish line on the magnetic map], *all of the rocks in that basement – the lower levels – are from South America. This is something new and fascinating. I hope it gives you an idea about why it's neat to think about physiological provinces in ways I'm encouraging you do.*

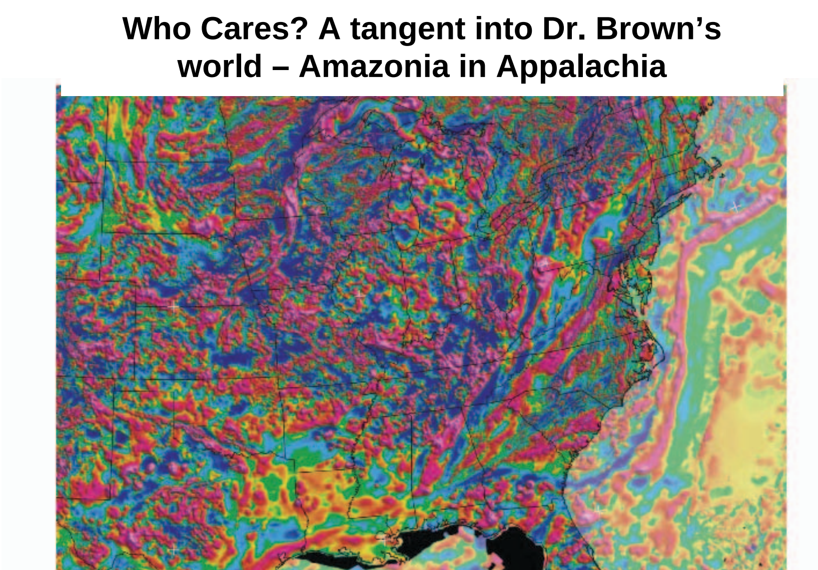

Figure 5. Slide display of magnetic map featuring the eastern part of North America.
Image is provided by the US Geological Survey [http://crustal.usgs.gov/projects/namad/DNAG.html].

In this very brief (approximately two minutes) episode, Professor Brown shared a particular form of data display, a magnetic map, organized to reveal distinct physiographic characteristics of a location familiar to the students, the United States. Recognizing that for students the map might look "like nonsense", he briefly decoded and interpreted the significance of the colors as he gestured to the line from Alabama to New York. Brown further suggested that such data have contributed to the recent discovery that "all of the rocks in that basement are from South America." Hence, the slide also exemplified the collection and reading of data in relation to a theoretical model, plate tectonics. Finally, Brown linked this ongoing research back to the concept of physiographic provinces, which the prior lecture had begun to define.

Brown's apparent intent was to show how a scheme for characterizing parts of the earth's crust had advanced a theory that revolutionized the subfield of geology (and which animated the course), plate tectonics. As we examined this episode, we were taken with Brown's move to open a window on the use of a particular form of data representation in supporting, or constructing, a scientific explanation. Magnetometer readings assist geologists in determining the placement and types of rocks below the surface of the earth. Coordinating these readings enables researchers to identify significant similarities and differences in crustal features, and to make conjectures about how they came about. Hence, for practicing geologists the magnetic map is an inscription that does work. While in the prior lecture the term "physiological province" existed as one of many vocabulary items, here Brown reframed it as a construct that, like the map, is a tool of practice.

And yet, Brown labeled the slide and his discourse around it as a *tangent*. This was not the usual business of GEOL 101, but a detour into Brown's world outside the lecture hall. In that figured world of research science, the purpose of an inscriptional display is scientific—organizing data, supporting reasoning, providing evidence—rather than simply explanatory or illustrative. Accordingly, competent "reading" of such displays involves understanding these purposes, recognizing the work that they do and assessing their affordances and constraints in relation to other inscriptions. Of course in this other world, inscriptional competence also includes the generation of new and sometimes novel inscriptions. Here in the lecture hall, however, Brown only alluded to this intricate task of reading.

Episodes like "Amazonia in Appalachia" made clear that instructors brought a rich sense of the conceptual and empirical significance, purposes, and limits of the images they shared with students. As with Latour's (1999) pedologist, these images were part of a complex chain of reference, telescoping the features of phenomena observed in scholarly investigation to systems of conjecture and hypothesis. For these instructors, even textbook diagrams could reference and connect to more "scientific" displays. However, such sense was invisible to students. While inscriptions projected via PowerPoint were an all-pervasive feature of the undergraduate lectures, for the most part, they remained unexamined enactments of practice.

Given our view that understanding of inscriptional practice is an essential dimension of science content knowledge for teaching, we found ourselves drawn to those rare moments when faculty in some way called attention to inscriptional work, signaling a different kind of engagement with the content. At these times, the instructors drew explicitly on their experiences as practicing scientists in the fields of structural geology and tectonics (Brown), ecology (Dillon), and microbial genetics (Wiley). Our coding scheme tended to pick up these moments in two ways: either coders indicated "higher" level descriptors (interpreting rather than taking as given; modeling reasoning or conventions, rather than telling, etc.), or we had some initial disagreement about how the episode should be coded and sometimes ended up "double-coding", for example, as tell *and* invite reasoning.

We consider these episodes to be not merely interesting examples of instructors' converging identities, but also as opportunities to be exploited. In the following pages, we present and comment upon three more episodes to illustrate how, even within the constraints of space, time, number, and normative culture, introductory level science lectures might become spaces in which practices of science take a more central role in pedagogy.

B. Biology Episode 1: Navigating Multiple Inscriptions of the Same Phenomenon (February 26, 2007).

During weeks 7-8 of the 15-week Spring ’07 semester, Professor Wiley devoted 3 lectures to the primary processes of molecular biology, DNA replication, transcription, and translation. The lecture from which this episode derives was the second lecture in this set. His goal was to explain various aspects of DNA replication. During this 25 minute episode, Wiley referenced the 3 slides (see Figure 6).

All three slides in the episode depict DNA replication; different aspects of the process are made salient on each slide. The first slide (Figure 6: top) focuses on the semi-conservative nature of DNA replication. It shows the double-helical structure of the DNA, and uses color to distinguish “old” strands from “new” strands. The double helix and the color convention are retained on the second slide (Figure 6: middle), which focuses on origins of replication and includes depictions of pre-process, in-process and post-process DNA molecules. The third slide (Figure 6: bottom) focuses on the actual process of replication. Although the color convention for the “old” and “new” DNA strands is retained, other inscriptional elements vary considerably in relation to the first two slides: the helical nature of the DNA molecule is no longer depicted, many parts are labeled, and two entities are added (the enzymes DNA polymerase and DNA ligase). Interestingly, the inscriptions of the DNA molecule in the first and third slides are quite similar; they could easily be superimposed, retaining many of the same features. The first two slides were from the textbook; Wiley had obtained the third from a website associated with a similar course at another university. Wiley used each of these slides extensively, pointing to various locations and adding his own diagrams to the first and third slides:[11] the three sets of paired lines on the middle right (ultimately with nucleotide letters—not shown) on Slide 1, and the group of geometric figures under “Step 2-Elongation” on Slide 3. He progressed from one slide to the next, periodically asking students to name facts (e.g., *What’s needed to go into mitosis*?) but answering most of questions himself due to lack of student response.

In addition to inviting students to name facts, Wiley invited students to practice reasoning by posing a “riddle” (his words) early in the episode while still using the first slide. The riddle concerned how one aspect of the process of replication could occur (i.e., overall 3’ => 5’ synthesis of a DNA strand) given a constraint inherent in the process (nucleotides can only be added to a growing strand in the 5’ => 3’ direction). He said,

> *I am going to present you with a “riddle”. Which way do you think this* [DNA replication] *is happening? … One chromosome is growing this way and one the other* [pointing to diagram], *but I’m going to tell you in just a minute that DNA only grows in one direction. This causes a problem. How can this be? … DNA polymerase* [is the] *major enzyme that copies DNA … it can only add new nucleotides to the 3’ growing end of the chain. The reason for this is at the end you have a 3’ OH group hanging off – so* [the] *strand only grows in 5’=>3’ direction … I am going to leave you with a little riddle* [posed earlier] *that we will try to answer in a minute.*

[11] Wiley used an overhead and transparencies of his prepared PowerPoint slides, making it easy to add to them during a lecture. He routinely elaborated text on a slide and twice (both in this episode) generated his own diagrams during a lecture.

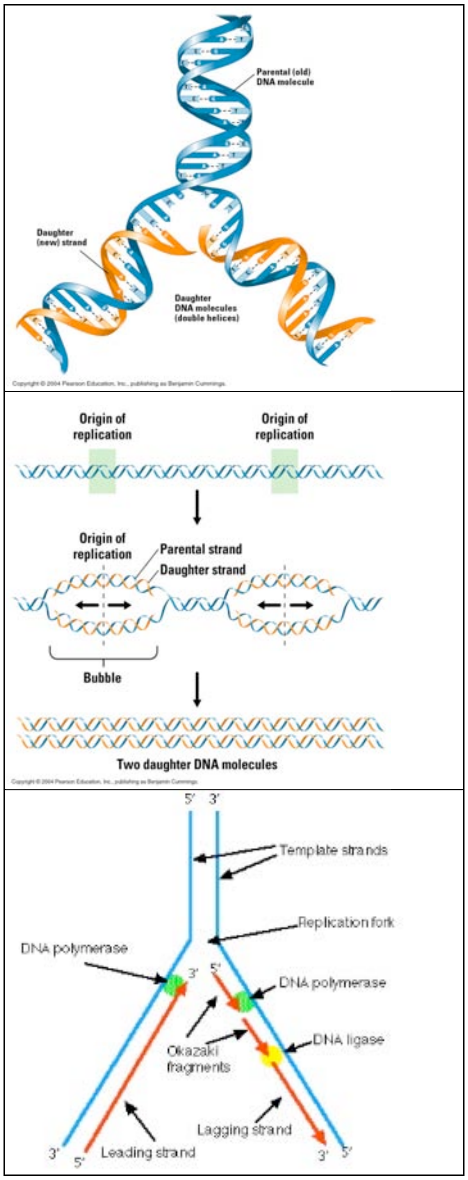

Figure 6. Slides of DNA replication.
Slide #1 – From Campbell, Neil A., Reece, J.B., and Simon, E. J. Essential Biology, 3rd Edition, 2007, p. 176, Fig 10.6. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.
Slide #2 – From Campbell, Neil A., Reece, J.B., and Simon, E. J. Essential Biology, 3rd Edition, 2007, p. 177, Fig 10.8. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.
Slide #3 – From http://www.uic.edu/classes/bios/bios100/f05pm/lect10.htm by Michael Muller, 2010. Reprinted with permission.

The answer to this riddle was depicted in the third slide, but when he reached the third slide and posed the riddle again, students remained silent. Because the first slide did not provide information that would have been useful in solving the riddle, to respond when the question was initially posed, students would have needed to refer to another source, perhaps a reading assignment. The third slide however did contain use information for solving the "riddle", had students used the slide as a reasoning tool and been able to interpret it. When no one offered a solution upon seeing the third slide and hearing the riddle again, the instructor provided the solution using the slide as part of his explanation.

Clear in this episode was Wiley's strong metarepresentational competence. Wiley moved fluidly between different inscriptions of the same phenomenon, adapting textbook images by adding diagrams that included only the features necessary to highlight particular aspects of the phenomenon of interest, simplifying even to the point of misrepresenting some (i.e., the relationship between the various enzymes which was clarified by Wiley's diagram). These adaptations emphasized the relationships across the slides. For example he added a diagram to the first slide using the convention for representing DNA that would be used later in the third slide (i.e., straight parallel lines for the DNA double helix as opposed to paired helical lines). He added a diagram to the third slide of the protein complex that orchestrates the different replication events, two components of which were shown as separate entities in the provided diagram and one that was not shown at all.

However, this complex inscriptional knowledge was not an object of his instruction. Instead, he treated each inscription as a transparent illustration. Wiley's ability to meaningfully navigate the inscriptions remained tacit in the figured world of the introductory science lecture.
What might it look like to make the inscriptional work more visible? One possibility would be for Wiley to pose the riddle with the third slide projected and to encourage students to see if they could figure it out *using* the displayed inscription. He could engage the students in a conversation about what the components in the diagram might mean and what they might indicate about the process of DNA replication. Or to provide even more challenge, he might pose the riddle without the red arrows labeled "Okazaki fragments" in the diagram, asking students if they could figure out how to solve it. The riddle is an interesting one – and a question that scientists trying to understand the process asked themselves. One can imagine these scientists generating diagrams much like the one shown based on the data they had and wondering if the pieces now known as Okazaki fragments could be the solution and if so, how the gaps in between them be sealed.[12]

An alternative approach might be to include in his explanation something about the relationships among these inscriptions, especially between the very similar first and third slides. Taking this tack one step further, he might ask the students to look across the inscriptions to identify the relationships among them and the representational conventions being used and to speculate about the differences among them in relation to the particular content being considered. This would introduce students to metarepresentational competencies as well as provide an avenue toward a deeper understanding of the process being represented.

C. Geology Episode 2: Visualizing As an Explicit Instructional Goal (March 30, 2007).

"Strike and Dip" is a convention by which geologists display 3D structure in two dimensions. In this next section we describe an ambitious attempt to help students understand this key inscriptional tool of structural geology. In the episode described below, Brown placed in each student's hands a simple model (what he called a "strike and dip machine" comprised of two intersecting index cards) and asked students to manipulate the cards in order to visualize 3D structure represented by the 2D strike and dip notation. The episode, during which the instructor momentarily stepped away from the projected image, stood out as the clearest effort we observed to develop students' metarepresentational competence and as such provides a unique example of how such competence might begin to be addressed within the lecture hall. Also important here was Brown's productive leveraging of his dual identities: Brown deliberately enjoined his

[12] They are sealed by the enzyme DNA ligase.

experience and expertise as both scientist and instructor as he worked to make the notational practice and purpose accessible to students.

The structural geology unit came in the 11th week of the 15 week course, and was designed to engage students in one of the central tasks of geology: representing geologic structures and processes – which are three (and four) dimensional phenomena – in two dimensions. This practice is, as the instructor put it, basic to “what geologists do” in academic and commercial enterprises. In the homework assignment and lab that accompanied the three unit lectures, students were asked to “read” two-dimensional inscriptions, visualize the geologic features represented, and also use the notational system to inscribe hypothetical geologic data. While earlier in the course, Professor Brown had shared different representations of data – for example magnetic, thermal, and topographical maps – this was the first time that he asked students to read *and* produce conventional inscriptions.

Figure 7. Photograph taken at Joshua Tree National Park.
Used with permission from Dr. Brendan Bream, Production Geoscience-Special Studies Group, ExxonMobil Production Company.

Brown launched the unit with a photograph (projected in his PowerPoint slides) of a young girl standing in front of an outcropping at Joshua Tree National Park (see Figure 7). He immediately noted the photograph’s limitations:

> *What you can’t see, is in the dike if you could follow around the outcrop, there’s a different expression of it here… [?] a bit of a different resistance to weathering. This is pure geometry. Rocks have some inherent geometry to them. Not like sedimentary rocks, which are flat all the time. There are variations in thickness in the exposed dimensions. I want to teach you the way that geologists take this 3-dimensional structure and represent it on a map.*

For the next half hour Brown projected diagrams, via PowerPoint slides, schematizing the forces that act on the earth’s crust to create different kinds of deformations above and below the surface: “The big thing to get today is that you can deform rocks with differential stress, and it modifies how the rocks look and the volume they occupy” (lecture, March 30, 2007).

Then Brown turned up the lights in the lecture hall to introduce a “strike and dip machine”. Strike and dip, he explained, is the way that geologists represent on a map the results of stress and strain – like the outcropping in the photo he showed at the beginning of class. *The strike and dip is the most regularly used way to obtain information about the geometry of the rock. You first take a compass and measure in the field to get the exact orientation of a plane.*

Here, Brown paused to distribute two index cards to each student in the lecture hall, and asked students to hook the cards together to form two intersecting planes.

Brown*: If you have two planes that intersect, what do they define?*
Student 1: *A line*.
Brown: *A line. We define that as a strike. So use your larger card to represent the imaginary horizontal plane. The strike line is where the two planes intersect. My imaginary plane is the white note card. My inclined surface is the purple note card. Where they intersect defines the strike line. As you rotate the cards around this way, the strike line swings. You get the angle relative to north-south. So now orient your intersecting planes so the strike line is north-south. (*Brown establishes that students in the lecture hall are facing south and students adjust*.) One line has to be horizontal. How would you rotate your cards so the strike was east-west?*
This is the place where some people say, what are you talking about? …Who has no clue what I'm talking about? (About 10 hands go up.) *Okay, I'll go over it again.*

Anticipating that many students would have trouble "seeing" the model, Brown repeated the explanation. Then he asked students to hold up their "strike and dip machines" to define a strike line that is northwest-southeast. As students reoriented their cards, the instructor pointed and nodded to those who "had it", and nudged his own cards to suggest change to others. He continued,

Brown: *So we have a loose orientation of strike. We do this because geologic information about rocks is always 3-dimensional. This usually is not taught in introductory classes, but because it's what I do, I like teaching about it.*
We can show the orientation with a number, how many degrees rotated from north- south, or with a pair of directions that are 180 degrees from each other, northeast-southwest. Who is comfortable with this concept?
(Two students raise hands.)
So that's the first half. The second part is the dip. If I were blindfolded, how would you tell me about this line?
Student 2: *It's diagonal*.
Brown: *Directionally, how is it oriented?*
Student 3: *Northeast-southwest.*
Brown: *Okay, so take your plane and align it. The dip is oriented at 90 degrees off the strike line, and shown as a tick off the strike line. What dip tells me is at a cross-sectional view the number of degrees from horizontal that I go down on an inclined plane. Putting these two things together, we know everything we need to about the inclined plane.*
So now orient your cards so strike line is NE-SW. What direction is it dipping? You can take your card and force it to dip to the SE 30 degrees. A strike on a map and a dip and a number tell me how a formation is oriented. With the

dip on this side, can be 0-90 degrees. Why not greater? Because past 90 degrees it's dipping in another direction.

One way to help you visualize is this: You have the imaginary horizontal plane. One way to think about it is that it intersects top of surface, and you get the strike line. The dip line shows slope of formation away from strike line [Brown refers to slide shown in Figure 8].

One thing we tell people to do when they are learning to be geologists – is to drip some water on the outcrop. The direction the water goes is equal to dip – it is the fastest way to go down. So the water will run off in dip direction. The dip angle is magnitude from the horizontal.

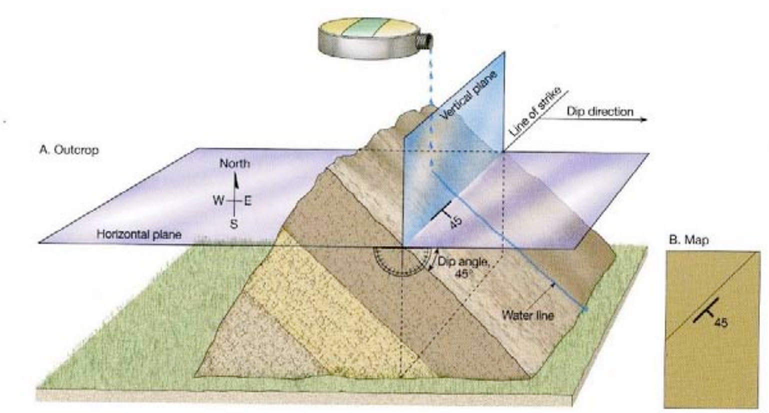

Figure 8. Slide of a three-dimensional view of the imaginary plane.
From American Geological Institute, AGI/NAGT; Busch, Richard, M., Laboratory Manual in Phsyical Geology, 8th Edition, 2008, p. 196, Fig 10.1. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

Thus, while Brown opened the lecture with a fairly "standard" review of the forces which act on the earth's crust to produce different kinds of rock formations, half way through he shifted away from the PowerPoint to help students visualize how an inscriptional convention (strike and dip) coordinates the relationship between the orientation and slope of an outcropping. In the final minutes of the lecture, Brown introduced one further abstraction, block diagrams (see Figure 9). Unlike most of the diagrams students had encountered to this point, block diagrams lack any sort of literal depiction of the contours of an outcropping. However, through a combination of lines (marking sedimentary layers) and directional notations, these diagrams enable one to convey important information about relative age, orientation, and slope.

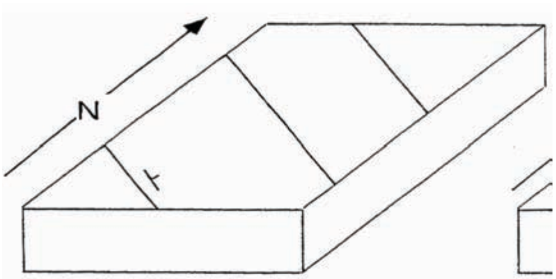

Figure 9. Slide of a block diagram.
Used with permission from the Department of Earth and Environmental Sciences, Vanderbilt University.

In our interview on the day preceding this lecture, Brown noted that structural geology is an unusual topic for a non-majors course.[13] However, because of his own academic and applied interests in this area (noted above), he had been excited to learn that the topic was included by the senior faculty member who designed the course. Brown iterated this connection in lecture: *This usually is not taught in introductory classes, but because it's what I do, I like teaching about it.*

This was not the first time we had observed Brown expose students to a set of problems that are central to his identity as a researcher and petroleum geologist. Interestingly, each of those cases surfaced fundamental problems of "seeing" and inscribing. In earlier lectures, Brown had juxtaposed "birds-eye" and cross-sectional views, highlighting the constraints of each in making geological features visible. At one point, realizing that one of the slides was confusing to students, Brown drew a simplified diagram on the board and pointed out that the way the slide rendered 3D information distorted (and confused) the view he sought to project. In the lecture described here, he problematized everyday ideas about representation – showing students that literal depictions like photographs actually obscure what may be happening below the surface. We were further intrigued to realize that the sequencing of slides in the lecture reinforced and extended this counter-intuitive notion: over the course of the March 30 lecture, Brown projected a set of representations that grew increasingly "spare" and yet which conveyed dimensions a photograph could not. In the lectures that followed, Brown continued to assert the necessity of an inscriptional convention to distinguish one formation from another in a two dimensional representation. The "content" was not merely a set of different types of geological formations, but rather tools and strategies for representing important distinctions among them. Like Wiley, the content and crafting of his lectures revealed sophisticated metarepresentational competence.

And yet we fear that this move to draw students into the realm of disciplinary practice may have been subsumed by the institutional and cultural constraints of the undergraduate lecture hall. First, while the challenge presented was to move from three-dimensional phenomena to two-dimensional representations, students started from two-dimensional images. Students were not in the field encountering 3D features to be conveyed to colleagues positioned elsewhere. Rather, they worked to inscribe hypothetical data presented as text/numbers on the block diagrams included in their homework sheets. Thus, the problematic relationship between inscription and landform disappeared. For Brown there was a clear chain of reference from inscription to a geological outcropping of a sort he has encountered up close; for students the references were back to two dimensional objects, whether photographs or block diagrams. While ideally students would seek to visualize the phenomena represented by their inscriptions, we wonder whether students took this step. In the lab sections that week, students were asked to fold cardstock prints into block diagrams, to color in particular sections, and to interpret the contours and relationships among the layers depicted. It was unclear that students linked these representations to real or hypothetical landforms. Student conversations as they worked suggested the block diagram problems seemed more like puzzles (often confusing), than inscriptions for geologic data. Even as the instructor spoke the language of scientific practice, students mostly worried about getting the information they needed for the test. Unlike the "Amazonia in Appalachia" episode, inscriptional practice *was* the subject of learning here. However, as the square peg of disciplinary practice was squeezed into the round hole of

[13] And in fact, this focus on inscriptional conventions stood out in a course designed to support students as thoughtful citizens able and critical consumers of environmental policy.

introductory course norms, from students' perspectives the inscriptional task became decontextualized, and so unproblematized.

This is not an indictment of Brown's skill as an instructor. Indeed, in introducing the index card "strike and dip machine", Brown established a bridge between the two dimensional notation developed by field geologists and the three dimensional perspective the notation signifies – an insightful pedagogical move.[14] Rather, we are interested in the opportunity (not pursued here) to problematize the notational solution and so further develop students' metarepresentational competence. To take this next step, Brown might ask students to wrestle a bit with the problem before providing a solution – for example asking them to consider what features of an outcropping ought to be conveyed, and to justify their choices by explaining why such features would be geologically significant. In this scenario, students might assume a geological perspective to explain why features like orientation and slope are important in the first place. In both semesters, the geology professors periodically posed questions during lecture and asked students to talk to their neighbors about their answers. Here Brown could solicit and share inscriptional solutions, again highlighting why certain dimensions were geologically significant, and comparing the affordances and constraints of each. Or, perhaps he might pose several different solutions (conventional and non-conventional) for students to consider, asking them to consider the tradeoffs among those. Yet another possibility would be to ask students to use the conventions to describe 3D phenomena that they observe – a desk, a building, a sculpture, and *then* choose. In these ways, Brown could highlight a representational challenge and a conventional solution, establishing the basis for developing metarepresentational competency.

D. Biology Episode 2: Reasoning About Evidence in a Complex Inscription (November 13, 2006).

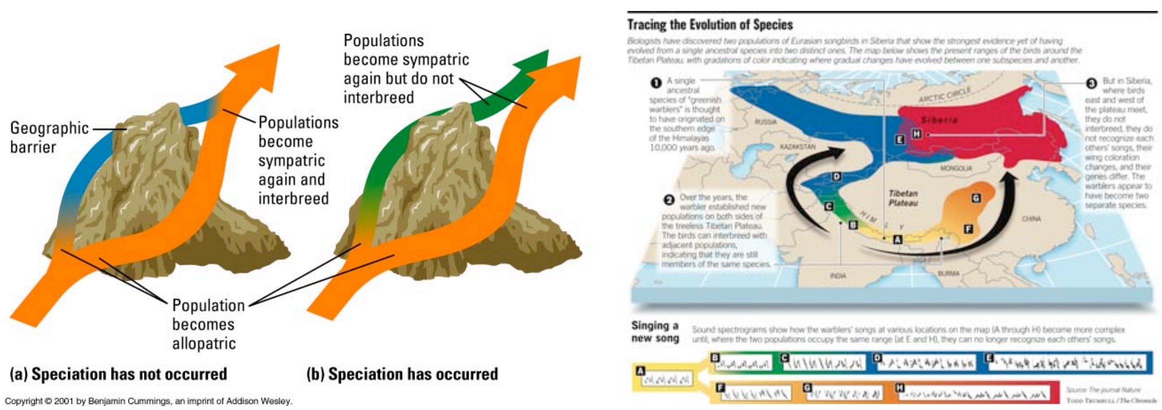

Figure 10: Generic slide of allopatric speciation and slide of a putative example of allopatric speciation.
Left image - From Campbell, Neil A., Reece, J.B., and Simon, E. J. Essential Biology, 3rd Edition, 2007, pp. 276, Figs 14.9. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.
Right image – From Trumbull, T., San Francisco Chronicle Graphic Titled "Tracing the Evolution of Species". All Other Rights Reserved by San Francisco Chronicle. Credit: Photog/San Francisco Chronicle.

[14] Moreover, the size of the index cards made visible not only the intersecting planes described in the notation, but also student comprehension – a quick glance around the lecture hall told Brown who was following and who was not.

Clearly there is a tradeoff here. Bringing such an activity into the lecture hall would take a precious half session away from another topic. However, we also believe that such a trade might enable more students to understand deeply the central unit challenge: visualizing and representing three-dimensional phenomena.

Scientists routinely incorporate evidence and arguments into inscriptions but inscriptions that contain these components of science-in-the-making are not often included in introductory science lectures. In this episode, a set of interrelated inscriptions originally intended for a science-savvy audience was used to present a putative present-day case of allopatric speciation (speciation that occurs as a result of geographic isolation). In her discussion of the evidence-presenting slide (see Figure 10), Professor Dillon interpreted and reasoned with the various inscriptions in the slide. However, she did not explicate what she was doing and how she was doing it. Much like what we saw in Biology Episode 1, when acting in the figured world of a lecturer, Professor Dillon used skills common to the figured world of a scientist without treating these skills or their application as objects of instruction.

During weeks 10-12 of the 15-week Fall ’06 semester, Professor Dillon devoted 8 lectures to the topic of evolution. The lecture from which this episode derives occurred halfway through the evolution segment. In this lecture, Dillon used 14 slides, 10 of which displayed inscriptions. The two slides shown in Figure 10 were used during this 8-minute episode.

The first (Figure 10: left) is a figure from the textbook depicting a generic population (represented by colored arrows) splitting into two populations by virtue of a mountain in its midst and coming back together either as the same species or as two different species, the latter of which specifies an allopatric speciation event. This slide not only provides an abstracted visual of geographic isolation but also indicates that geographic isolation does not necessarily result in speciation but it can. The second (Figure 10: right) is a complex slide, the primary source of which was the scientific journal *Nature* (Dillon’s source of the image was the *San Francisco Chronicle*). It displays two pieces of data that serve as evidence for allopatric speciation, a map showing the territories of 8 subspecies of warblers as distributed around the Tibetan Plateau (a “circular” geographic barrier) and sound spectrogram of each subspecies’ song arranged in a divergence pattern. Subspecies E and H no longer interbreed, making this an excellent example of speciation.

In this episode, the first slide was displayed for approximately three minutes while the instructor explained allopatric speciation with specific reference to the slide and talked more generally about difficulties associated with mounting an argument for speciation given the vast amounts of time over which most speciation events would occur:

> *The problem biologists have when we find two different species is we question did they diverge from a single species … it is difficult to know if they started out as the same species because of the time it took.*

This slide served as a segue to using the second slide for approximately five minutes to exemplify, explain further, and provide evidence for a speciation event for which space rather than time was the more critical factor. While displaying this slide, the instructor told both facts and reasoning, and modeled reasoning as she interpreted each of the two primary components of the slide, the map and the sound spectrograms, and coordinated them to come to the conclusion that subspecies E and H have evolved into separate species as follows:

> *These are subspecies, not different species, because there is an indirect gene flow.* ***A*** *can exchange genes with* ***B****,* ***B*** *with* ***C****,* ***C*** *with* ***D****, but* ***D*** *can't exchange with* ***A****. This example looks at the different songs of related birds and whether or not they will mate … the species are changing as they go around the plateau—the real suggestion that actual speciation has taken place are at spots where the two ends of the plateau come together* [Professor D. points to the overlapping territories of species **E** and **H**]*—now the two species at the two ends can't interbreed … showing us how the slow process could have occurred … and that's what we are all looking for, any type of evidence for this [speciation].*

This episode highlights the instructor's ability to interpret, coordinate, and reason about evidence presented in inscriptional form. In her explanation Dillon appeared to follow a chain of reasoning to make the case for speciation—invoking indirect gene flow,[15] evidenced to her by the territory distributions on the map, and song divergence, as evidenced to her by the sound spectrogram display. Given their richness and intent, the focal inscriptions offer a ripe opportunity to model and guide student development of multiple inscriptional practices. However Dillon made no explicit reference to *how* the map "showed" indirect gene flow or *how* the sound spectrograms, individually and by their arrangement, "showed" song divergence or *how* the two displays taken together made a case for speciation.

Imagine if at this point, the instructor had taken reasoning with this slide one or more steps further, an ambitious step for an instructor in courses of this ilk but one with high potential payoff in the realm of exposing students to and engaging them in scientific practice. Given the partial voicing of her reasoning using the inscriptions on the slide, one possible move may have been to elaborate that reasoning so that students could observe more elaborate modeling. This elaboration could have taken the form of a more detailed "think aloud" or could have explicitly moved between pedagogy and practice with the instructor making explicit connections between her thought processes and components of the inscriptions (e.g., the territory markings on the map indicate indirect gene flow because…). Another possible tack might have been to shift from *showing* students reasoning by talking it through, starting with the claim that material on the slide provided evidence for allopatric speciation and engaging students in the reasoning. This could have been accomplished by posing questions like (a) what is the relationship between the territory map data and the sound spectrogram data and how is it represented, (b) what aspects of the territory map support the claim that allopatric speciation has taken place, and (c) what aspects of the sound spectrogram data support the claim. In this scenario, which would ideally include scaffolding on the part of the instructor and interaction among the students, the students would have had the opportunity to *interact with* the data with the goal of figuring out its potential significance rather than *hear about* the data and its significance as the instructor put all the pieces together.

It is interesting to note here that use of figures from primary sources like the journal *Nature* in a non-majors introductory science course is quite uncommon, yet this slide accompanied one of the few episodes that we observed *in toto* involving reasoning about evidence. This suggests that a more global move that instructors could take toward incorporating disciplinary practice into lectures would be to rely less on textbook inscriptions while increasing their use of inscriptions from primary literature.

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[15] Dillon had already covered gene flow in a previous lecture, but it is possible that students did not recall its meaning as she reasoned about the evidence in the figure.

V. Discussion: Realigning pedagogy and practice.

The preceding analysis starts from the assumption that honing in on undergraduates' access to, and understandings of fundamental disciplinary practices like inscription and argument provides a fruitful means of conceptualizing the pathway from undergraduate science coursework to pedagogy of elementary science grounded in disciplinary practice. The episodes presented above indicate several distinct challenges to be addressed in conceiving of how more typical forms of undergraduate science instruction could afford candidates a view of inscriptional practice as enacted in the figured world of science-in-the-making, and so contribute to their "reform science" content knowledge for teaching at the elementary level.

The first is the task of understanding inscriptions as acts of practice. In scientific practice, inscriptions are a form of content that requires unpacking, i.e., analysis of significant features and the relationships they express (Bowen and Roth, 1998). During most biology lectures, however, instructors projected inscriptions as if they were transparent: interpretation was presumed to be a relatively simple act. Hence, while instructors interpreted inscriptions for students in the course of explaining phenomena, we found very few instances when instructors assisted students in understanding the basis of that interpretation, i.e., how he/she moved from inscription to referent to significance, much less made explicit reference to inscriptional convention.

In contrast, the acts of "seeing" and denoting were highly problematized in the geology course; the instructor referred to challenges of visualizing three and four dimensional phenomena given one's position on the surface of the earth, or presented with two dimensional inscriptions during each of the lectures we observed (including those not analyzed here).[16] The geology episodes thus served to surface two other challenges to an undergraduate pedagogy of scientific practice. The first, highlighted in the "Amazonia in Appalachia" episode, concerns instructors' conceptions of the legitimacy of offering beginning students more than a glimpse of their "outside" work as a scientists. Clearly, we think it worth encouraging faculty to draw upon their experiences in "doing science" to make more transparent the practice (rather than just the products) of science. However, if instructors signal that these ventures into the "real" world of science are interesting but of marginal relevance to beginning students, then most students will not take them seriously, knowing or assuming that the contents of these forays will not be on the test. The second problem, exemplified in the Strike and Dip episode, is how to move from recognizing problems of "seeing" and inscribing to enabling students to attend to the affordances *and* constraints of various inscriptional "solutions".

The divide we found between the instructors' treatment of inscriptions during undergraduate lectures and their inscriptional practices beyond the lecture hall is consistent with the findings of Bowen and Roth (1998) in their study of the use and interpretation of graphs in undergraduate ecology lectures. In their analysis, Bowen and Roth focused on components of the figured world of the *ecologist* that remained hidden in the figured world of the *ecology lecturer*, and the impact that the lack of explication of these components might have on student learning. Bowen and Roth concluded that "it is difficult to claim that lectures are an effective format for students learning about the conceptual material of a domain, especially that supported by the representation practices of that domain" (p.87) and suggest that students would be better served

[16] The degree to which these differences are a reflection of the instructor's fields of practice vs. pedagogical style is an interesting question.

by participating in seminar type courses that would require them to generate, use, and present inscriptions based on more authentic investigative work.

We do not disagree with this conclusion. However, given the virtual certainty that lectures will continue to be the primary format of introductory science courses for some time, it is important to consider ways in which instructors might capitalize on their dual membership in the figured worlds of scientific practice and undergraduate introductory science, making inscriptions and inscriptional practice objects of instruction in the lecture context. As suggested in our "what-if the instructor had …" questions, we believe that even in the context of an introductory lecture course, instructors might help make disciplinary practices more salient and accessible by altering the instructional mode in deliberate and focused ways. Specifically, they might offer more invitations for students to reason about and practice inscriptional conventions, to invent means of representing data, and to examine the affordances and constraints of different inscriptional choices.[17] In providing students with opportunities to see inscriptions as tools and to practice with them, instructors take a step toward making new identities and practices available – for their students and themselves – within the figured world of undergraduate introductory science.

For prospective teachers, these experiences are crucial. As argued at the outset of this paper, helping students to recognize inscriptional practice is a crucial step toward providing them access to science as a dynamic, multi-faceted human endeavor as opposed to a rhetoric of conclusions. Without opportunities to engage critically with practices of representation themselves, teachers are unlikely to know how to help their students participate in this key dimension of science.

Finally, while we have a particular stake in supporting the development of prospective teachers' content knowledge for teaching, we believe that an emphasis on inscriptional practice is relevant also to students who do not seek careers in teaching. Specifically, such an emphasis supports a broader goal of preparing prospective "consumers" of science, an aspect of scientific literacy mentioned by all four of the instructors we observed. The ability to weigh the credibility of scientific argument presumes the ability to think critically about the inscriptions through which evidence is presented, to see inscriptions not simply as conveyors of information, but rather as representations of particular forms of analysis. If our graduates lack experience reasoning about the relationships assumed in the inscriptions they confront and so simply take them as "given", then we have fallen short of our goals.

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[17] Instructors might argue that some, if not all, of these aspects of disciplinary practice are covered in the labs that accompany many introductory non-majors science courses. However, it has been our experience that this is not the case. For example, especially in more "cookbook"-type labs, students are rarely, if ever, asked to collect data and then display it in a meaningful form. They may indeed collect data according to a scripted protocol but the lab manual typically provides a table to be filled in or the axes of a graph to be completed thus denying students the opportunity to think about *how* to construct a meaningful display. Even if labs do provide this kind of opportunity, confining inscriptional practice to the lab downplays its rightful place as an object of instruction and still leaves students more often than not confused by the multitude of opaque, problematic inscriptions that are part and parcel of introductory science lectures.

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