TEACHING AND LEARNING THE NATURE OF SCIENCE IN INQUIRY-ORIENTED COLLEGE SCIENCE COURSES

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Abstract

The authors are engaged in a long-term study of the instructional practices and student outcomes in a mature inquiry-oriented undergraduate science program. The research reported here began with an assessment of science faculty members' implicit theories of inquiry-oriented teaching and learning. Their practices were assessed through classroom observation and analyses of out-of-class assignments. Inquiry-related student outcomes were assessed through a questionnaire that required open-ended responses to simple scientific research scenarios and an interview that probed epistemological views. Both instruments were administered at the beginning and the end of introductory, inquiry-oriented courses in a range of fields. Comparison data was collected from beginning students who were not enrolled in science courses and from several more traditional introductory courses. Current results suggest that students in inquiry-oriented courses showed greater gains in scientific reasoning skills and epistemology than students in the comparison groups.

Introduction

The understanding of scientific inquiry is a core target outcome of recent standards for K-12 science education (NRC, 1996; AAAS, 1993). The understanding of inquiry has also been emphasized in some reports on the college science curriculum (Advisory Committee, 1996), and there appears to be a growing interest in inquiry-oriented teaching at the college level. The reasons for the interest include the following claims: (1) that understanding how scientific knowledge is arrived at is as much a part of science as are established concepts; (2) that introducing students to scientific inquiry increases their mastery of conceptual content; (3) that the understanding of inquiry is a higher-order cognitive outcome that transfers across scientific domains and is central to scientific literacy for the nonscientist; and (4) that inquiry-oriented instruction increases interest and participation in science.

The present research concerns practices and outcomes in college-level inquiry-oriented instructional settings. We seek to understand what is happening in the classroom and laboratory and to characterize what students take away from the experience. We have had the opportunity to study the inquiry-oriented curriculum in the School of Natural Science at Hampshire College. From the standpoint of purely descriptive research, this program offers several advantages. It is an example of sustainable reform in the sense that it has been in operation for nearly thirty years and continues to enjoy the commitment of its faculty. It has been implemented across all of the sciences. The faculty has articulated challenging goals for introductory instruction and adopted a comprehensive range of student-active methods for reaching them.

Our current research extends to other institutions the methods that were developed to characterize the Hampshire curriculum, allowing comparisons among a range of institutional settings, student characteristics, and faculty conceptions.

The courses and curricula we study were created by front-line science faculty members. There is much to learn about how to reach the goal of sustainable change in undergraduate science education through research on initiatives that arise and persist indigenously in groups of teaching scientists. The impact of the relevant psychological and educational theory can be enhanced when educational researchers work directly with groups of faculty who are committed to change and are aware of its challenges. To emphasize this point, the present paper is purposefully naïve in the sense that it seeks to explore what faculty members are thinking and doing without imposing evaluative frameworks that might be derived from the educational or psychological literature.

Goals vs. methods

Although they are sometimes run together, it is important to maintain a distinction between the goals or intended learning outcomes of inquiry-oriented instruction and the methods that are adopted to achieve the goals. Methods of instruction begin as hypotheses that are subject to test, and, even when validated, are subject to economic pressure, revision, and competition from alternatives. Goals are perhaps more stable but also change with society's needs and with the evolution of psychological theory. Our research includes multiple methods for independently assessing faculty goals, student learning outcomes, and classroom practice.

The goals of inquiry-oriented curricula

In interviews with faculty members at several sites we have found that inquiry-oriented changes are typically undertaken in the pursuit of multifaceted and ambitious goals which the faculty believes are not being adequately met by current instruction. The overall goals of different efforts tend to be very similar, although the emphasis on specific objectives can vary considerably. The following objectives for students are typically expressed to some degree by faculty members involved in inquiry-oriented reform.

Cognitive Skills

Content analyses of interviews with faculty members revealed several goals that are cognitive skills in the sense that students are expected to acquire some of the active skills of a working scientist at a rudimentary level. Several interrelated clusters of cognitive skills emerged in our analysis.

Primary inquiry Skills. Several of the skills are related to the cycle of inquiry that is typical of scientific research and that is often cited as a foundation of reform-oriented curricula: Question-theory-hypothesis formation; research design; data gathering; data analysis & interpretation; theory-hypothesis critique and reformulation. The curricular goal is that students will learn to generate and recognize researchable questions, to generate and critique research designs, to organize and analyze data, and to see the implications of data for hypotheses or theories.

Quantitative skills. Several quantitative skills emerged as typical goals of inquiry-oriented instruction. Although these skills are closely related to the inquiry skills, faculty members distinguish them conceptually and often describe specific instructional strategies for improving them. One set of skills concerns handling quantitative data. Students are expected to learn how to create and interpret graphical and tabular summaries of data sets and to reason about variability and error in data. Another set of skills involves setting up and reasoning with quantitative models, either to make predictions or to interpret data.

It is important to note that faculty members distinguish these skills from skills at symbol manipulation and calculation. The latter skills may be important instructional goals, but they are not discussed as specific targets of inquiry-oriented instruction. The inquiry-oriented quantitative skills might be described as a general ability to think about data and models and their relationship to reality. For example, instructors might distinguish between being able to calculate the standard deviation of a set of values and being able to think about the relationship between sample size and variability, or between being able to take the first or second derivatives of a symbolic expression and being able to go from a verbal hypothesis to an appropriate graphical sketch of the relationship between two variables.

Primary literature skills. In some inquiry curricula, teaching students to locate, organize, and read primary literature is a distinct goal (although the accessibility of the literature in particular research areas influences the degree to which this goal is adopted for beginning students). Since reading primary literature intelligently requires inquiry skills, there is considerable overlap between the two areas. Faculty members list additional skills, however, that they believe are involved in working with primary literature. These skills include locating relevant literature, ranking papers by their sources and abstracts, quickly identifying important claims, and generating a conceptual organization for a set of papers. They depend on developing an understanding of the discourse of scientific writing, which ranges from knowing how scientific papers are structured to being sensitive to how researchers speculatively extend the generality of their findings in discussion sections. More generally, exposure to primary literature may help students to understand and learn to cope with the conflicting findings and disagreement that are typical of active areas of research.

Scientific communication skills. A final cluster of skills concerns scientific communication, or more direct participation in scientific discourse. These skills include working collaboratively, commenting on others' work, and presenting one's own ideas in writing, in conversation, and in stand-up presentations.

Students' epistemologies

Faculty members involved in inquiry-oriented instruction often mention a desire to change students' views about the nature of science and the status of scientific knowledge. We made a distinction between philosophical and sociological concerns, although these two categories are not always easy, or even possible, to separate.

On the philosophical side faculty members expressed a hope that students would shift from relatively naive to more sophisticated views of science. In a generic naive view science is a body of unassailable knowledge possessed by scientific authorities, and the scientific method is a fixed procedure that can be applied piecemeal to natural phenomena to yield proven truths. More sophisticated views recognize the uncertain, open-ended, and theory-laden nature of scientific knowledge, and they show a more nuanced appreciation of the uncertainties, details, and importance of the research process and the evidence it produces.

It is worth noting that college faculty report that they see many beginning undergraduates who hold static and authority-based views of science, since reform-based K-12 curricula are in part also aimed at changing such views. Several faculty members also noted that shifts in students' epistemological stances can be complicated, sometimes including, for example, a radically relativistic phase.

On the sociological side the hope is that students will move toward a deeper appreciation of the social nature of the scientific enterprise. Scientific research is carried out within a social context by groups of researchers and it is therefore influenced by a complex of historical, cultural, political, and social factors. Further, the pursuit of scientific research and development has political and moral dimensions.

Field-specific content

The mastery of established, field-specific content has traditionally been the primary goal of college science instruction. Although instructors rarely think of inquiry as a unit that can be added to a syllabus, the issue of how to mesh content-learning goals and inquiry goals is a major area of disagreement. One reason for the range of opinion is the practicalities of instruction. Many instructors believe that different teaching methods and learning activities are appropriate for content and inquiry goals. Thus, they think in terms of a trade-off between the two types of goals. The range of opinion is also generated by conflicts among implicit theories of how content knowledge and inquiry skills are cognitively represented and acquired. For example, a faculty member with a constructivist orientation think that all concepts should be learned in inquiry contexts.

Motivational Goals

Faculty members involved in inquiry-oriented instruction often place some stress on motivational-attitudinal goals that they believe are not well served in more traditional instruction, where motivation might be said to begin and end at the classroom door for most students. These goals include increasing the interest in science, increasing the interest and participation in science of women and members of under-represented minority groups, and increasing students' confidence that they can do science or participate as citizens in science-related policy debates. The emphasis on these goals raises serious issues for both research and curriculum development. To the extent that the hypothesized relationship between the cognitive and motivational goals is clear, instructors do not typically consider inquiry goals and motivational goals to be independent. The most common hypothesis seems to be that inquiry-oriented instruction is intrinsically motivating or plays a causal role in positive attitudinal-motivational change. It is possible, even likely, that different inquiry-oriented curricula will have differing cognitive and motivational outcomes. For some students there could be trade-offs between the two kinds of outcomes. An inquiry curriculum could be a motivational success and a cognitive failure, or vice versa.

Instructional methods

In its pure form, the traditional college science curriculum expresses a particular view of how and when inquiry skills should be learned. The mastery of substantial bodies of established knowledge is held to be prerequisite to engaging in inquiry. Lectures, examinations, solving textbook problems, and completing highly constrained laboratory exercises are thought to be the most efficient methods for achieving the mastery. Substantial involvement in inquiry activities begins in graduate school or perhaps in the final undergraduate year. One consequence of this view is that most college students, particularly those who do not major in the sciences, never engage in inquiry processes. Inquiry-oriented faculty members report impressions that most undergraduates do not acquire inquiry skills, which these faculty members consider to be as much a part of science education as the mastery of content knowledge.

The idea that inquiry-oriented instruction should result in the acquisition of cognitive skills has the consequence that students should spend time practicing the skills. Many of the innovations in inquiry-oriented courses can be viewed, then, as attempts to allow students to practice one or more of the cognitive skills that were discussed above. Since college students are typically not prepared to undertake scientific research at a professional level, teachers must design inquiry-oriented learning activities that are accessible but still build the target skills. In fitting these activities into a course, they must also deal with the need to give up some traditional activities to make way for the skill-oriented activities, which raises the possibility that some of the learning outcomes associated with the traditional activities may also have to be sacrificed.

Teachers have devised a very wide range of learning activities intended to build inquiry skills, and they have introduced them into courses to widely varying degrees, producing considerable variation in time on task. There is, in practice, considerably less agreement among faculty members about the methods of inquiry instruction than there is about the goals. The range of beliefs and commitments about what to do, how much of it to do, and when to do it constitutes a very large hypothesis space for researchers. We do not know very much about "what works" in college-level inquiry instruction, particularly when cost effectiveness and variations among institutions, faculties, and students are taken into consideration.

The goal of changing students' epistemologies raises an additional issue about teaching methods. Instructors are not as clear about how specific learning activities are aimed at epistemological change. Epistemological change is often implicitly hypothesized to be a natural consequence of or side effect of inquiry activities.

Theoretical Status of Inquiry Skills & Epistemological Stances

The expressed goals of inquiry-oriented instruction rest on at least two hypotheses that are of great interest from the standpoint of cognitive psychological theory and that pose considerable challenges to the researcher. The first hypothesis is that inquiry skills and epistemological change are intended to be higher-order cognitive outcomes that transfer across content domains. A subsidiary hypothesis is that a person's epistemology, beyond being a collection of verbalizable attitudes, is a complex cognitive structure that influences thought and action. The fundamental challenge for researchers is that little that goes on in the classroom or that goes into normal student assessment is directly useful in evaluating the transferability of outcomes.

The existence of abstract cognitive skills

The assumption that higher order cognitive representations and skills can be learned has not enjoyed universal acceptance within psychology and education. Within modern psychology debate about the existence of general mental representations and skills extends at least back to the early 20th Century controversy over Thorndike’s claim that the transfer of learning across tasks is mediated by identical elements. Within contemporary cognitive psychology it could be argued that there is abundant and diverse evidence for a lack of generality in cognitive skills. The sources include failures of empirical support for Piaget’s abstract-structural theory of development and the emergence of theories of domain-specificity in development (Carey, 1985; Hirschfeld & Gelman, 1994), people's poor performance on some abstract deductive reasoning tasks (Wason & Johnson-Laird, 1972), and the discovery of the limitations of Newell & Simon's theory of problem solving (GPS) and of the domain-specific nature of much expert knowledge (Larkin et al., 1980).

There are at least two reasons, however, for continuing efforts to enhance general outcomes in science education (and education generally). First, much of the theory and evidence that limits generality is in fact compatible with both the existence of abstract cognition and with its importance in education and in life. To give one example, because of their limitations, the reasoning heuristics of GPS have come to be called "weak methods" (e.g. VanLehn, 1989), but the existence of these heuristics in human cognition and their effectiveness in attacking challenging, novel problems was documented in Newell and Simon's (1972) original research on the GPS model. Second, there are significant, well-supported bodies of theory that support several kinds of generality. The notion of metacognitive representations and skills, for example, is an accepted part of current cognitive developmental theory, and its theoretical role in scientific reasoning has been well explicated by Kuhn (1991; Kuhn et al., 1988). At a more microscopic level, Anderson (1993) has developed and shown empirical support for his ACT* model, in which the elements of skills are condition-action productions containing variables that support considerable generalization.

The existence of inquiry skills

The contemporary cognitive psychological account of the kinds of skills that are the subject of this paper has been developing for more than a decade (e.g. Resnick, 1987). The general cognitive domain of human inference and judgment has been the subject of extensive theoretical and empirical research (Nisbett & Ross, 1980; Holland et al., 1987; Thagard, 1988; Baron, 1994). This research has uncovered many reasons why the target skills are difficult for people to acquire, but it has also given psychologically-sound characterizations of quite general skills that can be acquired (e.g. Cheng & Holyoak, 1985; Cheng et al., 1986). Kuhn (1991; Kuhn et al., 1988) has developed a coherent theory of reasoning skills, shown that they can be assessed, and shown that they are acquired by some people.

There is similar support for the existence of the kinds of quantitative skills that were described above. Nisbett (1993) and his colleagues, for example, have shown that is possible to teach the general application of the law of large numbers, a key aspect of statistical reasoning. Schoenfeld (1980) has developed methods for teaching mathematical heuristics (derived from Polya's work) that are at a level of generality comparable to the basic quantitative modeling skills emphasized in inquiry-oriented courses.

The theoretical status of epistemological representations

Epistemology, as a psychological construct, has been the subject of much less theoretical work than cognitive skills, and consequently its theoretical status is somewhat underdeveloped and contested (Hofer & Pintrich, 1997). Researchers such as Perry (1970) and King and Kitchener (1994) conceptualize a person's epistemology as a domain-independent psychological entity.

Others, such as Carey and her colleagues (Carey et al., 1989; Carey & Smith, 1993; Smith et al., 1999) have developed assessments that are specific to scientific epistemology, with the implication that epistemologies could have a degree of domain-specificity. In our research we employ epistemological interviews that are specific to science, in the sense that we try to get at students' views about issues such as the nature and purpose of experiments and theories in science. This methodological decision is not based on a strong theoretical view, although we do think that it is likely that people's scientific epistemologies are specific to science at least in the sense that they further specify more general epistemological views.

There is disagreement about whether epistemological change follows a stage-like developmental progression and is limited by general cognitive developmental constraints, or whether it is highly responsive to features of the educational environment from middle childhood on. Our research does not address epistemological change in precollege students, although Smith et al. (1999) have presented evidence that 6th graders' epistemologies are sensitive to schooling. Our working hypothesis is that epistemological development in college and beyond is largely a function of specific educational experiences, or, more generally, of specific features of a person's intellectual environment. As noted above, sophisticated epistemological views and thinking are sparsely distributed in the adult population (King & Kitchener, 1994; Kuhn, 1991), making it unlikely that they are general maturational or developmental outcomes. We see a striking and potentially profound analogy between King and Kitchener's (1994) finding that graduate students in the social sciences had higher epistemology scores than graduate students in mathematics and Lehman, Lempert, and Nisbett's (1988) finding of differences in statistical reasoning among graduate students in psychology, medicine, law, and chemistry. In both cases the achieved level of competence appears to be a function of specific features of educational regimes.

In the context of our research it is important to conceptualize a student's epistemology as potentially more than a collection of attitudes or even as a conceptual network that mainly supports an ability to answer general questions about the nature of science and to give examples. Inquiry-oriented faculty members clearly intend the target epistemology to play an active metacognitive role. This faculty intention comes out in numerous statements, e.g. in frequent anecdotes about admonishing students to always ask what the relevant theory is and how the study or bit of evidence under consideration relates to the theory. Kuhn (1991) presents a conceptualization of epistemology as active metacognition, and she found relationships between her subjects' epistemologies and their argumentation performance. The study by Smith et al. (1999) provides less direct but also suggestive evidence. In a study of the role of schooling in pre-college students' epistemological development, they found that students in a constructivist classroom that emphasizes inquiry skills had significantly higher epistemology scores than students in a control classroom.

Tentatively we can hypothesize that the metacognitive role of a person's theory of knowledge is that it is an overarching structure that monitors and coordinates the application of more specific inquiry, quantitative, and discourse skills. A scientific epistemology can be viewed as a set of interconnected abstract principles. At least two conditions must hold for this conceptual structure to play an active role in cognition. First, relevant aspects of situations must activate the principles. Second, the activation of at least one of the principles should activate the entire structure, which should in turn activate the application of specific cognitive skills. For example, suppose a student A's epistemology contains the principles that scientific knowledge is probabilistic and must be supported by empirical evidence and that particular scientific claims should be interpreted within a theoretical framework. Suppose student B makes a strong assertion that aspartame causes prostate cancer. Ideally, the assertion would activate student A's epistemology, leading her to ask about the data that supports the assertion and about how the findings can be interpreted within theories of carcinogenesis. Hearing more about the data, particular design and statistical skills might also be activated, and student A might ask questions about sample size and might generate the thought that aspartame intake might be correlated with obesity.

Teaching inquiry skills and epistemology

The above considerations suggest that higher-order inquiry skills and active epistemologies can be acquired, but they say little about how to teach them at the college level. In the following sections we describe some of the teaching methods that we have observed and the initial measures of the student outcomes that we have made.

Teaching methods & learning activities in inquiry-oriented courses

Over the past two years we have done intensive observations in nearly thirty introductory classes at three institutions. The courses incorporated a range of inquiry-oriented innovations. We have looked at how faculty members actually implement the learning activities that they identify as contributing to inquiry skills and epistemological development. We have measured the amount of time devoted to these activities. We have looked at these factors in the context of how the entire course is conducted. The findings are extremely rich both qualitatively and quantitatively and can not be fully described here, but several generalizations and observations can be offered.

First, faculty members who commit themselves to inquiry goals actually do make students aware of the goals and do design and implement learning activities that reflect the goals. This finding is not as obvious as it might seem, because the pull of content-coverage oriented teaching is very strong in the sciences. It is strong enough that in some of the courses we have looked at the value placed on inquiry goals and the amount of time devoted to them appears not to be sufficient to produce noticeable or measurable effects on students.

The second finding, then, is that the degree to which the courses are devoted to inquiry goals, and therefore, often, the amount of class, laboratory, and out-of-class time devoted to inquiry activities varies over a wide range. At one end of the scale we have observed introductory courses that are organized entirely around inquiry goals. For example, a course in human movement physiology was organized around students developing and carrying out original research projects in an electromyography laboratory. Standard physiology content was covered only to the extent necessary to support the development and execution of the projects. Students' knowledge of standard physiology content was never assessed directly. Evaluation was based on the research project and the activities that supported it, such as locating, understanding, and critiquing primary papers. At the other end of the scale we observed courses in which inquiry-oriented activities occupied a small percentage of class time relative to more conventional content goals and in which students' grades or evaluations were not strongly weighted by their performance on the inquiry activities. For example, we observed a course in which students read and critiqued a single primary article. Little class time was devoted to this activity, and it counted very little toward the final grade. In research discussed below we have found that changes in students' inquiry skills and epistemologies are positively related to the value placed on and the amount of time spent on inquiry goals and activities.

Third, the content of the activities devoted to common inquiry goals varies considerably. For example, the teacher of the movement physiology course just described believes that designing and carrying out a single, semester-long project is an ideal way to build primary inquiry skills. A contrast is provided by an introductory chemistry course that we observed at a large university. A high percentage of classroom time in this course was devoted to inquiry activities in which small groups of students used simulation software to explore standard chemical phenomena under the guidance of the instructor. These activities were highly oriented toward the content of a conventional chemistry course, but they also repeatedly forced students to make predictions, design simulated experiments, and interpret data. The teacher of this course also hopes to build primary inquiry skills in the students. Students in the two courses showed comparable gains in a measure of inquiry skills discussed below, but it seems unlikely on further study that the two courses have identical student outcomes.

Fourth, we have found that inquiry-oriented faculty members tend to inject inquiry content into conventional teaching activities, such as lectures, standard laboratory exercises, and discussions of textbook content. For example, we observed an introductory topic-oriented physics course on elementary acoustics that included both substantial student project activity and standard textbook coverage, problem sets, and laboratory demonstrations. The professor consistently colored, and even subverted, the standard material with inquiry themes, however. He stressed the ways in which models were imperfect representations of reality; he introduced historical background that illustrated how theories developed and changed in the light of various kinds of evidence and influence from areas of theory; to the point of frustrating some students, he put more emphasis on strategies for approaching problems and understanding the problem situation in terms of physical concepts than he did on the algebraic manipulations that led to the correct numerical answer; and he spent time fouling up standard laboratory demonstrations to illustrate their limitations. At this point we have no evidence on the separate effects of this kind of alteration to conventional teaching methods.

Fifth, we have seen little evidence that teachers have designed specific learning activities to teach epistemological metacognition. There is some evidence from interviews that their implicit theory is that epistemological change is a consequence of the acquisition of inquiry skills. Instructions to students on how to read and critique primary articles come closest to direct instruction in using epistemological principles to guide inquiry. In the conventional parts of their courses inquiry-oriented instructors also often model epistemological metacognition. For example, in summarizing the class discussion of papers on human evolution, a faculty member often systematically reviewed alternative theoretical frameworks, the strengths and weaknesses of evidence, and the logic and assumptions of the arguments connecting the evidence with the relevant hypotheses and theories.

Assessing the acquisition of inquiry skills

We have begun a research program in which students' primary inquiry skills are assessed via their written answers to open-ended questions. Our goal is to develop an instrument that can be reliably scored and administered to relatively large numbers of students. We have used the current version of the questionnaire in pre-post designs to assess change in inquiry-oriented and more traditional courses.

The items on the questionnaire are based directly on the primary inquiry skills discussed above and have been critiqued or co-developed by inquiry-oriented faculty members. Each item presents a non-technical scenario and then asks the student a series of open-ended, short-answer questions that are related to the instructional goals. The scenarios are sparse enough that students almost never answer the questions in terms of domain-specific technical knowledge. For example, a question that asks students to critique an experiment and some data concerning the response of two varieties of corn to two levels of watering has never been answered in terms of specific knowledge of plants or agriculture.

The scoring procedure rates the logical quality of students' reasoning and in some cases the number of ideas that they are able to generate. The procedure has been refined to a simplified rubric by the second and third authors of the present paper. In an assessment of reliability their independent scores were in 90% agreement.

In one study (Stillings, Ramirez, & Wenk, 1999) we compared change during the first semester of college in four groups of students: (1) Students who took inquiry-oriented science courses at Hampshire College; (2) Students at Hampshire who were not enrolled in a science course; (3) Students who took a conventional introductory biology course at another, comparable college; and (4) Students who took a moderately reform-oriented general science course at the same college. Pre-test scores in all groups were statistically indistinguishable, and only the students enrolled in inquiry courses showed gains on the measure.

In another study (Ramirez, 2000) we compared change over one semester in three types of introductory chemistry sections at a large state university: (1) A small section in which small groups of students used simulation software to explore chemical phenomena under the guidance of the instructor in nearly all of the class meetings; (2) A small lecture-oriented section in which individual students used the same software outside of class and did not do small-group work in class; (3) a large lecture-oriented section which did not employ the software or do in-class group work. Pre-test scores were statistically equivalent in all classes. Only the first group showed significant change from the beginning to the end of the semester.

Over the coming three years we will be doing similar studies at several colleges, universities, and junior colleges, looking at the effects of a variety of inquiry-oriented interventions.

Assessing epistemological change

In a pre-post interview study Wenk (1999; 2000) compared students from intensively inquiry-oriented introductory courses (n=15) to students from more conventional courses (n=15). The courses were taught at two comparable liberal arts colleges and had comparable enrollments and students. Part of the interview was devoted to questions about the justification of scientific knowledge, the role of evidence in science, and the nature of uncertainty and disagreement in science. Results were coded in terms of a developmental stage scheme related to those of King and Kitchener (1994) and Perry (1970). In pre-interviews students enrolled in the two types of courses were at the same developmental stage. In post-interviews students in the intensive inquiry courses showed greater stage gains, reaching a level that is more typical of advanced college students or beginning graduate students in some other studies, and beginning to appreciate the limited evidential contribution of individual scientific studies, the development of evidence over time, and theoretical context of evidence.

Future work

Our work over the next few years has three main components:

1. Correlating course observations at a finer grain with the development of inquiry skills.

2. Revising our epistemological interview to give it a firmer relation to research on precollege students' epistemologies and using the new instrument to study college students' epistemological development longitudinally.

3. Working with particular groups of faculty members to improve their inquiry-oriented instruction.

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