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ABSTRACT

The varying impacts of three instructional environments for introductory chemistry on the inquiry skills of undergraduate students were studied. The first two environments were traditional (TR) and guided-inquiry (GI) laboratory-based instructional situations, and the third was a separate lecture course for nonscience majors that emphasized critical reasoning (CR) as one of the course goals. GI is an approach that emphasizes support for guided discovery and promotion of metacognition. The study assessed how students in each instructional setting looked at evidence, made conclusions based on the evidence, and evaluated the evidence critically for reliability and validity. Participants in the first-semester study included 50 students in the CR chemistry course, 44 in the GI laboratory class, and 20 in the TR sections. A second study compared seven GI students with seven TR students. Results indicated that both the GI students and the CR students performed significantly better than the TR students. Implications for instruction and future research are discussed. (Contains 3 tables and 15 references.) (Author/SLD)

The Effects of Instruction on Undergraduate Students' Inquiry Skills

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Abstract

The purpose of this study is to investigate the varying impacts of three instructional environments for introductory chemistry on undergraduate students' inquiry skills. The first two environments are laboratory-based instruction, traditional (TR) and guided-inquiry (GI). The third environment is a separate lecture course for nonscience majors which emphasizes critical reasoning (CR) as one of the course goals. The study assessed how students in each instructional setting look at evidence, make conclusions based on the evidence, and critically evaluate the evidence regarding its validity and reliability. The results indicate that both the guided-inquiry students and critical reasoning students performed significantly better than the traditional laboratory students. Implications of these findings and future research will also be addressed.

Introduction

One goal of chemistry curricula is to develop science process skills, or inquiry skills. Traditionally, the teaching of inquiry skills has been limited to the scientific method implicit within the laboratory experience. On a precollege level, students often experience scientific inquiry as a superficial process of performing experimental exercises with known outcomes. College students do not fare much better in their experimental experiences, though there may be a greater emphasis on discussion of results. However, this mode of hypothesis-experimentation-conclusion is not a true reflection of scientific inquiry for scientists.

The purpose of this study is to investigate the impact of three instructional environments on students' inquiry skills. First, I will describe what I mean by inquiry skills in greater detail. Next, the three instructional environments (a traditional chemistry laboratory (TR), a guided-inquiry chemistry laboratory (GI), and a critical reasoning nonmajors course (CR)) will be elaborated in greater detail. Then, I will present the methodology for assessing inquiry skills in the three environments. Finally, the results of the study and their implications on instruction will be discussed.

Inquiry skills

Authentic scientific inquiry is a cognitively complex process that emphasizes planning and reasoning skills. The main purpose of scientists is to pose questions to study and develop appropriate methods to study those questions given the literature in the field. Scientists also try to make sense of their experimental results by considering their contribution to supporting or understanding a theory, its validity, and its reliability. In contrast, the primary emphasis for students in science class is the data collection. Typically, precollege and college experiments are "cookbook" in nature. Students follow the prescribed procedures step by step, so very little planning is asked of the students as relates to experimental design. Also, since students usually know the expected outcome to an experiment prior to completing the experiment, students need not grapple with the experimental data in order to make sense of it and draw conclusions.

	Scientists	College students
Purpose of experimentation	Explore system not yet understood	Verify known concept
Question	Develop appropriate questions to study	Given in laboratory manual
Procedures	Develop methods to answer the posed question	"Cookbook" in nature
Data analysis	Integrate concepts with empirical evidence	Rote algorithmic calculations
Explanation of results	Require sensemaking on microscopic and macroscopic scales	Shallow; Outcomes known prior to experimentation
Process	Trial and refinement over an extended period	One week stand alone experiment
Metacognitive activity	High	Low

Table 1. Comparison of the typical laboratory activity of scientists vs. college students.

For the purposes of this study, I claim that critical thinking and metacognitive skills are major components of scientific inquiry. Brown et.al. define metacognition as the awareness of and monitoring of one's thinking (Brown, Bransford, Ferrara, & Campione, 1983). Metacognitive skills are essential in evidence interpretation and the construction of scientific arguments (Germann, Aram, and Burke, 1996). In the area of experimental design, scientists need to develop relevant and reasonable experimental questions, offer hypotheses and predictions of expected outcomes, and develop appropriate methodologies to test their hypothesis. Each stage requires thinking and reasoning skills. Posing a reasonable question requires a scientist to be familiar with the prior research in that area as well as the limitations of his experimental capabilities. In order for a scientist to develop a hypothesis, he must realize the implications of related research and concepts as well as

offer sound reasoning to support the hypothesis. To develop an appropriate methodology, a scientist must determine the types of data which will offer compelling evidence to answer the posed question. In order to refine a hypothesis or develop a theory, a scientist must be able to evaluate experimental evidence and determine its worth and its significance in light of other relevant information. Students are not likely to productively incorporate contradictory evidence into their current theory without higher levels of metacognition (Chinn & Brewer, 1993). However, an awareness of their understanding of an experimental system as well as their understanding of their own conceptions will enable the students to achieve a more coherent understanding. Furthermore, Schoenfeld (1987) has demonstrated that the promotion of metacognition can improve success in problem solving. In a sense, the scientific inquiry process is a form of authentic problem solving, compared to the rote exercises typically referred to as problem solving in chemistry courses (i.e., problem sets). Consequently, metacognition is another goal of immersing the students in authentic scientific inquiry.

Three Instructional Environments

Traditional Chemistry Laboratory (TR)

The first instructional environment is the traditional chemistry laboratory. The laboratory has been the primary focal point in developing science inquiry skills. While the lecture is traditionally the place to transmit conceptual information and ideas, the laboratory serves as the primary arena to put the conceptual into practice. Typically, the laboratory provides hands-on experiences in which students are involved in the scientific method. Ideally, the students are compelled to negotiate meaning from their experimental observations and data. However, the experiments are usually rote procedural exercises as compared to meaningful problem solving activities (Tobin, 1990). As a result, the laboratory experiences foster little metacognition or critical thinking. Because students are never allowed to design and carry out their own experiments, they are denied fundamental opportunities to engage in legitimate scientific activity (Burbules & Linn, 1991). Furthermore, students participating in the traditional laboratory sections are usually provided with the necessary equations in which to manipulate their experimental data. Consequently, they are not compelled to examine evidence critically .

Even students are critical of the learning value of traditional laboratory experiments.

> *Besides learning the calculations, I find the lab quite obvious (I've learned the concepts in high school). I know the concept is pretty useful since we can make predictions of the enthalpy of many reactions by using Hess' Law, but the lab itself*

wasn't what I called stimulating since all we did was pour chemicals and measure its temperature.

These comments, conclusions from an undergraduate student's chemistry laboratory report, reflect an attitude that pervades many undergraduate chemistry programs. Instead of being a place where learning is exciting and discoveries are captivating, the chemistry laboratory and its experiments represent tedium, where meaningless exercises and cookbook activities are the norm. As this student's comments illustrate, simply being in the laboratory and mixing chemicals is not enough to develop inquiry skills.

Students need and deserve to be challenged through more authentic experiences. "Authentic" can imply two different levels: a contextual level and a cognitive level. An authentic contextual level targets the tangible research activity and strives to provide students with real world contexts for learning chemistry and for carrying out experiments. An authentic cognitive level, targeting the unseen cognitive processes, enables students to acquire and develop scientific inquiry skills. These levels are not mutually exclusive from one another. Chemistry departments, and science fields in general, are presently striving to provide learning opportunities that mirror how expert chemists practice their domain (Lloyd, 1994; Illman, 1993; Holme, 1994).

Guided-inquiry laboratory (GI)

The second learning environment is the guided-inquiry laboratory. To create more educationally effective laboratories, my colleagues and I incorporated findings from recent educational research in the areas of metacognition, conceptual change, and problem-solving into a framework for instructional design (Brown et.al., 1983; Strike and Posner, 1992; Schoenfeld, 1992). The result was the guided-inquiry laboratory for introductory chemistry (Chemistry 1A) that prompts students to grapple with key chemical concepts and come to a better understanding of their meaning and relevance to biological systems (Rickey, Tien, Stacy, & Kegley, 1996). It is designed to appeal to the large proportion of Chemistry 1A students who are majoring in the biological sciences and/or planning to attend medical school. This laboratory course is designed within a framework for instruction that includes the following four components: (1) support for guided discovery, (2) promotion of metacognition, (3) investigation of meaningful problems, and (4) exploration of concepts through authentic scientific inquiry. Three of the four aspects of the framework, support for guided-discovery, promotion of metacognition, and exploration

of concepts through authentic scientific inquiry, are particularly relevant to students' ability to evaluate evidence.

The guided-inquiry laboratory curriculum seeks to provide authentic inquiry experiences for the students of Chemistry 1A. Based on inquiry gains for students who were taught scientific inquiry in an authentic context, Carey and Smith (1991) argue that teaching inquiry skills should be situated in the context of genuine scientific inquiry. The curriculum endeavors to be "authentic" through the study of biologically-relevant chemistry. Its activities include: developing and refining models of various chemical systems, designing experiments, investigating an experimental question using different approaches, and answering an experimental question based on multiple data sources. Each of these activities compels the students to engage in the cognitive practice of scientists. The activities are situated in biologically-relevant systems such as the chemistry of the stomach and antacids. I believe that the exploration of concepts through authentic inquiry will foster students' development of inquiry skills.

We support guided discovery in the special sections of Chemistry 1A both through the structure of the laboratory modules and through the instructional methods employed by the teaching assistants. We have based our instructional methods on the modeling, coaching, scaffolding and fading paradigm described in the Cognitive Apprenticeship theory of Collins, Brown, and Newman (1989). By structuring the modules such that there is a modeling phase and an advising phase, we ensure that students have a basic understanding of the chemical concepts and techniques relevant to the module before attempting to design their own experiments. During the modeling phase (the first two weeks of a four-week lab module), students gather experimental data in a somewhat structured environment. Then, based on the evidence collected in the initial weeks, students learn to develop experimental questions of interest, make predictions of possible outcomes, and design experimental protocols to test their hypotheses in the advising phase. During the final weeks of a module, students experience the spectrum of inquiry as they collect data, refine procedures, analyze data, and draw conclusions. In addition, the students are asked to critique their peers' projects and integrate the class data as a whole. Based on these experiences, I hypothesize that students will develop enhanced scientific inquiry skills, including the ability to analyze experimental designs and data critically and draw proper conclusions (Welch, Klopfer, Aikenhead, and Robinson, 1981).

We promote metacognition by requiring students to design their own experiment, to monitor their understanding through a POE (Predict-Observe-Explain) process, and to explain their results at multiple levels. Champagne, Klopfer, and Anderson (1980) demonstrated that students learned more from the laboratory experience when they actively made predictions, observed an experiment, and then explained what was observed. Students are compelled to monitor their understanding of the observed phenomena through the POE process as they reconcile their predictions to the experimental data and justify their explanations based upon the experimental evidence and conceptual understanding. The POE process prompts the student to think about their initial conceptions and refine them as necessary in order to reconcile their experimental results.

Students are compelled to consider the microscopic and macroscopic perspectives as they explain their experimental results. Ben-Zvi, Eylon, and Silberstein (1986) demonstrated that students often fail to connect the macroscopic and microscopic levels of understanding their experimental results. By encouraging students to consider experimental phenomena through more than one perspective, I believe that students come away with a deeper, more integrated understanding.

Critical reasoning nonmajors course (CR)

The third approach to instruction, critical reasoning, involves a newly-developed course for nonscience majors (Chemistry 10). In the context of learning personally-relevant chemistry, this course emphasizes the application of chemistry to everyday problems and the evaluation of chemistry-related studies published in newspapers and magazines. It includes two-hours of lecture and a one-hour "activity" period each week. Although this course does not emphasize authentic scientific inquiry in the laboratory, effort is made to involve students within a cooperative learning environment. The following describes the major components of the class in fostering critical reasoning skills.

First, the semester begins with the professor explicitly modeling expert inquiry processes. Specifically, the professor makes thinking visible while developing a model for understanding the chemistry involved in the sense of smell. As the students engage in hands-on activities and demonstrations, the professor is key in engaging students to discuss experimental results and encouraging students to develop and refine models of understanding based on their results. After each activity or demonstration, the professor strives to motivate the students to want to understand why certain compounds would yield similar smells. As a result, a model for understanding the sense of smell emerges as

students progress from seeing the importance of the components of the molecules (i.e., molecular formulas), to the connections of the individual atoms within the molecule, to the shapes of molecules. Within this model refinement, students are also collecting data and interpreting simple statistics like percentages.

Second, students are required to keep a journal to record their reactions to each lecture, including reactions to the instructor's comments about the process of science. As these journals are reviewed periodically by the course staff, students receive feedback, support, and encouragement to reflect upon and think critically of the material they are learning.

Third, media critiques are another part of the course requirements. Students are required to summarize a recent article published in a non-scientific publication (such as Time, The New York Times, etc.), discuss the role of chemistry, and critique the reporting in terms of its validity. These critiques are specifically assigned throughout the semester in an attempt to increase students' awareness of the impact of chemistry in their everyday lives. Furthermore, the assignments encourages students to be critical of the media's reporting, their claims, and their evidence.

Fourth, students are involved in two debates during the semester. One debate surrounds the controversy of using "paper vs. plastic", and the other debate focuses on the use of pesticides (environmentalists vs. agribusiness). Before each debate, students are separated into two camps and given reading materials to prepare a defense of their position. Thus, students are given opportunity to develop skills for using evidence to support their stance and counter arguments from the opposing side.

	Guided-inquiry Laboratory (GI)	**Critical Reasoning Course (CR)**	**Traditional Laboratory (TR)**
In Class activity	Experimental design	Model refinement	Procedural exercise
Individual assignments	POE and multiple levels of explanation	Critical evaluation	Algorithmic data manipulation
Authentic Inquiry	Yes	Yes	No
Metacognitive level	High	Medium	Low

Table 2. Comparison of three learning environments

The metacognitive levels described in Table 2 reflect the emphasis of each approach on reflection and monitoring of one's understanding. In the guided-inquiry course, designing

experiments, reconciling predictions with observed results, and developing explanations on multiple levels require a great deal of metacognition on the part of the student. On the other hand, very little metacognitive activity is prompted in the traditional laboratory course. Finally, some reflection is required of the critical reasoning students through the journal assignments as students are asked to record their thoughts and reflect on what they have learned in lecture.

The traditional laboratory serves as a control group to measure whether the guided-inquiry laboratory approach or the critical reasoning approach is more successful at fostering student inquiry skills. For the guided inquiry laboratory, it is hypothesized that the structure and focus of the course, including the opportunity to design experiments, will be instrumental in developing inquiry skills beyond the traditional group. For the critical reasoning course, the four components comprise the main ingredients of fostering students' critical reasoning. Students are usually motivated by what is deemed important and graded by the teacher. Since the latter three course requirements are assessed and determine a significant portion of a student's final grade, it is hypothesized that students will develop critical reasoning skills through the course beyond those of the traditional group.

Methods

All students participating in the study were UC Berkeley undergraduates. The critical reasoning course was only offered during the Semester 1 study, so the Semester 2 study examines the differences in inquiry skills that arise in the traditional and guided-inquiry instructional environments.

In Semesters 1 and 2, the students in the traditional laboratory and guided-inquiry laboratory were enrolled in the same introductory chemistry course, Chemistry 1A, but were in different laboratory sections. Typically, the traditional laboratory students followed step-by-step procedures each week and had little opportunity to engage in experimental design or decision-making. In contrast, the guided-inquiry laboratory provided an authentic scientific inquiry experience within a guided-discovery environment as students developed experimental questions and experimental designs. In addition, the guided-inquiry sections were required to reconcile predictions with observed results and explain results on multiple levels. The two sections that participated in the guided-inquiry laboratory were randomly selected.

In Semester 1, four of the remaining twenty-four traditional sections served as the sample population representing the traditional laboratory. The students enrolled in the two guided-inquiry sections participated in the normal sequence of Chemistry 1A laboratory experiments, except for the last four weeks of the laboratory course when the guided-inquiry curriculum was implemented.

In Semester 2, students from two traditional sections and the two guided-inquiry sections were randomly selected to participate in the study. Based on average scores of exams administered prior to implementation of the guided-inquiry curriculum, the students in each group were determined to be equivalent.

Data Source

The instrument used to assess students' ability to evaluate evidence consisted of written questions about two research studies. The initial study presented two fabricated studies both relating to effectiveness of sunscreen products. Given these two studies, one with data relating to how much ultraviolet radiation is transmitted by various sunscreens and another with statistical data relating the incidence of skin cancer with the use of sunscreens, students are asked to comment on the validity of the studies' conclusions drawn and to comment on the weaknesses of each study. Students were also asked to explain the mechanism of how sunscreens work. Finally, students were asked to compare the two studies as to which was more "scientific". At the end of the term, the instrument was given to all students in Chemistry 10 (n=50) and the guided-inquiry laboratory sections (n=44) and to students in four randomly-selected sections of the traditional laboratory (n=20).

A second study was conducted in Semester 2 to seven students in the guided-inquiry sections and seven students in the traditional lab sections. The second instrument presented two recently published studies investigating the possible causal relationship between silicone implants and immunological disease. The first study conducted basic research on the effects of silicone on animals, while the second study was an epidemiological study. After completing the activity, the students were interviewed to clarify their written responses.

Results and educational implications of the study

Semester 1 Results

Analysis of the data from Semester 1 demonstrated some differences regarding student ability to offer microscopic explanations of phenomena, improvements of methodology, valid interpretations of evidence, and student beliefs about the nature of science.

First, regarding microscopic explanations of the mechanism involved in sunscreen protection, critical reasoning (CR) students outperformed both guided-inquiry (GI) and traditional (TR) students. Interestingly, although the TR course provided more instruction to support a microscopic understanding of the electromagnetic spectrum, CR students were more likely to give acceptable explanations which included a microscopic perspective ($p < 0.07$[1]). TR students only gave macroscopic explanations (of those who gave explanations, 13 of 20). These results may reflect the goals of each instructional approach since TR students were never prompted to consider the microscopic level for their laboratory experiments. However, although the GI approach emphasized the integration of microscopic and macroscopic understanding, there were no significant differences between GI and TR students.

Thus, GI and TR students rarely connect the given empirical data with relevant conceptual material covered in the Chemistry 1A course. In addition, some students spontaneously included tangential issues. These findings suggest that more is needed to help students become more metacognitive and think about how their knowledge from chemistry lectures can be connected with lab results and everyday experiences.

Second, critical reasoning students also were more likely to offer relevant methodological improvements of the fabricated studies than traditional students ($p < 0.07$). This tendency may result from the focus of the CR course on the critical examination of evidence and its collection (e.g., through media critiques and debates). However, as compared to CR students, TR students appear to be more conscious of the importance of controlling variables in an experiment ($p < 0.09$). I believe this result is indicative of the greater experimental emphasis of the TR laboratory.

No statistically significant trends arose when comparing guided-inquiry students to either group. Since the guided-inquiry curricula includes an experimental design aspect, one might expect GI students to be more critical of the methods than CR or TR students. However, in Semester 1, there was only one opportunity for students to design their own experiments. Given more opportunities to design experiments and critique their peer's

[1] Unless otherwise noted, all p values are calculated using Fisher's exact statistical calculation.

designs, I expect GI students to be able to outperform TR students in future implementations of the GI curriculum.

Third, concerning interpretations of the evidence, students were asked to evaluate the validity of a journalist's conclusion of the evidence. Compared to the traditional students, more critical reasoning students were able to give valid justifications to refute the journalist's claim ($p < 0.05$). Furthermore, CR students were much more critical of the journalist's claim and offered pertinent factors that the journalist did not take into consideration ($p < 0.05$). The significance of the latter finding reinforces the value of encouraging the CR students to examine evidence critically. Arguably, TR students were supposed to develop such critical skills when examining their own empirical data. However, CR students, and not TR students, demonstrated the ability to look beyond the scope of the given study to account for other factors that were relevant to the investigation. Although GI students also offered better explanations than TR students to refute the journalist's claim, they were not as likely to mention other factors that were ignored by the journalist.

The last significant finding involved student beliefs about the nature of science, specifically their beliefs about what causes a study to be "scientific". Guided-inquiry students used the exper nental data as a criteria for "scientific" more than critical reasoning students ($p < 0.05$). Since GI students had a more extensive and rigorous laboratory experience than the CR students, GI students are more likely to associate the quality of the "science" with the data and the methods of collecting the data. However, similar arguments could be made for the TR students, and <u>no</u> such differences were observed between TR and CR students.

In summary, the results indicate the critical reasoning environment was more successful in fostering inquiry skills than the traditional laboratory environment. CR students demonstrated more microscopic understanding in their explanations, offered more valid improvements to the fabricated studies, and interpreted the given evidence more critically.

Semester 2 Results

A different instrument was administered in Semester 2 for two reasons. First of all, the guided-inquiry laboratory curriculum included experiments on sunscreens, while the traditional laboratory did not. Therefore, to avoid possible repercussions of domain familiarity and experience, a different subject area seemed necessary. Second, instead of presenting fabricated studies, I felt that providing actual results from research journals would provide credence to the inquiry assessment.

The course exams were used to determine how similar the GI and TR students were before differences arose in the laboratory experience. Midterms 1 and 2 were administered before the guided inquiry curriculum was implemented in the laboratory. The average performance on those two exams for the two groups (seven in each group) were equivalent. Thus, any inquiry skill differences that arise between the GI and TR students are likely to be a consequence of the different laboratory experiences.

The most notable finding involved the student critique of one of the studies. Guided-inquiry students were significantly more critical of the methods and data as compared to the traditional students ($p < 0.02$). This evidence offers support that students in GI labs develop better inquiry skills than control group. In addition, GI students tend to ask for more clarification of the study to achieve a better understanding of the study ($p < 0.06$). I believe that this provides support that GI students are more metacognitive than traditional students because they are more likely to look beyond the given information to try to understand the bigger picture.

A cumulative scoring was tabulated to assess the overall quality and coherence of student explanations. Based on the higher average of the seven GI students, the GI students show a tendency of giving better explanations, i.e., explanations that are valid and critical of methods and data ($p < 0.08$, one-tail t-test).

Instructional Group	Mean # of Valid Explanations	Standard deviation
Guided-inquiry	7.4	1.7
Traditional	5.7	2.4

Table 3. Explanations of Guided-inquiry vs. Traditional instruction

In summary, analysis of Semester 2 data demonstrated that the guided-inquiry students were better prepared to critically examine the methods and data of an experiment. Thus, it seems reasonable to conclude that the guided-inquiry instruction is more successful in fostering inquiry skills than the traditional laboratory.

Educational implications

One issue that arose revealed that students generally gave more credence to data obtained using instruments than to statistical data based on human populations because they perceived the transmission data to be more "scientific". Given this result, the question

arises whether students put more credence in data which they perceive to be "scientific", without critically examining the reliability or validity of that piece of evidence in the context of the situation.

A significant number of students in the GI laboratory, compared with the TR students, offered more solid reasoning when answering the posed questions. The majority of students in the GI laboratory also demonstrated understanding of weaknesses in the studies and offered reasonable suggestions to improve each study. These results suggest that, if we are interested in promoting the ability to critically evaluate evidence as a main goal of the freshman chemistry laboratory, we should consider designing lab courses that incorporate authentic scientific inquiry within a guided-discovery environment.

The critical reasoning students also demonstrated significant success in evaluating the two research studies. Overall, critical reasoning students did perform significantly better than students in the traditional laboratory sections. These results imply that students can successfully develop scientific inquiry skills through activities outside of the laboratory. The critical reasoning course (Chemistry 10) was implemented for the first time during the Semester 1 study. Although students in the critical reasoning course did not experience the practice of authentic scientific inquiry in the laboratory as in Chemistry 1A, the nonmajors were encouraged to think critically through the lecture and various course requirements. In addition, the student journals provided ample opportunities for individuals to voice their opinions concerning the evidence and/or model development presented in the lectures. Their ability to reason critically was also fostered through weekly assignments which required students to read and critique recently published scientific articles. Furthermore, questions on the midterm and final exam were designed specifically to assess students' ability to evaluate evidence critically. Through these activities, the Chemistry 10 instruction apparently fosters the development of students' critical reasoning component of inquiry skills.

One hypothesized consequence of the guided inquiry curriculum is that the promotion of metacognitive skills will foster greater conceptual understanding. Using the exam performance as a measure of conceptual understanding, the test questions typically fell into the following categories: knowledge-level, comprehension-level, and problem solving which involved application of concepts and formulas. Based on the exam scores alone, the expected improvement of conceptual understanding is not supported. However, an interesting line of future research would be to develop assessments that go beyond the

typical algorithmic problems found on exams in order to measure conceptual understanding.

In conclusion, on investigating the impact of three instructional designs for introductory chemistry courses, the guided-inquiry laboratory and critical reasoning lecture course were more successful than the traditional laboratory alone in developing students' inquiry skills. Future work will examine the reproducibility of these results when an entire semester of guided-inquiry curriculum is implemented and the traditional and guided-inquiry sections are taught by the same individuals.

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