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Improving Students' Inquiry Skills and Self-Efficacy through Research-Inspired Modules in the General Chemistry Laboratory

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Supporting Information

ABSTRACT: Research projects conducted by faculty in STEM departments served as the inspiration for a new curriculum of inquiry-based, multiweek laboratory modules in the general chemistry 1 course. The purpose of this curriculum redesign was to improve students' attitudes about chemistry as well as their self-efficacy and skills in performing inquiry activities. Students' ability to plan experiments and interpret data improved throughout the semester, as did their confidence in conducting research-like lab activities. Improved confidence was observed among men and women, science and engineering students, and Caucasian and international students. These outcomes are similar to those found with authentic research-based experiments. The curriculum had less of an impact on students' attitudes about chemistry. A research-inspired curriculum offers many benefits to students without the difficulties of designing actual research-based projects for general chemistry classes.

KEYWORDS: *First-Year Undergraduate, Laboratory Instruction, Curriculum, Inquiry-Based/Discovery Learning, Interdisciplinary/Multidisciplinary*

■ INTRODUCTION

Chemical educators continue to develop new curricula consistent with the statement by the National Research Council that "scientific inquiry is at the heart of science and science learning."[1] Undergraduate research experiences for STEM majors foster more positive attitudes about their discipline, increase gains in subject matter knowledge, and inform students of their future career possibilities.[2−5] While not all students have the opportunity to perform research, authentic research-based chemistry lab curricula developed by the Center for Authentic Science Practice in Education[6,7] and others[8−10] allow students to reap some of the same benefits of a research experience as early as their first year of college.[6−8,10−12]

Authentic research lab activities are similar to the more well-known inquiry experiments but differ in that students' experimental results contribute to real research projects conducted by scientists.[13] This distinction leads to noteworthy results. Russell and Weaver have shown that research-based experiments impart a greater understanding of the nature of science to students compared to inquiry experiments.[12] Such outcomes may be due to students taking ownership of their work and the feeling of being part of a greater research endeavor.[12,14] Both approaches to laboratory instruction have greater educational value than traditional, verification experiments.[6,11,12] Actual research experiences[15] and authentic research-based modules[6,11,14] can improve retention of students, especially of women, in STEM majors. Educators and policy makers recognize this as a major challenge.[16,17]

While superior to inquiry experiments, curricula for authentic research require more effort to design since data must be useful to research scientists and collaboration with a scientist is necessary. Developers of the CASPiE program provide some advice for overcoming challenges of creating research-based modules,[18] but nonetheless, inquiry experiments remain easier to implement and are still highly recommended for the first-year chemistry teaching laboratory.[1]

Giving consideration to both the benefits of involving first-year students in research and the relative ease of designing inquiry-based experiments, the authors created a suite of inquiry-based modules for the General Chemistry 1 lab course which relate to science and engineering research conducted at Florida Tech. These modules are "research-inspired" rather than research-based. In the spectrum of laboratory pedagogies, this approach lies between inquiry and authentic research since students perform open-ended experiments related to actual research but their work does not advance any research project.

Following the implementation of the modules, the authors collected data for three semesters from over 500 General Chemistry 1 students. The purpose of this study is to determine the extent that research-inspired experiments can improve (1) students' perception of their own abilities to perform inquiry tasks (i.e., self-efficacy), (2) their attitudes toward chemistry, and (3) their inquiry skills, such as developing a hypothesis, designing an experimental procedure, and interpreting their data. Data was analyzed to measure gains by members of different demographic categories, including gender, nationality/ethnicity and college affiliation in order to understand how a research-inspired curriculum affects these groups. Results are compared to research of other pedagogies, most notably authentic research-based curricula. Descriptions of the curriculum development, assessment tools used, and results of the research-inspired lab module implementation are presented.

CURRICULUM DEVELOPMENT

The authors replaced 12, one-week verification experiments with four modules in which students studied a single topic in greater depth. Over 95% of Florida Tech's General Chemistry 1 students major in STEM disciplines other than chemistry, so the authors felt that interdisciplinary topics would appeal to more students. To highlight the relationship between general chemistry and research, the chosen topics relate to active research projects at Florida Tech. Faculty performing research in these areas served as advisors during the development and implementation of the module activities inspired by their research. The authors and an advisor for each module discussed aspects of the advisor's research that would be both interesting to students and appropriate for the general chemistry laboratory. During its development, they met to ensure that the module remained consistent with the advisor's research. Advisors suggested articles that the authors used to write the introduction for each module handout. They also recommended the articles to students for further reading. As discussed in the Assessment Methods section, advisors also reviewed student lab reports.

Individual modules, which will be described in future publications, are summarized in Table 1. Each module spans three, 3 h lab sessions. Modules are conducted and graded as follows. Four-member teams perform the "skill building" experiment to learn the basic laboratory techniques needed to conduct experiments during the next 2 weeks, known as "inquiry" sessions. Upon completing the skill building experiment, students choose one aspect of the chemical phenomenon to explore in more detail from a list of options. Four components determine a student's grade for a module: pre- and post-lab quizzes (10 points), data sheet (30 points), lab report (100 points) and reflection statement (10 points).

Table 1. Summary of Module Topics

Module	Name	Interdisciplinary Subjects
1	Production of NO_x gas by lightning	Physics, meteorology
2	Improving the strength of composites	Mechanical engineering
3	Remediation of industrial effluent using iron nanoparticles	Nanotechnology, environmental science and engineering
4	Removal of pharmaceutical pollutant from natural water	Environmental science and engineering

Prior to the first laboratory session, students are expected to read the module handout containing background information, a step-by-step procedure for the skill building exercises, safety notes, and any necessary supporting information. Each student completes a pre-lab quiz at the beginning of the lab session. The graduate student teaching assistant (TA) then presents a short summary of the procedure and safety issues. Students use an Excel spreadsheet, which the authors designed, to graph data and perform some of the more difficult calculations that students have not yet learned in the lecture class. Students record their results of the skill building exercise on a data sheet, which the TA grades based on accuracy. Data sheets contain preformatted tables for students to enter their data. This is both easier for the TA to grade and prompts students to enter the correct data. After turning in their data sheet, students individually complete a post-lab quiz. Pre- and post-lab quiz questions are drawn from the module handout.

Four-member teams are advantageous for several reasons.[19] Module procedures are more complex than typical experiments conducted by two lab partners. This arrangement also promotes teamwork, a valuable "soft skill" essential for conducting research. Whenever possible, teams stayed together throughout the semester. Each team member chooses a role to play during the module, as described in Table 2. Team members rotate through the four roles during the semester so that every student plays all roles. Each role involves writing a certain portion of the lab report. If necessary, a three-member team can combine the roles of the two technicians and omit a background section of the report. Roles give students more structure and minimize the opportunities for a single student to avoid work or dominate the group by performing too much of the work.

Table 2. Description of Roles and Responsibilities for Each Team Member

Team Role	Experiment Responsibilities	Lab Report Section
Manager	Keeps team members organized and performing their roles, communicates team's progress and concerns with TA and helps teammates as needed	Discussion
Chemist	Prepares all the chemicals and solutions	Procedure
Instrument Technician	Operates any instrumentation used in the experiment	Background and research hypothesis
Software Technician	Records all data and operates any software	Results and data analysis

Team members meet after the skill building lab session to choose a research topic for further exploration during the inquiry sessions. The module handout provides three or four inquiry topics from which to choose. The team writes a statement describing the topic, hypothesis and a brief procedure. The TA evaluates this at the beginning of the first inquiry session before students can start their work.

Upon completing the inquiry sessions of the module, students work together as they write the module report. This provides another opportunity for students to develop teamwork skills. The TA grades each student's section of the report based on the module report rubric. As an incentive to work together, 20% of each student's report grade is equal to the average report grade of the student's other teammates. In cases where a student failed to turn in a report section or committed plagiarism, that student's grade was not included in the average. The data sheet rubric emphasizes accuracy and precision of results. Grades for the results and discussion sections are based on the presentation and explanation of results, respectively. This mix of skill building and inquiry is analogous to a researcher following a published procedure to practice a technique, verifying that results match the literature, then pursuing a new line of research with results judged on the quality of the researcher's explanation.

Finally, each student evaluates his or her own performance as part of the team and the performance of his or her teammates in a private reflection statement. If reflection statements reveal a conflict within the team, the TA can discuss the issue privately with each team member.

Each module requires students, as a group, to choose a research topic, propose a hypothesis, plan a procedure to test that hypothesis, and determine which data to collect. As they write the module report, individual students gain other inquiry skills, such as organizing the raw data into an appropriate format (i.e., graphing the correct independent and dependent variables) and interpreting their data in order to reach a conclusion about their original hypothesis. As students cycle through each role within the team, each student has the opportunity to gain all of these inquiry skills. Overall, this approach places the modules at level 2 (problem provided to students; students develop procedure, choose data to collect and interpret data) using the rubric of inquiry experiment characteristics developed by Bretz et al.[20] Students modify the skill building procedure to perform their inquiry activities rather than create an entirely original procedure, consistent with an inquiry level position between levels 1 (problem and procedure are provided to students) and 2 for the procedure. Students choose a topic for investigation from a list of options rather than propose their own topic, a position between levels 2 and 3 (students choose problem to investigate) with regard to the choice of problem to explore. The authors selected this level of inquiry because, based on their experience, it is best suited for their first-year students.

■ ASSESSMENT METHODS

Students performed the four modules in General Chemistry 1 laboratory beginning in fall 2010. Project assessment occurred during the fall 2010, spring 2011 and fall 2011 semesters. Students in General Chemistry 1, a combined lecture and lab course, during the fall semesters are typically new, traditional, first-year students majoring in engineering or science. The spring semester enrollment of General Chemistry 1 consists of traditional first-year students as well, some new and some repeating the course. All students admitted to College of Science or the College of Engineering must take General Chemistry 1, including the laboratory.

The relevance of each assessment tool to measuring the project goals is summarized in Table 3. A copy of each survey is included in the Supporting Information.

Table 3. List of Assessment Methods and Their Associated Research Goals

Assessment Method	Research Goal		
	Improve Inquiry Skills	Improve Self-Perception of Inquiry Skills	Improve Attitudes about Chemistry
SPiCE Survey		X	X
Module Opinion Survey		X	
Lab Report Grades	X		
Lab Report Evaluation	X		

The authors created the Student Perceptions in Chemistry Evaluation (SPiCE) instrument to measure students' attitudes about various aspects of chemistry and their perceptions of their own inquiry skills. This survey was not anonymous because the authors wished to study the relationship between students' responses and their demographic characteristics. It contains 32 Likert scale items with 8 items in each distinct subscale: perceived abilities with respect to Inquiry Skills, Lab Skills and Lecture Material and a fourth subscale for students' perceptions of how chemistry affects the world around them (Real World). The scale spanned values from 1 (strongly disagree) to 5 (strongly agree). Students completed the survey during the first and last lab sessions of the semester. The authors designed half of the survey items and drew the remaining items from three existing instruments: the Chemistry Attitude and Experiences Questionnaire (CAEQ),[21] the Chemistry Expectations Survey (CHEMX),[22] and the Colorado Learning About Science Survey (CLASS).[23] A hybrid instrument was chosen because no single existing survey addresses students' attitudes or perceptions in all these areas and the use of multiple surveys could lead to survey fatigue among students.

A module opinion survey asked students about the quality of the module and their experience in the laboratory. In addition to the ten, 5-point Likert scale items with selections ranging from strongly disagree to strongly agree, students could respond to open-ended questions about the most and least favorite aspects of the module. This survey was anonymous.

Students received written feedback from their TAs for their own section of the laboratory report prior to turning in the next report. They also knew the overall report grade since that value contributed to 20% of each student's grade. However, students did not see each other's report section grade and feedback. Teaching assistants used a rubric prepared by the authors in order to promote consistent grading across all lab classes.

The authors evaluated student laboratory reports in two ways for the purpose of this study. An analysis of each student's report grades throughout the semester was not useful since each student within a team wrote a different section of the lab report for each module. Some sections, such as the background, are easier to write than others. However, the authors did not feel that a lab report for any particular module was more difficult than any other. Therefore, the grades for each report section were compiled and tracked throughout the semester (e.g., a comparison of grades earned by students writing the procedure sections of different modules).

During the first semester of this study (fall 2010), the authors and TAs selected three lab reports for each module that they viewed as good, fair and poor (nine reports evaluated for each module). Faculty advisors who helped design each module reviewed these reports. The purpose of this review was to verify that TAs accurately evaluated students' abilities to gather, organize, and interpret their data. The reviewers also suggested improvements to the module's introductory text to help students better understand the research upon which the module topic is based.

Students individually completed a pre- and post-lab quiz for each module. While the quizzes did not assess the ability of students to work as a team, quizzes do promote behaviors that improve teamwork, such as learning the experiment subject matter, preparing for the lab session and paying attention to their team's work.

All assessment tools and the project as a whole received IRB approval. Students received a consent form that described the project and stated that students could opt out of sharing data with the authors. Only data from consenting students is included in the analysis. The authors employed additional assessment tools during the fall 2010 semester but, for various reasons, found that they were ineffective or unhelpful. More details are found in the Supporting Information.

■ RESULTS AND DISCUSSION

A series of analyses were performed using SPiCE data in order to learn how the curriculum redesign affected students' self-efficacy and attitudes about chemistry. Student populations were $n = 190$ in fall 2010, $n = 71$ in spring 2011 and $n = 249$ in fall 2011.

Students completed SPiCE surveys during the first (pre-) and last (post-) laboratory sessions, respectively. Pre-to-post changes in subscale and total scores were statistically similar between the fall 2010 and the fall 2011 semesters. These results indicate a reasonable degree of consistency in student responses to the survey across semesters. Spring 2011 results showed considerable differences compared to the fall results and, due to the small sample size, yielded few noteworthy results. Only the most significant results of these analyses are presented here, but readers can find complete results and analysis in the Supporting Information.

Goal 1: Improve Students' Self-Efficacy in Performing Inquiry Tasks

Self-efficacy refers to the confidence a person feels about succeeding at a particular task. Confidence in succeeding in chemistry correlates with students' choices of college classes and careers,[24,25] attitudes about chemistry[26−29] and their anxiety in the lab.[28] Therefore, improving the self-efficacy of women and minority students can help to improve their retention in general chemistry. Most students in Florida Tech's first semester of general chemistry are not chemistry majors, so improving their attitudes about general chemistry could have a profound impact on how the chemistry department is viewed campus-wide.

Overall, students in each fall semester began with positive views of their abilities. Thirteen SPiCE items address self-efficacy (items #1, 4, 7, 9, 11, 14, 16, 17, 22, 23, 24, 30, and 32, see Supporting Information). The average pre-score for all these items was 3.6 out of a maximum of score of 5 with no item scored below a value of 3.0 (see Table S4, Supporting Information). Relatively high self-efficacy for science majors has been seen before[26] and is reasonable given that students selected to major in a STEM field. Table 4 lists 10 SPiCE survey items, including all eight items in the Inquiry subscale, which showed notable individual gains between the pre- and post-semester surveys ($p < 0.05$). Nine of the items address self-efficacy and one item (#10) deals with teamwork. Understanding students' self-efficacy with regard to laboratory inquiry skills is a major component of this project so these items deserved more detailed analysis.

Table 4. SPiCE Items Selected for Detailed Statistical Analysis

Item No.	Item Statement	Scale
9	I am very comfortable designing lab experiments.	Inquiry
11	When I am presented with a chemistry problem for lab investigation, it is easy to formulate a relevant research question and hypothesis.	Inquiry
14	After reading the procedures for lab experiments, I'm always able to conduct the experiment without supervision.	Inquiry
16	When conducting lab experiments, I know how to collect usable and accurate data.	Inquiry
17	Once I have raw data from an experiment, it is easy for me to organize and chart them.	Inquiry
22	When presented with lab results, I know how to interpret and draw conclusions from them.	Inquiry
23	When looking back on a lab experiment, I have difficulty figuring out how my lab procedures and errors affected my results.	Inquiry
24	I struggle when trying to understand how information in background articles relates to my lab procedures and results.	Inquiry
10	I enjoy working with teammates to design and develop procedures for lab experiments.	Lab Skills
7	After reading an article about a chemistry experiment, I can easily write a summary of the main points.	Real World

Only analyses of items 7, 9, and 11 were found to be statistically significant at an adjusted alpha level of $\rho < 0.005$, based on the Bonferroni method. Item 7 addresses the ability of the student to summarize a chemistry experiment. Item 9 pertains to students' perceived ability to design lab experiments and item 11 pertains to their ability to formulate research questions and hypotheses to guide lab investigations. Items 9 and 11 reflect important aspects of the curriculum since, after completing their skill building exercises, each team designs their own procedure to perform their inquiry experiments during the next 2 weeks and develops a hypothesis related to their chosen research question.

A second analysis of these 10 items was conducted on the basis of student gender, ethnicity/nationality and college affiliation. These demographic groups showed consistent, statistically significant improvement with regard to items 9 and 11 of the SPiCE survey for the fall 2010 and fall 2011 terms. Results are presented in Figure 1. For reference, a survey value of 3 on a 5-point scale represents a neutral response while a value of 4 indicates a positive or agreeable response. Improved responses for other items are presented in the Supporting Information. In those cases, the presemester score changed from agreement to a more strong agreement. All gains among demographic groups reported here are statistically significant with $p < 0.005$. Standard deviations for results in Figure 1 are 0.8−1.1 with individual standard deviation values found in the Supporting Information.

Pre-to-post increases in mean scores were found for items 9 and 11 responses from males and females within the fall 2010 and fall 2011 data sets (Figure 1a, b). Female students began with lower self-efficacy than male students, a scenario frequently observed in general chemistry,[26,27,30] although not always.[29,30] In this study, women made strong gains after completing the research-inspired modules, each semester equaling or exceeding the confidence of the men. This gap in confidence between men and women in high school and college has been reported elsewhere for research experiences[16] and in other STEM subjects[31−33] but there are only a few reports of self-efficacy of men and women changing during a semester of general chemistry.

Villafañe et al. tracked self-efficacy of general chemistry students throughout the semester of a general chemistry course without a laboratory component.[27] They used five items from the CAEQ survey, one of the sources of items for the SPiCE survey. However, only one item, the ability to explain a chemistry concept to another person, appears in their survey and SPiCE. Overall, students initially showed low self-efficacy but gained confidence during the semester. Female students started the semester with lower self-efficacy than their male classmates but differences between the two groups were smaller at the end of the semester. These outcomes are similar to those found in the present study, albeit the study by Villafañe investigated self-efficacy only in a lecture course.

In another such study, self-efficacy of students in a New Zealand university were studied using the CAEQ survey taken at the beginning and end of the first semester of general chemistry and at the end of the second semester.[26] Their laboratory curriculum consisted of verification experiments.

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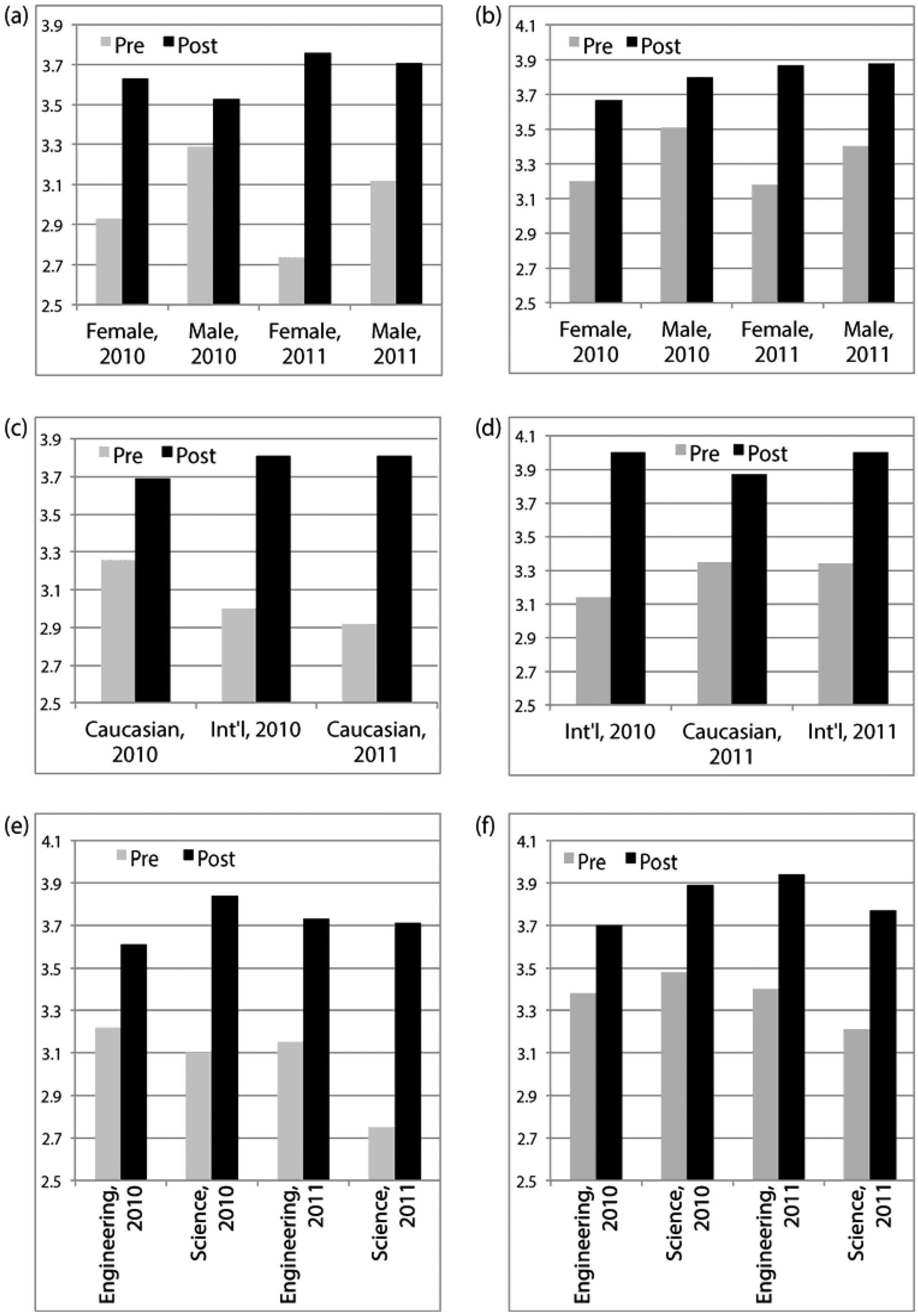

Figure 1. Improvements in student self-perceptions of certain inquiry skills analyzed with respect to student gender for items 9 (a) and 11 (b), ethnicity for items 9 (c) and 11 (d), and college affiliation for items 9 (e) and 11 (f) of the fall 2010 and fall 2011 SPiCE instruments.

The self-efficacy gender gap for some survey items closed at the end of the first semester but persisted until the end of the second semester of general chemistry for other items. Self-efficacy of women improved over two semesters and ultimately equaled the confidence of male students with regard to "proposing a meaningful question that could be answered experimentally." In the present case, the confidence of women and men to "formulate a relevant research question and hypothesis" (SPiCE item 11) was equal after completing only one semester of the research-inspired lab modules. Again, only a few CAEQ survey items were the same in the survey used in that research and the SPiCE survey.

For the fall 2010 data set, both international students from ~45 countries and U.S. Caucasian students showed pre-to-post increases in mean scores for item 9. International students made similar improvements for items 11 and 14. Pre-to-post increases were found for American students of different ethnic backgrounds on a number of other items (e.g., Hispanic students on item 9; African American and Asian American students on item 11; Native American students on item 14), but due to the relatively small number of students in these ethnic groups and the fact that this test for statistical significance is sensitive to sample size, these results were not statistically significant at $p < 0.005$. With respect to the fall 2011 data set, both U.S. Caucasian and international students achieved pre-to-post increases on item 11, while the former group also made gains in items 9, 16, 22, and 7. International students at Florida Tech face the challenges of mastering a second language (most are from non-English speaking countries) and adjusting to new culture, sources of stress that domestic students do not encounter.[34] Stress can affect students' self-efficacy,[35] which may explain why international students achieved pre-/post-semester gains for only four survey items while domestic students gained in six items in total over the two year period of the survey.

Students majoring in science and engineering achieved gains related to SPiCE items 9 and 11 as shown in Figure 1e, f. In both the fall 2010 and fall 2011 semester data sets, these pre-to-post gains were greater in magnitude for College of Science students than for College of Engineering students. Significant pre-to-post increases in mean scores for item 7 (writing a summary of a chemistry experiment) were found for College of Science students in fall 2010 and for College of Engineering students in fall 2011. Engineering students were less enthusiastic about working in a team in fall 2011 (item 10), but they were more confident about interpreting experimental results (item 22) and understanding the effects of experimental errors (item 23).

These findings help the authors convince nonchemistry majors of the relevancy of the General Chemistry I laboratory. Most students enrolled in General Chemistry 1 are engineering majors who only take one semester of chemistry and often view the subject as uninteresting and unrelated to their major. Although the General Chemistry 1 laboratory did not change their opinion of chemistry (as demonstrated by the lack of statistically significant pre-to-post changes in other SPiCE items), the laboratory curriculum did bolster their self-efficacy with regards to research skills. Greater self-confidence with respect to research tasks gained during the general chemistry lab is useful to engineering students when they pursue research and co-op positions in the future.

Authentic research-based lab experiments provide students with many benefits. Purdue University students performing CASPiE authentic research-based experiments in the general chemistry lab appreciated being given the responsibility for designing experiments and displayed greater self-confidence in designing new experiments.[11] Students performing verification or inquiry experiments in that same study showed no such gain. Overall, results of SPiCE items 9 and 11 mirror the improvements in self-efficacy observed for students completing an authentic research-based curriculum.

Biology students felt more confident employing a variety of inquiry skills, including designing experiments and interpreting data after completing an authentic research-based lab curriculum, compared to students who performed verification experiments.[36] This study used a quasi-experimental design in which students self-selected into the lab sections teaching the research-based experiments. Those students showed statistically significant ($p < 0.05$) gains in such skills as designing experimental procedures, interpreting data and discussing results. The present study involves all General Chemistry 1 students and shows that they made similar gains for the same tasks (SPiCE items 9, 11, 17 and 22).

Goal 2: Improve Students' Attitudes about Chemistry

A second goal of this project was to improve students' attitudes about chemistry, including both the lecture class and chemistry experienced outside the classroom. Students' opinions of their performance in the Lecture Material subscale items remained unchanged. While it is disappointing that students did not end the semester with better attitudes about solving chemistry problems and studying the lecture content than when they started, connecting their lab work to lecture topics was not a point of emphasis for the laboratory curriculum. Student attitudes about laboratory skills did not improve, with the exception of item 10 which addressed teamwork. This overall lack of improvement in student attitudes about lab skills was surprising given their relevance to the successful completion the laboratory course.

Student attitudes remained mostly unchanged in the SPiCE Real World subscale. Only SPiCE item 7 of the Real World subscale showed pre-to-post improvement for more than one semester. Of all the items, this one related most closely to the curriculum. Students write a background section of their report which requires them to read and summarize information they find in reliable sources, such as Popular Science and Scientific American magazines and Web sites for the Environmental Protection Agency, the National Weather Service and the National Nanotechnology Infrastructure Network. While it may be surprising that writing a background section to a single laboratory report can improve students' self-efficacy, gains from one lab experiment are not unprecedented. Cacciatore and Sevian found that a single inquiry experiment improved the problem solving abilities of students[37] and Rudd et al. found that writing one laboratory report improved students' abilities to express concepts in their writing.[38] Given the potential gains in skills from a single assignment, it is not unreasonable to expect some gain in confidence also.

These results indicate that the research-inspired laboratory modules did not have the desired positive effect on students' opinions about chemistry, despite the emphasis placed on connecting students' experimentation with research conducted by faculty at their own school. A greater involvement in actual research appears to benefit students in this regard. Reports of the impact of authentic research-based experiments on chemistry attitudes show generally positive results. Experiments developed through the CASPiE program have improved students' attitudes about importance of chemistry in their lives and careers.[6,7,11] A survey of students in an authentic research-based lab course showed improved attitudes about science and research compared to students who chose to perform verification experiments.[6] Other preliminary results of chemistry majors who participate in a two-year curriculum that moves them from verification experiments to independent research projects report significantly more interest in continuing their research.[39] However, a recent report of a research-based experiment did not inspire students to pursue research opportunities any more than the other traditional lab experiments they performed.[8] The only significant pre-/post-semester gain in the current study was directly tied to an assignment (writing the background section of their report), suggesting that changing students' attitudes about chemistry necessitates concrete actions rather than expecting them to infer the benefits of chemistry to their daily lives.

Students' attitudes about the research-inspired modules themselves and their experiences in the laboratory were positive based on their responses to an opinion survey completed after each module during the fall 2010 and spring 2011 semesters. Generally, their views were consistent for all four modules during each semester. The surveys recorded fewer negative responses and more frequent positive responses during the spring semester than the fall. This is likely due to the authors clarifying certain steps in the module procedures after the fall semester and the practice gained by the TAs teaching the modules. Revisions to the module procedures were based on feedback from students, the project's research advisors and TAs.

Overwhelmingly, students felt that the lab equipment was adequate and their TA was helpful. For each of these items, students answered with either "agree" or "strongly agree" more than 70% of the time, averaged over four modules during each semester.

Each survey showed that almost half of students found the topics interesting but only ~30% of students found the module topic relevant to their major. Given that students study a wide variety of disciplines, it is not unexpected that a module topic would appeal to a minority of students. Also, first-semester students may not understand the relevancy of the topic to the discipline they are just beginning to study. In each survey, approximately 20% of the students did not find the topic interesting. Students were ambivalent about whether the research topics were too limited in scope.

Four survey items asked students if the module imparted certain skills or knowledge. Approximately two-thirds of students responded that the background information provided in the module handout was helpful in understanding the purpose of the module. Even more students believed that the skill building exercises helped them perform their inquiry experiments and the module helped them learn to design an experimental procedure. Most students felt that the module increased their knowledge of the relevant chemistry topics, although the modules did not change their attitudes about chemistry. These results are consistent with the findings of the SPiCE survey analysis.

Due to the curriculum's designed interdependence of students within a team, it was not surprising that students overwhelmingly (~75%) viewed the modules as promoting teamwork. However, SPiCE results mentioned previously did not show any statistically significant improvements in students' attitudes about working in a team and in fact engineering students viewed teamwork less favorably by the end of the semester.

Students considered each module to be educational and held favorable views about how the modules were taught. These outcomes are typical among college students performing inquiry-based experiments in chemistry[40,41] and biology.[42] The design of the modules is consistent with recommendations found in the literature regarding the importance of the lab manual, TA preparation, and providing students with sufficient background knowledge and lab experiences which prepare them for inquiry activities.[42,43]

Goal 3: Improve Students' Inquiry Skills

While Goal 1 addressed students' self-efficacy with respect to inquiry skills, Goal 3 focuses on students' actual abilities to perform these tasks. Achievement of this goal is measured by lab reports, lab quizzes and overall grades in the lab. For each module, each team member wrote a different section of the report: background, methods, results, and discussion (three-member teams did not write a background section). The authors analyzed report section grades for the fall 2010 semester in order to determine if students improved their abilities to plan and perform experiments and interpret their results. Background section grades were very good (>80%) throughout the semester and did not improve noticeably. Grades for 20 teams were studied because only these teams remained completely intact throughout the semester and no team members were penalized for plagiarism (which earned a grade of zero for that section). Table 5 shows that students' performance on the three lab report sections improved throughout the fall semester. Statistically significant gains ($p \leq 0.05$) in grades were seen for each report section with most of the improvement occurring between reports for modules 1 and 2. The teams' average report grades for these three sections increased from 69% to 82%. Effect sizes measured by comparing grades for module 4 vs module 1 were medium to large, with values ranging from 0.6 to 1.[44,45]

Table 5. Average Report Section Grades with Comparisons between Grades for Modules 1 and 4 and for Modules 2 and 4

Section	Module Number	Average Grade, %	p-Value and Effect Size (d) Comparing Modules 1 and 4
Methods	1	80	$p = 0.002$
	2	91	$d = 1$
	3	90	
	4	96	
Results	1	52	$p = 0.05$
	2	67	$d = 0.6$
	3	62	
	4	62	
Discussion	1	74	$p = 0.004$
	2	82	$d = 0.7$
	3	81	
	4	87	

Although teams improved their ability to express the experiment results, the Results section remained the most challenging for them throughout the semester. The TAs noted that students could adequately prepare the graphs of data but they often failed to organize or write about the data in any coherent way. Students treated all data as equally important and could not sufficiently distinguish between the important and inconsequential results. Students writing the discussion section tended to do a better job of seeing the "big picture" of the results. Although the TAs encouraged students writing these two sections to work together as they each wrote their separate reports, this apparently did not happen to a sufficient extent.

Module report grades show improvement in the ability of students to write and interpret their data. However, these gains may not be due solely to the module activities. Other experiences gained throughout their first semester in college may improve students' perception of their own abilities. Contributing factors include the composition class taken by almost all first semester students, any additional science laboratory courses they might have taken (e.g., biology) and their better understanding of the report requirements.

It is possible that lab report grades may not accurately reflect student learning. Therefore, the faculty advisors who helped guide the development of the module topics spot checked the lab report grading during the fall 2010 semester. This provided some assurance that students' report grades correlated with their understanding of inquiry activities and experimental results, as judged by independent experts who are familiar with each research topic. All four faculty advisors endorsed the grading by the TAs as fair and consistent with the expected level of student knowledge.

Average pre-lab quiz grades for each module ranged from 2.2 to 3.4 (out of 5 possible points), with a combined average of 3.0. Average post-lab quiz grades were between 3.4 and 4.4 out of 5 points with an overall average of 4.0. Pre- to post-quiz increases for each module were statistically significant at the 95% confidence level and effect size values were between 0.6 and 0.8, indicating medium to large effects.[44,45]

Overall laboratory grades for the modules included reports, pre- and post-lab quizzes and data sheets. Lab grades prior to fall 2010 consisted of only pre-lab quizzes and data sheets. The new curriculum required more work from students and was more thorough in its evaluation of their knowledge. Despite this, grades from fall 2010 differed by only 2.7% with grades in fall 2009 (81.0% and 83.7%, respectively). This is a small but statistically significant difference ($\rho < 0.05$). Grades for the spring 2010 and spring 2011 were 80.1% and 78.1%, respectively, but this difference of 2% was not significant.

Given the many differences in lab experiments and grading standards, it is difficult to directly compare student performance in this study to the performance of students at other schools. However, some similarities are apparent between student learning gains observed here and reports found in the literature. Exit interviews conducted as part of the previously cited Purdue University study showed that students performing CASPiE experiments demonstrated more content comprehension and a greater ability to explain experimental results. Those students conducting verification experiments made no gains in these areas and students performing inquiry experiments only improved in the capacity to explain the experiment topic.[11] As with project goal 1 (self-efficacy), benefits of research-inspired modules are consistent with those of the research-based curriculum and students' gains exceed those found when students are taught using verification or inquiry experiments.

CONCLUSIONS

Research-inspired lab modules increase students' self-efficacy in their ability to complete inquiry activities. These benefits were found among both male and female students, both science and engineering majors, and international and U.S. Caucasian students. Women and international students made the greatest gains in confidence. The quality of module reports improved throughout the semester, indicating that students are actually improving their ability to plan experiments and understand, describe and interpret the experimental data which they collect. These results show that the research-inspired curriculum leads to students achieving the first and third project goals (improving self-efficacy and improving inquiry skills, respectively). Results are similar to those observed in studies of authentic research-based experiments.

The influence of this curriculum on students' attitudes toward chemistry to their daily lives was less than expected and more similar to outcomes associated with inquiry or even verification laboratory experiments. This outcome suggests that merely showing students that a relationship exists between their experiment topic and actual research is insufficient to achieve the beneficial results associated with students performing authentic research in the general chemistry laboratory. Future efforts to improve student attitudes should take this into account.

Authentic research-based experiments provide the greatest benefits to students, including not only higher self-efficacy, improved inquiry skills, and content knowledge but also greater interest in research and a better comprehension of the nature of science. However, that approach is also the most challenging to implement, requiring collaborations with research scientists and experiment procedures that are appropriate for general chemistry. Research-inspired lab modules achieve some of the same positive outcomes of an authentic research-based approach and are easier to design. It is hoped that this approach to laboratory instruction can be a useful alternative to either inquiry or authentic research-based experiments.

ASSOCIATED CONTENT

Supporting Information

A copy of surveys described in this article and a detailed description of the data analysis methods. This material is available via the Internet at http://pubs.acs.org.

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Notes

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