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Community-Based Inquiry in Allied Health Biochemistry Promotes Equity by Improving Critical Thinking for Women and Showing Promise for Increasing Content Gains for Ethnic Minority Students

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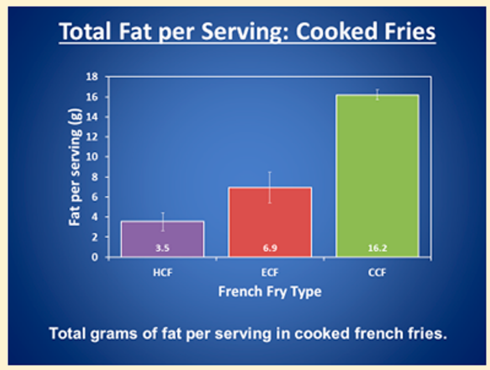
Ⓢ *Supporting Information*

ABSTRACT: In the Community-Based Inquiry (CBI) instructional method, cooperative student groups complete case study activities based on scientific literature and conduct their own laboratory investigations that address authentic community needs. This study compared critical thinking and content knowledge outcomes between traditional Introduction to Biochemistry lecture/laboratory and CBI curricula with human health case studies and local elementary school lunch nutrition laboratory investigations. CBI students experienced statistically significant critical thinking gains of medium effect size with female and male equity, whereas traditional students demonstrated no critical thinking gains with statistically significant sex disparity of medium effect size. Bifurcating student ethnicity into White and all other respondents revealed that the Other students gained statistically significantly more content knowledge in CBI than in the traditional group with a large effect size. Chemistry faculty concerned with developing both content knowledge and critical thinking skill in all students should consider using CBI not only for majors, but also for non-majors such as allied health students.



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■ INTRODUCTION

Rationale for Reform in Introductory Chemistry Courses

Many national reports call for reforming higher education introductory science, technology, engineering, and mathematics (STEM) courses to increase the number of science majors and to prepare all graduates with skills necessary for the modern workforce.[1−3] Critical thinking, in particular, is increasingly acknowledged as a set of marketable skills essential for college graduates. Surveyed college professors consistently rate critical thinking as the most important outcome of undergraduate education,[4] and employers rank its importance second only to communication skills.[5] However, while well over 80% of undergraduates believe their undergraduate experiences produce critical thinking gains,[6] only about 5% of those tested demonstrate proficient critical thinking skill, with over 80% demonstrating no proficiency.[7] If critical thinking is essential to academic and professional preparation, then higher education faculty should use instruction methods that measurably improve critical thinking ability.

Although critical thinking is acknowledged as an important outcome, it is defined differently by different researchers. One of the most comprehensive efforts to define and measure critical thinking was undertaken by Facione and the American Psychological Association who convened a panel of experts that participated in a Delphi process to posit a consensus definition.[8] They defined critical thinking as a "process of purposeful self-regulatory judgment that drives problem solving and decision-making" and articulated both behavioral (e.g., curiosity, open-mindedness, tendency to seek the truth) and cognitive (e.g., analysis, inference, evaluation) components of critical thinking. These behavioral tendencies and cognitive skills align closely with behaviors and skills necessary to be successful in STEM. While critical thinking as a construct has received attention in the chemical education research literature, little direct measurement of critical thinking achievement is reported (e.g., 9−11) even though numerous articles mention critical thinking as an important outcome. Insight Assessment has developed a valid and reliable assessment of critical thinking independent of discipline, the California Critical Thinking Skills Test (CCTST), based on Facione's work.[12] The CCTST allows for empirical evidence to support previous critical thinking studies in chemistry that show perceived improvements in critical thinking skill (e.g., 9−11).

Gender and ethnic equity is another longstanding concern of STEM educators. On average, White men have experienced disproportionate success in STEM relative to women and

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ethnic minority students. While female U.S. citizens made up 57.3% of undergraduate enrollment in 2006, they represented only 50.3% of the science and engineering bachelors and 41.0% of doctoral degrees awarded in 2010.[13] This disparity is similar for non-White ethnic groups who in 2006 comprised 38.9% of total enrolled students, yet earned only 35.6% of science and engineering bachelor degrees and only 30.6% of doctoral degrees awarded in 2010.[13] The number of degrees awarded to these demographic groups are even lower for physical sciences, with 41.3% female and 32.2% ethnic minority bachelor degrees awarded, and 31.7% female and 27.6% ethnic minority Ph.D.s awarded.[13] With an ever-increasing proportion of college attendees being female and ethnic minority students, it is imperative that this restriction in the academic pipeline be removed by increasing these students' success in STEM courses.

Potentially Beneficial Solutions

The effectiveness of inquiry learning and hands-on discovery in science classrooms is well-established.[14] National science organizations recommend that science be taught using inquiry because it is consistent with professional scientific practice and helps to encourage student curiosity and develop analytical thought.[15,16] Inquiry learning refers to "instruction that uses questions and problems to provide contexts for learning" and encompasses a variety of nontraditional educational methods including case studies, student-driven research, and service learning.[17] Inquiry learning exists along a continuum from instructor-guided, which tends to be most helpful for developing specific concepts, to open, which may be more effective for developing cognitive abilities.[15] A 35-study meta-analysis showed that inquiry teaching and learning methods significantly increase student content knowledge and critical thinking skills above traditional noninquiry science teaching.[18]

Cooperative small group work also increases student achievement in STEM.[19] A meta-analysis of 39 undergraduate science studies that addressed collaborative and cooperative groups found that achievement, attitude, and persistence outcomes were all significantly increased using small group learning.[20] Small group methods were particularly beneficial for ethnic minority student achievement and female student attitudes.[20] Another meta-analysis of 15 high school and undergraduate chemistry studies also found that small groups positively affected achievement.[19] Of particular interest to this study, chemistry student critical thinking ability also appears significantly improved by cooperative learning.[21]

The next step in the evolution of inquiry teaching and learning may be Community-Based Inquiry (CBI): cooperative student groups using science to investigate pressing community problems. CBI is being increasingly adopted in undergraduate education,[22,23] and strives to make scientific inquiry more engaging and relevant by combining student-driven research with service learning. In addition, CBI's community focus may especially foster female and ethnic minority student scientific identity formation by addressing their greater concern for social change relative to males, Whites, and current science degree-earning populations.[24−26]

Prior studies clearly indicate that higher education is insufficiently preparing students to think critically, that gender and ethnic disparity in STEM performance exists, and that more effective teaching and learning methods are available to promote critical thinking gains and STEM success for all students. Students need to be taught how to think critically, solve problems, and apply knowledge in new and unanticipated scenarios.[14,27] Inquiry and small group work in the context of solving community problems enable students to develop advanced thinking and problem solving skills.[14,28−31] Despite accumulating evidence for the efficacy of these research-based educational methods,[32] many instructors continue to teach science using traditional approaches focused on information delivery. If the barrier to education reform is a belief that the information delivery model exposes students to more content than nontraditional instruction methods, research data demonstrating the effects of pedagogy like CBI upon both student critical thinking and content knowledge should prove valuable.

Students pursuing studies in allied heath careers provide an interesting study sample in chemistry. These students, especially pre-nursing students, often have low self-esteem with regard to science,[33] perceive that science courses are difficult,[34] and may have more misconceptions about chemical concepts after one college level chemistry course than high school students do prior to entering college.[35] Previous researchers have suggested that teaching chemistry to nursing students with a more context-based or guided inquiry approach could be beneficial.[33,35] This study focuses on an introductory biochemistry course taken by allied health majors.

Research Questions

The purpose of this study was to investigate the effects of a Community-Based Inquiry (CBI) curriculum on critical thinking and content knowledge outcomes in an allied health 100-level college biochemistry course. The CBI method used several research-based educational strategies including case studies, student-driven inquiry around a local community problem, and cooperative small groups. The course framework focused on immersing students in authentic biochemistry inquiry and explicitly addressing metacognition, problem solving, and critical thinking skills while simultaneously developing content knowledge. Previous work has shown CBI produces significant critical thinking gains in introductory biology courses,[31] but the question of how it affects content knowledge outcomes remained. This study was designed to answer four major questions in an introductory biochemistry course:

- How is allied health student success affected by a rigorous, inquiry-based approach to teaching and learning chemistry?
- How do overall critical thinking outcomes compare between CBI and traditional instruction methods?
- How do overall chemical content knowledge outcomes compare between CBI and traditional instruction methods?
- How do critical thinking and content knowledge outcomes compare for students of different demographic groups between and within CBI and traditional instruction methods?

■ METHODS

This study employed a nonrandomized control-group design to compare critical thinking and content knowledge outcomes between a CBI curriculum and a traditional lecture/laboratory course curriculum.

Participants

Study participants were recruited in consecutive years from the third quarter of a 100-level Introduction to General-Organic-Biochemistry (GOB) series at a regional comprehensive university in Washington State. Introduction to Biochemistry, a four-credit lecture and separate one-credit laboratory, is

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required for allied health science majors. Students agreed to participate in the study by signing an institutional review board-approved informed consent form on the first day of class, and they were awarded course points for completing paired pre-and post-instruction assessments based strictly on participation and not on performance. Demographic information was also collected, and was coded to maintain participant anonymity.

Study Design

Introduction to Biochemistry was taught using a traditional lecture/laboratory approach in Spring Quarter 2010 and then using CBI in Spring Quarter 2011. The same lecture instructor taught both traditional and CBI groups in a fixed-seating, auditorium-style lecture hall for 50 min, 4 days per week. Traditional and CBI groups were each divided into three laboratory sections that met in a designated and fully equipped chemistry teaching laboratory for 110 min, 1 day per week. The same chemistry graduate student with a biochemical background served as the primary laboratory instructor for both the traditional and CBI groups, with either the lecture instructor or a cooperating faculty member providing supplemental instructional support. Critical thinking and content knowledge outcomes were measured and statistically compared between traditional and CBI groups.

Traditional Course and Curriculum

The traditional curriculum was delivered in four content blocks: (1) carbohydrates and lipids, (2) proteins and enzymes, (3) nucleic acids and gene expression, and (4) ATP/bioenergetics and metabolism. Eight 50 min lectures were delivered for each block, using Microsoft PowerPoint slides that accompanied the textbook with minor modifications. A content-based exam was given after each block with homework completion accounting for 10% of exam points. The biochemistry section of the American Chemical Society GOB exam served as the course final.

The traditional laboratory curriculum followed the Introduction to Biochemistry lab manual with stepwise instructions for how to carry out and analyze data in six experiments (see Supporting Information: *SD1 Lab Syllabus*). These included: the identification of an unknown carbohydrate and the qualitative analysis of urine through observations of color change, the quantitative analysis of glucose and protein solution concentrations using spectrophotometry and linear regression of a standard curve, the determination of relative unsaturation of cooking oils with bromine, and the quantitative analysis of vitamin C by titration. Students performed the laboratory experiments in pairs. To control for study subject attitude (Hawthorne Effect[36]), efforts were made for the traditional group to believe they were receiving novel treatment. Rather than simply completing data sheets, as in the first two quarters of the series, students wrote semiformal lab reports. The importance of critical thinking was emphasized and students were informed of research connecting critical thinking to scientific writing.[37] The remaining coursework consisted of prelab quizzes.

Community-Based Inquiry Lecture Course and Curriculum

The CBI lecture content and course structure were identical to the traditional curriculum, except a human health-related case study replaced two lectures during each of the four content blocks, representing 25% of the total lecture time for each block. Students formed self-selected groups of four in laboratory and maintained the same groups during the case study activities in lecture.

The CBI case studies used the interrupted case study method[38] and were based on published scientific literature. Each case study contained four stages that modeled the process of scientific inquiry and discovery. Students worked in cooperative groups of four and team members fulfilled specific duties based on the Process-Oriented Guided Inquiry Learning roles[39] of manager, scribe, spokesperson and reflector. The duties rotated among group members for each of the four case studies, giving each student the experience of each role. Groups were required to finish the preceding stage of the four-part case study before accessing the next. Idea generation and writing were team efforts. Teams submitted their initial work electronically and then met outside of class to revise and resubmit after receiving instructor feedback (see Supporting Information: *SD2 Case Study Assignment Description, SD3 Case Study Initial and Re-submission, and SD4 Manager In- and Out-of-Class Report Template*).

The case study assignments began with student teams exploring an authentic, published inquiry that was directly tied to course content. The first case study focused on the connection between the leading cause of death in America, heart disease, and dietary saturated and unsaturated fats.[40] The second case study followed the rationale behind the development of the first HIV protease inhibitor,[41] and the third case study diagnosed a novel genetic condition.[42] The final case study looked at the metabolic effects of sucrose and high-fructose corn syrup.[43] Each study connected the allied health students' interest in human health to the biomolecules they were studying. Two of the case studies were additionally relevant to this particular community because a chemistry department professor studies HIV protease inhibitors, and the world's tallest teenager, who has a genetic abnormality, lives near the city where the university is located (see an example case study in Supporting Information: *SD5 Case Study Fatty Acids*).

Following the approach used to think about and develop a published research article, the interrupted case study method allowed students time to think about and experience steps (and missteps) inherent to the scientific method. Students were initially given background information from a specific journal article and were asked to reflect on the scientific problem and respond to several questions designed to elicit analytical thinking. The questions did not necessarily have one correct answer; rather, focus was directed toward students explaining their reasoning. Next, students proposed an experimental design to test the authors' hypotheses. Students then reviewed the described experimental methods and predicted the results. Lastly, students analyzed results obtained by the authors and drew conclusions. At each stage, students compared their responses to those of the authors. The instructors explicitly asked for and required students to employ critical thinking skills throughout the case studies and continuously emphasized that multiple justifiable answers existed. See Box 1 for an example CBI case study outline and Supporting Information: *SD6 Rubrics* for the rubric used to score the case studies.

Community-Based Inquiry Laboratory Course and Curriculum

The laboratory provided the venue for the CBI cornerstone: student-driven, community-based research. Since the majority of students in the Introduction to Biochemistry laboratory were nutrition, exercise science or public health majors, school lunch healthfulness was selected as a locally relevant problem

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Box 1. Instructional Stages for the Dietary Lipids and Coronary Heart Disease CBI Case Study

Stage 1: Reading Background Information and Formulating a Hypothesis

Information: Students were told that coronary heart disease is linked to arterial plaque, which is associated with the ratio between plasma high-density and low-density lipoproteins (HDL:LDL). They were then introduced to a study that investigated the possible relationship between saturated, *cis*-unsaturated, and *trans*-unsaturated dietary fats and the HDL:LDL ratio.

Tasks: Students considered whether saturated, unsaturated, and *trans*-fats might affect coronary heart disease differently, and proposed a chemical mechanism by which that difference might occur. They also stated whether a larger or smaller HDL:LDL ratio would indicate that a dietary fat was "worse" than another in terms of coronary heart disease.

Stage 2: Designing an Experiment

Information: Students were given sections of the journal article explaining the researchers' inquiry into the relationship between human serum lipoproteins and the amount and type of dietary fats. In particular, the investigators hypothesized that dietary *trans*-fats would be more deleterious to HDL:LDL than saturated fats or *cis*-unsaturated fats.

Tasks: Students designed an experiment to differentiate between the authors' hypothesis and the corresponding null hypothesis.

Stage 3: Predicting Results

Information: Students were provided the experimental design described by the researchers.

Tasks: Students identified experimental controls and predicted results that would support each hypothesis.

Stage 4: Drawing Conclusions

Information: Students were shown the experimental results from the article.

Tasks: Students compared these results to their predictions. They identified whether the data supported accepting or rejecting the null hypothesis and whether the researchers supported their hypothesis. Finally, the students inferred the meaning of the data with respect to diet and coronary heart disease.

for investigation. Community input was solicited. With approval of the school board and facilitation from the district food services director who provided school menus and sample foods for analysis, the traditional "cookbook" laboratory experiments were abandoned in favor of quarter-long student-designed inquiries that provided a range of answers to the overarching question: How could the local public school lunch program be healthier?

To maximize student research design flexibility while simultaneously minimizing impact on the stockroom and mitigating chemical laboratory safety concerns, four laboratory techniques were made available for student research projects: the protein, unsaturated fatty acid, and vitamin C quantitation protocols from the traditional curriculum and a glucose/fructose quantitation assay using enzymes and UV spectrophotometry. During the second CBI lab meeting, student teams split into two pairs and each pair conducted two of the four protocols. The groups then reunited to explain the techniques they had learned to other students in their group. With access to the local school lunch menu, teams formulated research questions (e.g., Is there a relationship between the vitamin C content of carrots and the method by which they are prepared, such as uncooked, microwaved, or boiled?). Groups then wrote a research proposal with introduction, hypotheses, methods and materials sections. Each group member contributed at least one scholarly resource for the introduction, and the procedures included specific duties assigned to each team member.

While instructors discussed initial proposals with groups during the following lab meeting, students worked on a calculation assignment involving two questions about the major chemical and mathematical concepts of each of the four experimental protocols. Groups were expected to answer questions from their selected protocol, with instructor feedback and guidance, and then ask classmate peers for assistance with the other questions. Students revised their research proposals based on instructor feedback, resubmitted the proposals, and then began conducting their experiments (see an example group research proposal in Supporting Information: *SD7 Group Research Proposal and Final Report*). As expected, every group encountered unforeseen problems in experimental design and procedures, and troubleshooting required substantial teamwork and critical thinking. Data analysis also required significant investment of student time and thought. Rather than helping students avoid mistakes, missteps were considered valuable learning opportunities and were used to teach the nature of science as well as foster critical thinking through team brainstorming and consideration of what to do next. The final report consisted of the introduction from the research proposal, a modified methods section geared toward a more general audience, and results and conclusions (see the rubric used to score the research report in Supporting Information: *SD6 Rubrics* and an example final report in Supporting Information: *SD7 Group Research Proposal and Final Report*). Groups created a 10 min Microsoft PowerPoint presentation that they delivered in a public forum (see the rubric used to score the presentation in Supporting Information: *SD6 Rubrics* and an example presentation in Supporting Information: *SD8 Group Research Presentation*). One group also presented a summary of the students' most notable results at a school board meeting that was aired on local public television. At the conclusion of the course, individual students wrote reflections on their learning experience (see examples in Supporting Information: *SD9 Sample Student Reflections*).

Assessments

Critical thinking ability was assessed on the first and last days of each laboratory course using an online version of the California Critical Thinking Skills Test (CCTST), a multiple-choice, timed assessment. The CCTST was chosen for this study because it measures cognitive and meta-cognitive skills associated with critical thinking, is based on a consensus definition of critical thinking, and has been evaluated for validity and reliability for measuring critical thinking at the college level. The CCTST is nondiscipline specific and measures analysis, inference, evaluation, induction and deduction, all important skills for students studying science.[12] Initial validity and reliability tests of the CCTST showed it to be a valid and reliable tool when applied across disciplines, with validity indicated by 95% consensus of critical thinking experts and reliability measured by a KR-20 coefficient between 0.78 and 0.84 on a scale from 0 to 1.[44]

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Current reliability measures indicate the test retest reliability for the CCTST is 0.88 or greater when administrative test conditions are controlled as they were in this study.[45]

Biochemical content knowledge was assessed with the biochemistry portion of the 2000 version American Chemical Society (ACS) General-Organic-Biochemistry Chemical Education Examination at the beginning of each lecture course, and with the 2007 version of the same exam at course conclusion. While pre-test sensitization is not a concern for CCTST validity,[46] two different but parallel ACS exams were used to safeguard exam security and ensure the validity of national percentile comparisons.

Demographic information was collected during CCTST pre-test administration and coded to protect student anonymity. Participant sex served as surrogate for the socio-cultural construct of gender.[47] To maintain statistically appropriate sample sizes, all study participants who did not self-identify as White were classified together for the two-group ethnicity analyses. Since Whites are the majority race/ethnic group of the United States, this non-White group of students was used to gauge potential instruction effects upon ethnic minority students.

Student impressions of course quality were assessed with the standard forms completed in all departments of this university. On the last day of instruction, students responded to 29 items with ratings from 1 to 5, corresponding to a ranking of "low" to "high," "never" to "always," or "very poor" to "excellent."

Statistical Analysis

Content and critical thinking analyses were performed on participants who were enrolled concurrently in lecture and lab, consented to be a part of this study, and completed both the pre- and post-assessments for critical thinking and content knowledge outcomes. Paired-samples t tests were used to compare post-scores to pre-scores for traditional and CBI groups in order to determine whether score changes were significant. Pre- and post-test critical thinking and content knowledge national percentiles were calculated from mean scores through linear regression of the score-to-percentile table in the range immediately surrounding the scores of interest. Analysis of covariance (ANCOVA) was used to determine whether critical thinking and content knowledge post-scores of demographic groups (specifically, academic major, class standing, sex and ethnicity) differed significantly between or within instructional methods, after controlling for the effect of the pre-score covariates. Effect sizes for these differences were calculated as point biserial $r_{contrast}$, $r = [t^2/(t^2 + df)]^{1/2}$; $r = [F/(F + df_{error})]^{1/2}$.[48]

Kolmogorov–Smirnov and Shapiro–Wilk tests were used to assess continuous variable distribution normality and the Levene's test was used to assess homogeneous variance between different groups. A nonsignificant ($p \geq 0.05$) group/pre-score interaction term in an ANCOVA iteration was used to indicate slope homogeneity between compared groups and a scatterplot of residuals versus pre-score was used to evaluate residual homoscedasticity.

Because student instruction evaluations were only available as group reports, results could not be matched to individual student participants or demographic data. Mann–Whitney U nonparametric two-sample comparisons assessed whether student response distributions differed significantly ($p < 0.05$) between CBI and traditional course evaluations.

■ RESULTS

Participants

Nearly all students (>98%) enrolled in the Introduction to Biochemistry courses consented to participate in the study; however, not all participants completed all of the assessments. Statistical groups were maximized by using all of the students who completed the necessary assessments for each statistical measure. Table 1 delineates the participant demographics. Study participants consisted mostly of nutrition, exercise science, and public health majors; juniors and seniors; and females. The participant ethnic distribution was representative of the university as a whole (the majority, approximately 80%, being White).

Critical Thinking

Curriculum influenced student critical thinking gains, affecting some demographic groups more than others (see Supporting Information: *SD10: Descriptive Statistics*). Initial critical thinking scores in the Introduction to Biochemistry course were consistent with data collected on students at this level for other studies.[31,49] Critical thinking ability did not change significantly in the traditional group, but the CBI group experienced significant gains in critical thinking skills (Table 2). Instructional method did not affect male student critical thinking gains; however, female students performed significantly better in the CBI group than in the traditional group (Table 3). While significant sex disparity was observed in the traditional group critical thinking performance, $F(1, 58) = 7.36$, $p = 0.009$, $r = 0.34$, sex did not affect CBI group performance, $F(1, 58) = 0.03$, $p = 0.87$, $r = 0.02$ (Figure 1). These results indicate that, while

Table 1. Participant Demographics

		Academic Major Distribution (%)				
Curriculum	n	Nutrition	Exercise Science	Nutrition/Ex. Science	Public Health	Other/Undeclared
Traditional	61	45.9	26.2	6.6	13.1	8.2
CBI	64	43.8	23.4	1.6	25.0	6.3

		Class Standing Distribution (%)				Sex Distribution (%)	
Curriculum	n	Fresh/Soph	Junior	Senior	2nd Yr Sr/Post-Bacc	Female	Male
Traditional	61	13.1	47.5	32.8	6.6	85.2	14.8
CBI	64	9.4	53.1	31.3	6.3	75.0	25.0

		Ethnic Distribution (%)				
Curriculum	n	White	Latino	Asian	Native American	Other[a]
Traditional	61	78.7	3.3	3.3	1.6	13.1
CBI	64	78.1	12.5	3.1	1.6	4.7

[a]Includes "choose not to provide this information" response. No students self-identified as Black/African American.

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Table 2. Critical Thinking Assessment

Curriculum	n	Mean Pre-Test Score ± SEM (percentile)	Mean Post-Test Score ± SEM (percentile)	t	p	r
Traditional	61	15.7 ± 0.5[a] (43rd)	16.0 ± 0.7[a] (45th)	0.72	0.48	0.09
CBI	61	16.2 ± 0.6 (46th)	17.3 ± 0.5 (54th)	2.80	0.007	0.34

[a]Significantly non-normal distribution ($p < 0.05$).

Table 3. ANCOVA Results: Effect of Instruction Type on Critical Thinking by Sex

Sex	Curriculum	n	Mean Pre-Test Score ± SEM	Mean Post-Test Score ± SEM	F	p	r
M	Traditional	9	15.8 ± 1.4	19.1 ± 1.8	1.35	0.26	0.25
	CBI	14	15.8 ± 1.2	17.1 ± 1.3			
F	Traditional	52	15.7 ± 0.6[a]	15.5 ± 0.7[a]	4.42	0.038	0.21
	CBI	47	16.4 ± 0.6	17.3 ± 0.6			

[a]Significantly non-normal distribution ($p < 0.05$).

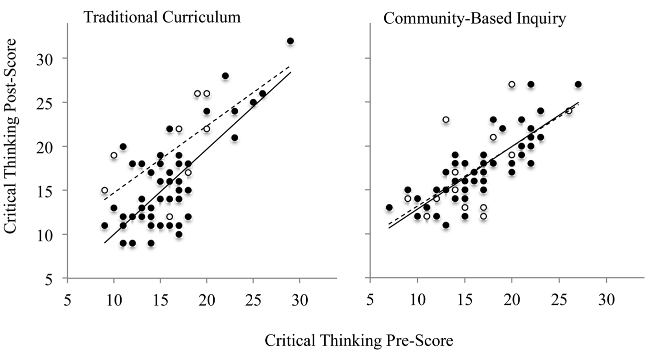

Figure 1. Community-Based Inquiry promotes gender equity in critical thinking skill gains. Students were assessed with the California Critical Thinking Skills Test which is a 34-question online multiple-choice exam. Regression lines contain paired pre- and post-test scores for male (dashed) and female (solid) students. Open symbols, males; filled symbols, females.

men benefitted from both curricula in this study, only CBI improved women's critical thinking skills and produced positive, gender-equitable critical thinking outcomes. Other measured factors, including academic major, class standing and ethnicity, did not significantly affect critical thinking outcomes. Statistical assumptions were met for all reported critical thinking analyses except for one: There was heterogeneous critical thinking post-score residual variance between methods for females and between sexes in the Community-Based Inquiry group. A post-hoc Welch's t-test comparing ANCOVA-adjusted critical thinking post-scores between methods for females confirmed the significance of the reported results.

Biochemical Content Knowledge

Chemistry content knowledge improved as expected in both the traditional and CBI groups (Table 4 and see Supporting Information: *SD10: Descriptive Statistics*). Interestingly, when the effect of instruction was parsed for ethnicity, it was discovered that instructional method did not significantly affect White student content knowledge gains, but students who did not self-identify as White performed significantly better in the CBI group than in the traditional group (Table 5; Figure 2). In fact, while there was no significant difference between ethnic group content knowledge outcomes in the traditional group, $F(1, 56) = 0.61$, $p = 0.44$, $r = 0.10$, non-White student content knowledge outcomes were significantly greater than those of White students in the CBI group, $F(1, 59) = 17.10$, $p < 0.001$, $r = 0.47$. These results suggest that the CBI instructional method could benefit ethnic minority students by facilitating their content knowledge gains in chemistry. Other factors measured, including academic major, class standing and sex, did not significantly affect content knowledge outcomes. All statistical assumptions were met for reported content knowledge analyses.

For Tables 2–5, while descriptive statistics of critical thinking and content knowledge raw data are provided, means and associated standard errors of non-normal distributions are nonideal representations of the data. The given test statistics are not directly based upon these raw score distributions; rather, paired t test statistics are based upon changes in outcome and ANCOVA test statistics are based upon residuals from the linear regression model.

Table 4. Content Knowledge Assessment

Curriculum	n	Mean Pre-Test Score ± SEM (percentile)	Mean Post-Test Score ± SEM (percentile)	t	p	r
Traditional	59	20.7 ± 0.9[a] (13th)	34.5 ± 1.1 (65th)	16.2	<0.0001	0.90
CBI	62	21.9 ± 0.8 (17th)	35.5 ± 1.1 (68th)	15.6	<0.0001	0.90

[a]Significantly non-normal distribution ($p < 0.05$).

Table 5. ANCOVA Results: Effect of Instruction Type on Content Knowledge by Ethnicity

Ethnicity	Curriculum	n	Mean Pre-Test Score ± SEM	Mean Post-Test Score ± SEM	F	p	r
White	Traditional	47	21.2 ± 1.1[a]	35.2 ± 1.3	2.48	0.12	0.16
	CBI	49	21.0 ± 0.8[a]	33.2 ± 1.1			
All Other	Traditional	12	18.9 ± 1.5	31.8 ± 2.2	8.51	0.008	0.53
	CBI	13	25.0 ± 1.8	44.1 ± 1.9			

[a]Significantly non-normal distribution ($p < 0.05$).

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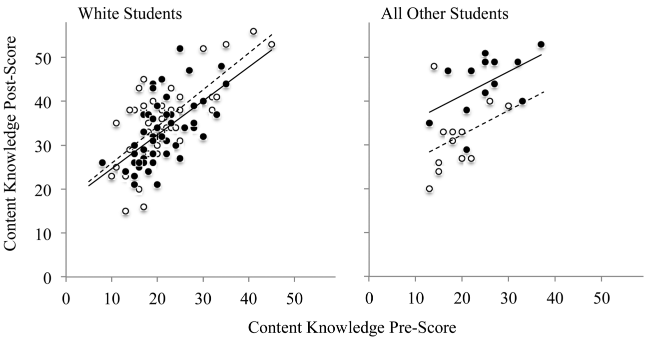

Figure 2. Community-Based Inquiry shows potential for improving chemistry content knowledge gains in ethnic minority students. Students were assessed with the biochemistry section of the ACS General-Organic-Biochemistry exam, which has 60 multiple-choice questions. Regression lines contain paired pre- and post-test scores for traditional (dashed) and Community-Based Inquiry (solid) instructional methods. Open symbols, traditional curriculum; filled symbols, Community-Based Inquiry.

Student Evaluations and Reflections

At the end of each quarter, students were asked to evaluate and reflect upon their biochemistry course. Students in CBI evaluated the lecture instructor significantly more favorably than did students in the traditional method in the following ways: Students were more confident in the instructor's knowledge ($p = 0.043$) and felt the instructor had greater overall teaching effectiveness ($p = 0.042$). They felt the instructor gave clearer explanations ($p = 0.010$), presented more alternative explanations when needed ($p = 0.002$), and answered student questions more clearly and meaningfully ($p = 0.005$) than in the traditional group. However, relative to the traditional method, the instructor spent less time speaking to the class. This apparent paradox may be explained by the other significantly increased evaluation responses: Students felt more encouraged by the instructor to express themselves ($p = 0.005$) and believed the instructor was more interested in student learning ($p = 0.007$).

CBI lab students stated that the course was more intellectually challenging ($p < 0.001$) and required more effort to succeed ($p < 0.001$) than students did in traditional instruction. This is not surprising, since CBI requires much more student learning responsibility than the simple direction-following required in traditional laboratory courses. Only one evaluation response distribution significantly decreased from traditional to CBI curricula: As a group, students felt the amount of work was less appropriate for the course level and credits in both lecture ($p = 0.003$) and lab ($p = 0.002$).

Although students initially experienced frustration when faced with the challenges of open-ended inquiry, the majority of them had very positive things to say about their learning experience at the end of the CBI course. Students confirmed the importance of relevance, for example, "All of us felt passionate about the topic because of our interest" and "I enjoyed the case studies because they really challenged me and related chemistry to real world issues." Students gained a sense of scientific identity, making statements such as "I felt like a real biochemist with all the independence allowed in lab" and "Through this process of pain and excitement, there is no way I am going to forget what we have accomplished this quarter in lab." They also expressed surprise about the authentic process of doing science. Some students acknowledged that prior research project experience always involved confirming predictions, while CBI required formulating alternative explanations.

■ DISCUSSION AND CONCLUSIONS

The Community-Based Inquiry (CBI) instructional model used in this study takes advantage of several research-based educational strategies, including case studies, small group learning, and student-driven inquiry, which makes it relevant to community stakeholders and scientists alike. An explicit focus on problem solving during both lecture and laboratory discussions and the use of intentionally formulated Socratic-style questions require students to think critically. This more interactive approach, when combined with systematic formative assessment and strategically employed metacognitive activities, forces students to analyze and evaluate their own thinking and to confront and revise their misconceptions.

Our experience with CBI indicates that in order to effectively build student critical thinking skills, students must become aware of their learning strengths and weaknesses. Deriving this awareness during their educational experience by reflecting on what and how they learned is an example of developing metacognitive skill. That process begins with the faculty member making clear in the syllabus and other supporting documents (e.g., learning expectations) the goal of critical thinking and how the skills of analysis, inference, and evaluation will be built during particular scientific experiences in the course. Because CBI is focused on authentic, applied science, critical thinking is a daily requirement. CBI instructors model how to process, reflect, and improve over time, and they assess learning using both traditional (e.g., exams) and alternative (e.g., performance rubric, case studies) measures. In CBI, students take intellectual risks and use mistakes as learning opportunities. They receive specific feedback on their work and are rewarded for growth over time. For example, in this study, the initial research proposal was worth 10%, the final research proposal was worth 20%, and the final research report and presentation were worth 40% of the lab grade. CBI requires students to explain their reasoning during both lecture and lab class as they solve problems so that others are able to observe and give respectful criticism. Making critical thinking expectations clear, explicitly connecting them to course experiences, requiring students to reflect on their learning process over time, and creating a classroom culture that allows mistakes and rewards growth over time appears to contribute to the significant critical thinking gains we observed. In this study, student critical thinking skills improved in CBI, while they did not change in the traditional course. These results are consistent with what has been observed previously in other science courses,[31] and confirm the transferability of CBI to improve critical thinking for chemistry students in allied health fields.

Many chemistry faculty express concern that time away from established teaching practices will reduce student content acquisition. This study shows that, even though 25% of the biochemistry lectures were replaced by case studies and the majority of the traditional lab curriculum was replaced with a single, quarter-long inquiry, students still gained the same amount of content knowledge as traditionally taught students. Community-Based Inquiry pedagogy thus develops student critical thinking while maintaining chemistry content gains.

This study also shows that students in allied health career paths are fully capable of handling a rigorous, inquiry-based course and that these students find value in activities that are

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relevant and authentic. Although they perceived the class to be a lot of work, they also acknowledged the challenge and felt they learned what it is like to be a scientist. CBI's increased effectiveness relative to the traditional approach may be attributed to several key pedagogical differences, including: (1) a course framework explicitly emphasizing and consistently requiring critical thinking; (2) an authentic process of investigative science that guides students in developing the knowledge, skills, and dispositions of engaged scientists; (3) focus on a community problem that engages student curiosity and intellectual abilities both in and out of class time; and (4) use of small cooperative groups and case studies that model best-practice science.

Importantly, this study also strongly suggests that the CBI instructional model facilitates increased learning for women and ethnic minority students. CBI may provide women and ethnic minority students with educational context and support that is not available in a traditional, direct information-delivery course. In addition, CBI's community focus and emphasis on social knowledge construction may allow women and ethnic minority students to better identify with the scientific enterprise and view themselves as active scientists.[50,51] These results also confirm the academic benefits of small-group, collaborative learning techniques for ethnic minority students observed previously in chemistry[52] and mathematics courses.[53]

Collectively, results from this study indicate that CBI pedagogy shows promise for furthering America's goals of promoting national scientific literacy and both diversifying and expanding the STEM academic pipeline. It confirms that students in allied health fields can succeed in science courses with a focus on relevance, rigor, and open-ended inquiry. With the additional potential for greater intellectual stimulation and integrated teaching, scholarship, and service, the CBI method is well worth chemistry instructor consideration.

Limitations

The major limitation of this study is the small number of ethnic minority and male students in the 2010 and 2011 student cohorts. In the enrollment and degree attainment statistics cited from the National Science Foundation (NSF) and in the analyses presented in this article, students are grouped as White or All Other ethnicities. While this classification differs from the NSF underrepresented minorities (URMs) categorization, this classification would tend to underestimate treatment effects. If, as historically has been the case, White and Asian students outperform URMs, then grouping all non-White students together would decrease the chance of a statistically significant finding with the Asian students and any potentially misclassified White students diluting the difference. In this study, White and All Other ethnicity student content knowledge outcomes were equivalent in the traditional method. It was the All Other ethnicity students in the CBI group that displayed increased content gains. Only one student in the CBI content analysis self-identified as Asian, and only one student chose not to identify his or her ethnicity. Grouping all non-White students together provided the sample size, comparison groups, and normality and homogeneity necessary to use the ANCOVA analysis. The statistically significant difference found between methods for the All Other group provides the impetus to investigate this phenomenon further in future studies.

Despite the small male sample size in this study, previous findings corroborate that CBI positively impacts both male and female critical thinking. In Fundamentals of Biology, both sexes gained critical thinking skills in CBI and neither gained these skills in a traditional curriculum, with a larger positive impact of CBI relative to the traditional curriculum occurring for females.[31] This previous study did not address content knowledge outcomes, however, making the increased non-White student content knowledge gains in this study all the more intriguing.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Examples of the lab syllabus, information provided to students about the case study assignments (assignment description, manager report template, example case study, and rubrics used to score student work) and examples of students work (case study submissions, research reports, research presentation, and student reflections); descriptive statistics for critical thinking and content assessments. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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