

A Transition Program for Underprepared Students in General Chemistry: Diagnosis, Implementation, and Evaluation

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S Supporting Information

ABSTRACT: We developed an online exam to diagnose students who are underprepared for college-level general chemistry and implemented a program to support them during the general chemistry sequence. This transition program consists of extended-length recitations, peer-led team-learning (PLTL) study groups, and peer-mentoring groups. We evaluated this program's impact on student performance in general chemistry using data from the fall semesters 2007, 2008, and 2009. We found that our transition program helped the underprepared students make significant gains in their course performance relative to other students when controlling for prior content knowledge and experience. PLTL did improve the performance of the underprepared students relative to other students in the lower 40% of the class. Inclusion of peer mentoring resulted in additional gains over the use of PLTL. Via surveys to students in the transition program, students agreed or strongly agreed that extended-length recitations and peer-mentoring groups improved their performance in general chemistry. This is important given the voluntary nature of our program.

KEYWORDS: First-Year Undergraduate/General, Chemical Education Research, Collaborative/Cooperative Learning, Testing/Assessment, Student-Centered Learning, Learning Theories

FEATURE: Chemical Education Research

At most universities, the introductory chemistry course has students with a diverse range of preparation, from advanced-placement courses to one year of chemistry. While all students have a transition from high school to college-level chemistry, this transition is more severe for those who are not well prepared in high school chemistry content, problem-solving skills, and study skills. The difficulties these students face typically result in low performances in the first chemistry course; hence, there is a need to diagnose these students early and give additional help.^{1–3} The methods of diagnosis have included standardized college-entrance exams, standardized chemistry exams, institution-developed diagnostic exams, and the first chemistry exam of the semester.^{1,2,4–9} Numerous studies have shown that several factors contribute in determining student performance; various methods have been tried to improve the students' preparation, including preparatory courses and different supplementary programs.^{3,10,11}

We have developed a transition program to fit into a traditional university lecture-course model. This program differs from most of the programs cited above by comprising these three steps:

1. Having the students review prerequisite content in the summer
2. Diagnosing the underprepared students before they arrive at the university
3. Implementing a supplementary program that is tightly integrated with the general chemistry course

All students are helped by reviewing prerequisite material, and the underprepared students may start on the standard course path with no delay.

The program outlined here consists of an online diagnostic exam, extended-length recitation classes, peer-led team-learning

(PLTL) study groups,^{12–14} and peer-mentoring groups. We will describe our transition program implementation, and the results of an evaluation examining the impact of this program on student performance in general chemistry using data from fall semesters 2007, 2008, and 2009.

■ GENERAL CHEMISTRY COURSE STRUCTURE

The general chemistry series at our institution is a two-semester series that enrolls approximately 700 students each semester; it has no out-of-sequence course, and the associated laboratory is a separate course. Weekly, the course has three 1-h lectures, mandatory 1-h recitations, optional instructor-led help sessions, and optional PLTL groups. Multiple lecture sections taught by different instructors are treated as one large course: the same problem sets, quizzes, and exams are given; students from different sections are mixed in recitations, PLTL groups, and help sessions; and the sections are combined for grading. The 35-student recitations, taught by graduate students, consist of a 15-min quiz and the working of instructor-selected problems, with possible group work.

■ TRANSITION PROGRAM STRUCTURE

Web-Based Review Tutorial and Online Diagnostic Exam

The tutorial Web site¹⁵ consists of modules providing these resources:

- A review of topics covered in most high-school chemistry courses with worked examples and self-test examples
- Practice problems

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- Practice quizzes
- Two versions of an online diagnostic exam

The tutorial Web site is intended to help incoming students review fundamental chemical principles, such as atomic mass, moles, chemical formulas, stoichiometry, limiting reagents, molarity, and redox reactions. The tutorial also includes introductory information about these topics: energy; forces and vectors; electromagnetic waves; and equations and graphs. These latter topics are not tested on the diagnostic exam, but are needed in general chemistry. The purpose of the online diagnostic exam is to identify students who are underprepared, as well as to encourage all students to review prerequisite material; hence, we developed an online diagnostic exam that tested mathematical skill as well as application of high school chemistry concepts.

Every first-year student who plans to enroll in general chemistry is notified that the online diagnostic exam must be taken before August 15. In the problem sets, hints are available to guide the students toward the solution, in addition to answers and detailed solutions. The multiple-choice quizzes are graded instantly and students are given feedback; hints are given for any incorrect answer.

Immediate feedback from the exam is given. Students who score 50% or higher are given this information:

- The number of correctly answered questions
- The topics they should review (any topic with more than 50% incorrect answers)
- Which topical review sessions they should attend in the fall

Students who score less than 50% on the online diagnostic exam are given this information:

- They answered less than 50% correctly (but not the actual score)
- The topics they should review
- They should take the second version of the diagnostic exam

The two versions of the exam cover the same content using different, yet analogous, questions.

Before the fall semester, students who have taken the online exam are ranked according to an algorithm that attempts to predict how a student will perform in the fall semester of general chemistry. For each student, this algorithm takes into account these factors, including the:

- Online diagnostic (OD) score
- Higher of the ACT math score or converted SAT-to-ACT math score, which is then converted to a percentile ranking for students based on the 2005 Chem 111 class
- Sum of STEM (science, technology, engineering, and mathematics) AP (advanced placement) exam scores

These measures were used in the following regression equation to generate predicted end-of-course (EOC) scores such that the predicted EOC score = $242.2 + [2.418 \times (\text{total AP STEM score})] + [0.312 \times (\text{percentile ACT Math})] + [0.798 \times (\text{OD score})]$. The R^2 value for the fall 2005 regression equation was 0.37, which indicated that a substantial amount of the final course variance could be accounted for by the precourse measures.

Transition Program

Approximately, the lowest 25% of the students based on predicted EOC scores are encouraged to join the transition

program run by the course instructors; however, participation in each component is optional. The incorporation of extended-length recitations (ER), PLTL groups, and peer-mentored study groups in the transition program is based on previous studies that show students learn better if they are active learners and study collaboratively as well as independently.^{12–14,16} Before registration, the underprepared students are preregistered in extended-length recitation sections; however, these students may switch to a regular recitation. The extended-length recitations are structured to promote active learning and last an additional 30 min, allowing time to solve problems in facilitated groups.

The implementation and evaluation of our PLTL program is described in Hockings et al.¹⁴ The PLTL-program instructors are consistent from year-to-year and are part of the general chemistry instructor group.

The peer-mentored study groups are facilitated by upper-level students who have been successful in the course, and have been trained in facilitating groups and using active-learning techniques. These groups of four–five students meet weekly for 2 h in structured homework sessions. In each session, the group discusses concepts covered that week in class; works collaboratively on homework, PLTL problems, or any question students may have; and discusses techniques for transitioning to a university-level curriculum. The transitioning discussions focus on skills such as time management, study skills, and test-taking strategies. These discussions are designed by the peer mentors during weekly meetings with the transition-program instructors who are part of the general chemistry instructor team; the main points summarized in handouts are given to the students at the end of each mentoring session. (See topics in the online Supporting Information.)

Although our peer-mentoring program is optional, attendance is mandatory for participants. Participants must sign a contract agreeing to these conditions: attending every peer-mentor session; arriving prepared for the sessions; studying cooperatively in a group; participating in new activities with an open mind; informing the peer mentor prior to an absence; and participating in a course PLTL study group. Students may have no more than two absences, thus, guaranteeing consistent attendance. Peer-mentored students must join the course PLTL program and attend their weekly PLTL session, which provide opportunities to solve problems with the rest of their colleagues in the class.

The peer-mentoring sessions differ from PLTL sessions in the following ways: the mentor is a balance between a PLTL facilitator and a tutor; the smaller mentoring group encourages more individual interaction; and individual student questions are the focus of the peer-mentoring sessions, although discussed in a group environment. The goal is to teach the students how to study effectively in an active-learning style while helping them learn the material.

METHODS AND RESULTS

Online Diagnostic Exam

The development of the online diagnostic exam was completed in summer 2005. The exam consists of 28 multiple-choice questions that cover the topics in the review module (described above and found on the Web site¹⁵) and range from straightforward calculations to challenging problems requiring the linkage of concepts and multistep calculations. To discourage guessing, 0.25 points are deducted for incorrect answers and zero

points are given for no answer. The average time taken for the exam is 1.5 h.

During the development, refinements to the exam were made by comparing the diagnostic exam results to student course performance of three sets of students in 2004 and 2005. Our initial refinement used a transition general chemistry class of 20 students and we consulted with a member of the College Board. The second refinement used a summer chemistry course consisting of 35 rising first-year students. This exam demonstrated a sensitivity of 100% (ability to accurately predict poor performance in general chemistry as evidenced by a grade of C– or below in the summer course) and specificity of 77% (ability to avoid false diagnoses of poor performance). Because we want to identify every student with deficiencies detected by the exam, the achievement of 100% sensitivity is the more important characteristic. Students who are incorrectly diagnosed as possibly performing poorly would not be harmed by any supplemental help. The final testing of the diagnostic exam occurred in summer 2005 with first-year students taking general chemistry in fall 2005. That summer, students made 3637 visits to the Web site, and took an average of six quizzes each. The mean score in 2005 was 49 with a high score of 92 (out of 100). This final test of the diagnostic was used to fit the ranking algorithm of the students based on the online diagnostic score, the ACT/SAT score, and the STEM AP exam scores. The implementation of the diagnostic exam for the study started in the summer of 2007. For 2007–2009, the mean score for the diagnostic exam was 54.4, SD = 19.9, $N = 1070$, with an average high score of 92 (out of 100).

Transition Program Analysis

The impact of the transition program on students' performance and perceptions was analyzed using data from first-year students enrolled in general chemistry during the fall semesters of 2007, 2008, and 2009. The general chemistry curriculum and grading scheme are decided by a small group of instructors who rotate into general chemistry; hence, both the curriculum and the grading scheme are consistent from year to year. In addition, during these three years, one instructor taught all three years with two other instructors who taught in the other section. Each exam is team-written by all instructors of the course, and group graded by instructors and graduate students. The exams consist of problem-solving and short-essay questions. Final course grades were used as the measure of academic performance. The final course score is a combination of quiz scores, midterm exams, and a comprehensive final. For this study, the final course scores for each year were standardized to a mean of 70 and standard deviation of 10. The predicted EOC score was used as a covariate in the analyses to control for prior chemistry content knowledge and coursework. (The predicted EOC scores were standardized to a mean of 70 and standard deviation of 10.)

This study compared the course performance of four groups of students with lower predicted EOC scores (the bottom 40% of the class). The groups were formed as follows. First, students with lower predicted EOC scores who enrolled in and completed the transition program formed two groups. The actual number of students who completed the transition program was 164, or 15% of the students with predicted EOC scores. Group 1 included students who participated in extended recitation and PLTL. Group 2 students were those who participated in extended recitation, PLTL, and peer mentoring. All but one of the students in these two groups had predicted

EOC scores of 67 or below. Using 67 as the cutoff score, all other students who did not participate in the transition program but who had predicted EOC scores of 67 or below were identified for the remaining two comparison groups. Of these students, Group 3 attended PLTL in addition to regular recitation, while Group 4 participated in regular recitation only. Of the 1070 students who had predicted EOC scores, 426 (40%) had scores of 67 or below and their data were used in the analyses.

At the end of the fall semesters 2007 and 2008, we examined the participating students' perceptions of the extended-length recitations and peer-mentoring groups via surveys. The questions in these surveys employed a five-point Likert response scale, in which strongly disagree = 1 and strongly agree = 5. Of the students who responded, 99 (70% response rate) participated in the extended-length recitations and 40 students (58% response rate) participated in peer mentoring. (See copies of instruments in the online Supporting Information.)

Student Characteristic Results

Of the 1731 first-year students who enrolled in the course, 1070 took the diagnostic exam. Because the predicted EOC score was used as a covariate to control for prior chemistry content knowledge and coursework, the subsequent analyses are based on the 1070 students who took the diagnostic exam and hence had predicted EOC scores.

The 1070 students who took the diagnostic exam had significantly higher final course scores than the 661 students who did not take the test: $M = 72.01$ versus 66.28; $t(1729) = 11.69$, $p < 0.001$. Therefore, the results of this study can only be applied to the 62% of students who voluntarily took the diagnostic because these students may have different characteristics than the 38% who chose not to take the diagnostic exam. For example, it might be hypothesized that students who took the pretest were more open to knowing their strengths and weaknesses in chemistry and subsequently had increased motivation to devote additional time to learning the material. However, from a practical standpoint, students who did not take the diagnostic had similar ACT mathematics scores to those who took the exam ($M = 33.01$ vs 33.25). Hence, apparently, choosing to take the diagnostic exam was not related to mathematical knowledge as measured by the ACT.

Percentages for the descriptive characteristics of the students such as gender, number of underrepresentative minorities, school division, and ACT math score are listed in two tables in the online Supporting Information; these demographics were obtained from the university student information database. The first table contains descriptive characteristics of students with a predicted EOC score; the second table compares characteristics of students with predicted EOC scores to those with no predicted EOC scores.

Comparing student demographics of students in the four groups having lower predicted EOC scores to the rest of the students having higher predicted EOC scores revealed a greater percentage of females (57% vs 43%) and more minorities (18% vs 8%) in these four groups. These four groups also had more students in arts and sciences (81.7% vs 74.8%), fewer engineering students (16.2% vs 23.8%), and slightly lower mean ACT scores (32.12 vs 33.99).

Comparing group 2 (ER, PLTL, and peer mentoring) with group 1 (ER and PLTL only), the percentages of females (64.7% vs 65.6%) and minorities (28.1% vs 25.0%) were

Table 1. Course-Performance Results for the Four Groups in the Study

Groups		Predicted EOC Mean (SD)	Final EOC Mean (SD)	N	Estimated Marginal Mean ^a	SE	Hypothesis	Effect Size ^b
G1	Extended recitation and PLTL participation	57.18 (3.56)	65.76 (7.25)	68	67.61	1.08	G1 > G4	0.76
G2	Extended recitation, PLTL participation, and peer-mentoring	58.09 (4.23)	70.25 (6.54)	96	71.60	0.90	G2 > G1 G2 > G3 G2 > G4	0.47 0.33 1.22
G3	Regular recitation and PLTL participation	62.38 (4.55)	69.61 (8.51)	189	68.59	0.64	G3 > G4	0.92
G4	Regular recitation only	62.12 (3.86)	61.62 (12.61)	73	60.75	1.01		

^aEstimated marginal means (adjusted means) at covariate predicted EOC score mean of 60.54, which takes into account prior knowledge. ^bEffect size of the marginal mean difference reported as the proportion of a standard deviation unit.

similar. Group 2 had slightly more arts and sciences students (90.6% vs 83.8%), while Group 1 had more engineering students (16.2% vs 6.3%). The mean ACT math scores for both groups were similar (31.24 vs 30.56).

We also compared the characteristics of students in our study (those who took the online diagnostic exam and have predicted EOC scores) and the first-year students in the class who are not in the study (i.e., those who did not take the online diagnostic exam and do not have predicted EOC scores). All of the characteristics within the two groups are similar within a few percentage points. Hence, the students in the study appear to be representative of the first-year students in our general chemistry course.

Performance Analysis

To examine the effectiveness of our transition program, we focused on the following research question: Does the combination of supplementary help activities in the transition program (extended recitation, PLTL, and peer mentoring) produce greater increases in final general chemistry course scores than regular recitation and PLTL or regular recitation only for students with similar predicted EOC scores, while controlling for prior chemistry content knowledge and coursework experience?

ANALYSIS

To examine our question, we studied students having a predicted EOC score of 67 or lower by placing them in one of four learning groups:

1. G1: Extended recitation and PLTL participation
2. G2: Extended recitation, PLTL participation, and peer mentoring
3. G3: Regular recitation and PLTL participation
4. G4: Regular recitation only

Six directional hypotheses were stated a priori (described below).

The means and standard deviations of the EOC scores for the four groups listed above, as well as the estimated marginal means (i.e., the estimated means when controlling for prior preparation), are reported in Table 1. To determine whether an overall effect for the four groups of students exists, an omnibus *F*-test was run using the SPSS general linear model (GLM) univariate analysis of variance procedure.¹⁷ The predicted EOC score was used as a covariate to control for prior chemistry-content knowledge and coursework experience. The results showed that the overall effect comparing the four group means was significant when controlling for prior content knowledge and coursework: $F(3, 421) = 22.79, p < 0.001$. Because the overall test was significant and the six directional hypotheses were stated a priori, pairwise comparisons were performed for

the specific hypotheses based on the estimated marginal means at the mean of the predicted EOC score covariate, $M = 60.54$. All significance levels reported below are based on the Bonferroni correction for multiple comparisons.

Our first hypothesis states that PLTL participation in combination with *extended* recitation and *peer mentoring* (G2) resulted in higher course performance than without peer mentoring (G1), when controlling for prior content knowledge and coursework (i.e., comparing the estimated marginal means). The group with mentoring (G2) scored 3.99 points higher on average in final course performance (SE = 1.35, $p = 0.01$), which is statistically significant. More importantly, the effect size for this mean difference of 3.99 points is 0.47 standard deviation units. In other words, the average-scoring student in the mentoring group is estimated to have a higher EOC score than 68% of the students in the extended-recitation, PLTL group with no mentoring, when controlling for prior content knowledge and coursework.

Hypotheses 2 and 3 state that PLTL participation in combination with *extended* recitation and *mentoring* (G2) resulted in higher course performance than groups with regular recitation and PLTL (G3), and, alternatively, without PLTL (G4), hypothesis 3, when controlling for prior content knowledge and coursework. The group with extended recitation, PLTL, and mentoring (G2) scored significantly higher than students in regular recitation with PLTL (G3) (mean difference = 3.01, SE = 1.14, $p < 0.027$, effect size = 0.33 SD units). This group also scored significantly higher than students in regular recitation and no PLTL (G4) (mean difference = 10.85, SE = 1.38, $p < 0.001$, effect size = 1.22 SD units). Again, the effect sizes are large; that is, the effect sizes indicate that the average-scoring student in the mentoring group is estimated to have a higher EOC score than 63% of the students in the regular recitation, PLTL group and a higher score than 89% of students in the regular-recitation-only group, when controlling for prior content knowledge and coursework.

Hypotheses 4 and 5 state that PLTL participation in combination with *extended* recitation (but without mentoring) (G1) results in higher course performance than groups with regular recitation and PLTL (G3), and, alternatively, without PLTL (G4), hypothesis 5, when controlling for prior content knowledge and coursework. The group with extended recitation and PLTL (G1) did *not* score significantly higher than students in regular recitation with PLTL (G3): mean difference = -0.98 , SE = 1.30, $p > 0.05$. However, this group did score significantly higher than students in regular recitation who did not participate in PLTL (G4): mean difference = 6.86, SE = 1.51, $p < 0.001$, effect size = 0.76 SD units.

Finally, hypothesis 6 states that PLTL participation in combination with regular recitation (G3) results in higher

course performance than regular recitation and no PLTL (G4), when controlling for prior content knowledge and coursework. The group with regular recitation and PLTL (G3) did score significantly higher than students without PLTL (G4): mean difference = 7.84, SE = 1.17, $p < 0.001$, effect size = 0.92 SD units. An effect size of 0.92 SD units means that the average-scoring student in the regular recitation PLTL group is estimated to have a higher EOC score than 78% of the students in the regular-recitation-only group, when controlling for prior content knowledge and coursework.

Results on Students' Perceptions

Figure 1 shows the results of attitudinal surveys given in the fall semesters 2007 and 2008; a histogram of student responses for

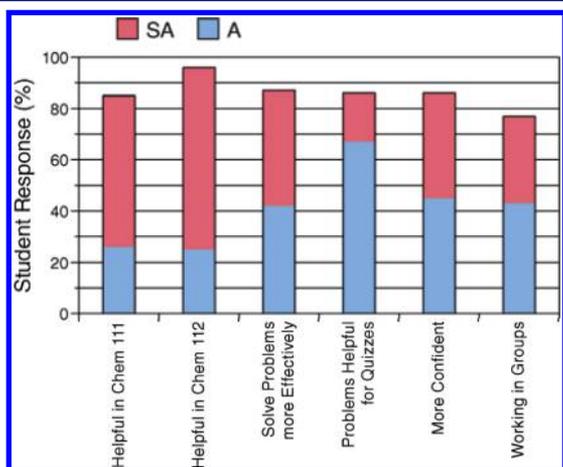


Figure 1. Percentages of strongly agree or agree responses from the students concerning the extended-length recitations. See the online Supporting Information for the survey instrument.

students enrolled in the extended-length recitation shows the six questions that directly relate to the extended-length recitations. The majority of the students agreed or strongly agreed that these recitations were helpful in general chemistry; the problems worked during these recitations taught them how to solve problems more effectively and helped them with the weekly quizzes; working problems in these recitations increased their confidence; and working in groups during recitation was helpful for general chemistry.

Figures 2 and 3 contain histograms of responses for students who participated in the peer-mentoring groups. As seen in Figure 2, even a higher percentage of the students agreed or strongly agreed that their experience in the mentoring group was positive; they would recommend the peer-mentoring groups to other students; the peer-mentoring, exam review sessions, and the peer-mentoring problems were helpful for exam preparation; peer mentoring helped them do better on quizzes and exams; and the peer-mentoring group helped improve their grades.

As seen in Figure 3, a high percentage of students agreed or strongly agreed that the peer-mentoring group improved their study skills and their problem-solving skills; explaining problems to other students in their peer-mentoring group helped them study; and overall it was beneficial to work homework problems as a group. In addition, a high majority agreed or strongly agreed that working in a peer-mentoring group made them feel confident in their abilities and increased their confidence in their chemistry abilities; and the study and

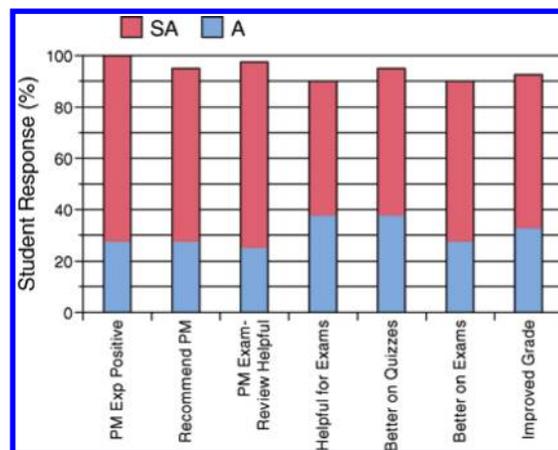


Figure 2. Percentages of strongly agree or agree responses from the students concerning the usefulness of peer-mentoring groups in helping to improve performance. See the online Supporting Information for the survey instrument.

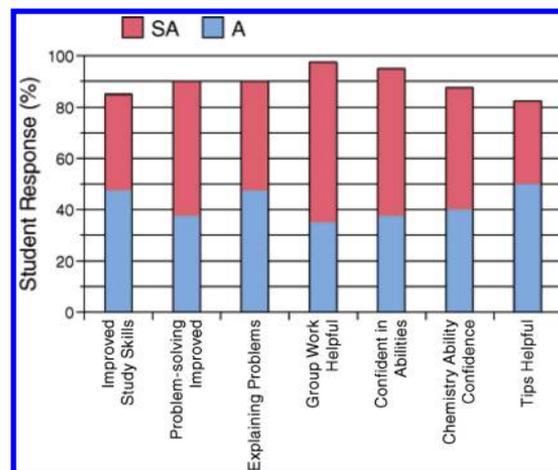


Figure 3. Percentages of strongly agree or agree responses from the students concerning the usefulness of peer-mentoring groups in improving skills and confidence. See the online Supporting Information for the survey instrument.

time-management tips offered by their peer mentor were helpful.

CONCLUSIONS

To better serve the underprepared students in our general chemistry course, we developed and implemented a transition program that consists of an online diagnostic exam, extended-length recitations, course peer-led team learning study groups, and peer-mentoring groups. We evaluated the impact of this program on student performance in general chemistry using data from the fall semesters 2007–2009. We have three main findings from our study, when controlling for prior content knowledge and coursework (i.e., when using the predicted EOC score as a covariate).

The first finding is that students in the peer-mentoring group and PLTL (G2) scored significantly higher than the other two groups with PLTL and no peer mentoring (G1 or G3). Although the differences in the estimated marginal means may not appear large, the effect sizes are quite significant from a practical standpoint (0.33 and 0.47 SD units). These effect sizes mean that the average scoring student in the peer-mentoring

group is estimated to have a higher EOC score than 68% and 63% of the students in the other two groups with PLTL (G1 and G3, respectively). Hence, it appears the peer-mentoring process is adding value over and above PLTL.

One might assume that peer mentoring is simply extra time on task. However, the extended-recitation group with PLTL (G1) did not score significantly higher than the regular recitation with PLTL group (G3), suggesting that more "time-on-task" may not account for the additional score increase found in the mentoring group. Of course, the extended recitation is only one-half an hour longer than the regular recitation, but it is group work facilitated by a course instructor versus being facilitated by undergraduates.

We believe the value of the peer-mentoring process is the structure of these sessions in which students are taught and encouraged to discuss in detail homework problems and PLTL problems in small groups (four–five students), as well as the study skills mentoring given by the undergraduate mentors. The other opportunities for students to ask questions are in the PLTL groups (8–10 students) or instructor-led class and help sessions, all of which are larger than the peer-mentor groups, and often underprepared students do not ask questions in these larger groups.

Last, all groups with PLTL had significantly higher EOC scores than the group without PLTL and these differences had the highest effect sizes, showing that PLTL does have a significant educational impact. It appears that students with lower predicted EOC scores are likely to get a substantial benefit from participating in PLTL, in addition to the peer-mentoring groups.

When we examined the attitudes of the underprepared students, we found that the underprepared students overall agreed or strongly agreed that the extended-length and the peer-mentoring groups helped them perform better in general chemistry, taught them how to problem solve more effectively, and increased their confidence in their abilities. Knowing the students' perceptions of the program is important because our program is voluntary. Our next step is to follow the performance of these students as they progress through their upper-level science courses and to determine whether one year of the transition program gives these students enough foundation to succeed in subsequent science courses, or whether they require additional support during their second year.

■ ASSOCIATED CONTENT

📄 Supporting Information

Tables containing the demographics of the students in general chemistry; topics of peer-mentoring transitional handouts; surveys concerning students' perceptions. This material is available via the Internet at <http://pubs.acs.org>.

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