Teaching with Technology

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Effects on Student Achievement in General Chemistry Following Participation in an Online Preparatory Course

ChemPrep, a Voluntary, Self-Paced, Online Introduction to Chemistry

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ChemPrep is a self-paced, noncredit course designed to help students prepare for general chemistry.[1,2,3] Students complete this short course before the beginning of the semester by accessing the material via the Internet using the OWL (Online Web-based Learning) system[4] developed at the University of Massachusetts–Amherst (UMass) *(1).* ChemPrep was created in response to a need we saw to improve students' overall preparation and opportunity for success in general chemistry. Currently at UMass, about 70% of students who enroll in the general chemistry course for science majors complete it with a grade of C− or better. Many science tracks use general chemistry as a "gatekeeper" course with advancement contingent upon "success", as measured by a minimum grade. Consequently, a large number of students—30% or more—either retake general chemistry or do not continue in science-based majors. Thus, many students register for general chemistry with trepidation, unsure of their ability to succeed.

Students enter general chemistry with a wide range of backgrounds and experiences. As with many large research institutions, UMass offers three different levels of general chemistry. In the large-enrollment course for science majors (GenChem), some students have completed high school advanced placement (AP) chemistry, others have returned to school with a myriad of career experiences but very little chemistry background and weak mathematics skills, and the bulk of the students are first- and second-year science majors who have experienced high school chemistry and mathematics courses of widely varying quality. In the course for nursing majors (Nursing), scientific abilities among the students tend to be lower, with fewer students having AP credit and advanced mathematics classes. In the honors chemistry course for majors (Honors), students usually enter with a strong background in high school chemistry, often AP, and many welcome the opportunity to prepare in advance for a fast-paced college-level course.

To address this diversity of backgrounds and experiences among the students, ChemPrep was developed as a self-paced preparatory course to help students review concepts, fill in content gaps, build confidence, and strengthen mathematical skills. Our goal is to offer students an enhanced opportunity for success in general chemistry. Students are allowed as much time as needed to master the material—prior to the start of the semester—with no penalties or grades attached. Because there are many different chemistry instructors teaching a number of different sections of GenChem, Nursing, and Honors courses, the material covered in ChemPrep is generic enough to prepare students for the breadth of content and emphases they will encounter in their general chemistry classes.

Online Preparatory Courses

Online courses are available to help students prepare for standardized college entrance exams such as the ACT and SAT tests, as well as for graduate and professional school exams (MCAT, GRE). While these courses have proven quite effective at boosting test scores by teaching exam-taking strategies *(2–4),* they are not necessarily designed to help students learn a subject but, rather, to hone a set of skills for a very specific end—performing well on an exam.

A variety of Web-based activities also exist that can be used to help prepare students for general chemistry, although these are stand-alone materials outside the context of a course and require a fair amount of effort on the part of the instructor to integrate *(5).* Activities like these may lack the extensive feedback and help structures designed to guide student learning. General chemistry students at the University of Iowa take an online placement examination to assess preparedness and determine placement into one of three introductory chemistry sequences *(6).* These students also use a set of

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online mathematics-based tutorials at the beginning of the course.

ChemPrep was constructed to be a comprehensive, stand-alone system with high-quality content and feedback to students. Because we wanted an environment in which students could work in the absence of a text or lecture, one challenge was to create a narrative to take the place of these resources. We used the strengths of the OWL system—information pages, mastery learning, and parameterization of numbers, chemical systems, and feedback—to provide the backbone. We were also able to use the OWL system to deliver the course free of charge.

The OWL System

OWL is an electronic learning environment originally created as a joint project between the Chemistry and Computer Science Departments at UMass *(7–14).* Student activities are supported by an authoring environment for the creation of instructional materials and by a set of course management tools, all of which are Web-based. OWL is currently used by over 20 departments on the UMass campus in disciplines ranging from physics and chemistry to resource economics and art history.[5] *OWL: General Chemistry* and *OWL: Organic Chemistry* are licensed and distributed by Thomson Learning–Brooks/Cole Publishing[4] and are used at over 150 college and university campuses nationwide.

ChemPrep, an OWL course for general chemistry, is based on the mastery principle, in which students continue work until they master chemical concepts using homework problems, interactive simulations, exercises, and tutors. The extensive database of homework questions is parameterized both numerically and chemically, so that students can attempt a question multiple times and see a variation of the basic question each time. A detailed solution specifically parameterized to each problem is provided as soon as the student submits an answer for evaluation. This type of instant, answer-based feedback has been shown to help students build confidence with the course material in a nonthreatening (and non-testing) environment *(15).*

ChemPrep and Its Implementation

ChemPrep covers six topics identified as prerequisite knowledge for a conventional general chemistry course.

1. Structure of matter
2. Naming chemical compounds
3. Measurement and calculations
4. Calculations involving quantities of matter
5. Chemical reactions
6. Mathematics skills

Each unit contains short information pages to present a concept or activity. Questions that follow develop a topic in the form of detailed feedback. Occasional interactive tutors or simulations allow students an alternative method of learning. Students are encouraged to use the OWL message system to ask questions or submit comments as they proceed through the material, although few take advantage of the opportunity. Messages are answered by an instructor, usually within 24 hours of submission. Our students report that this combination of resources permits them to work at their own pace without the need for a textbook or lecture.

Prior to the beginning of each semester in July and January, all students preregistered in GenChem, Nursing, or Honors chemistry courses are invited via email to participate in ChemPrep. Students work at their own pace, accessing the materials through a Web browser. They have until the first day of classes to complete the work and their progress is recorded in the OWL system. The entire course takes approximately 20 hours.

Our aim as we designed the course was to allow students with a strong high school background to move quickly through the material, focusing on areas in which they might have some gaps. Students who have not had a comprehensive chemistry course in high school or have not had high school chemistry for a number of years could use ChemPrep more systematically to strengthen their foundation in the skills needed for general chemistry. ChemPrep includes some of the quantitative aspects of chemistry and was designed to help students build confidence in their mathematical abilities. Thus it was hoped that students would start the semester on a more equal footing, regardless of background.

Study Design and Results

The off-sequence section of first-semester general chemistry (GenChem) in spring 2004 (S04) was chosen to be our first pilot group. Students (N = 373) responded more enthu-

Table 1. Distribution of Students Using ChemPrep, by Course

Course (Number of Students)		Initially Enrolled	ChemPrep Users[a]	ChemPrep Users/Nonusers (% of Total)
GenChem S04	(N = 373)	83	28	8
GenChem F04	(N = 658)	203	61	9
Nursing F04	(N = 180)	62	16	9
Honors F04	(N = 115)	52	26	23
Total	(N = 1326)	400	131	10

siastically than anticipated and 83 signed up for ChemPrep in December and January. Of the 83, 28 students completed more than 50% of the modules (Table 1). The progress of these students was monitored in the subsequent course. Online surveys were conducted at the end of both courses.

In the Table 1 "users" are defined as those students who completed more than 50% of the ChemPrep modules, and "nonusers" as those who did not sign up for the ChemPrep course. Students who signed up for ChemPrep but completed less than half of the work were not included in our analysis presented here. We plan further studies to examine the effects on this group. Of those students who were designated as users, all did a substantial amount of the work but only about half actually completed the entire course.

For spring 2004, the average grade[6] of ChemPrep users was 3.00, while the average grade of nonusers was 2.10 (Table 2). Anecdotal evidence (students' survey responses and other student comments) also suggested that the participants found the course helpful. Based upon these promising results, ChemPrep was offered to all students enrolled in any of our introductory general chemistry courses for the fall of 2004 (F04). As in the previous semester, participation in ChemPrep was entirely voluntary and students completed the material before the start of classes, during July and August. All students were presented with the same ChemPrep material; no modifications were made for the different courses or from the spring semester to the fall.

Once again only a small percentage of the GenChem students and an equal percentage of Nursing students (9%), actually completed ChemPrep (Table 1). For those in the Honors course, however, use levels reached 23%, an interesting difference in participation that will be discussed subsequently. Again, about half of the users completed all of the OWL work, and the average grades of users versus nonusers were higher (Table 2).

For Nursing students, ChemPrep users scored, on average, a full letter grade higher than nonusers. For GenChem students, the difference was slightly less than this. Even for Honors students, grades differed between users and nonusers by almost a half of a letter grade. In all cases, the differences between user and nonuser performance were statistically significant, being highly significant ($p < 0.01$) in all but the Honors chemistry course.

The percentage of students completing the introductory chemistry course with a grade of C− or better, which we defined as the rate of success in the class, was also examined. Historically, our success rates in the introductory chemistry courses have fallen between 65–75%. As shown in Figure 1, success rates for the ChemPrep users were much higher.

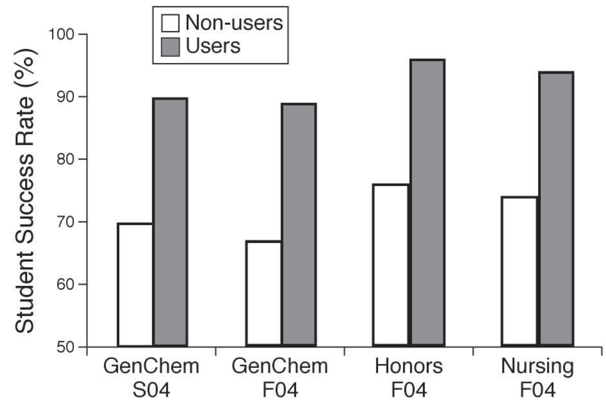

Figure 1. Relative success rates of students using ChemPrep and non-users, Fall 2004.

Determining the Effects of ChemPrep Participation on Final Course Grade Differences

As shown in Table 1, over 1300 students had access to ChemPrep in the spring and fall semesters of 2004. The question is, did the ChemPrep course really improve student grades in the class, especially among those students who would otherwise have been struggling, or was this simply a case of the better students self-selecting into ChemPrep? Given that the course was entirely voluntary, students who participated in ChemPrep were more motivated, for whatever reason, to make use of this resource. The question then becomes how would this higher level of motivation have affected their grades in the absence of ChemPrep; in other words, would they have performed better than the nonusers anyway—even without ChemPrep—and, if so, by how much?

To determine whether stronger students were self-selecting into ChemPrep, we used SAT I mathematics and verbal scores and the algebra and trigonometry scores on the university's mathematics placement exam as proxy measures for the students' prior achievement and ability. Pearson correlation coefficients between these measures and grades for each course

Table 2. Distribution of Average Grades for Student ChemPrep Users and Nonusers, by Course

Course	Nonuser Group (*N*)	ChemPrep Group (*N*)	Average Grades, Nonuser Group[a]	Average Grades, ChemPrep Group[a]	*P*-Value of Difference	Effect Size
GenChem S04	290	28	2.10	3.00	0.000	0.73
GenChem F04	455	61	2.26	3.04	0.000	0.62
Nursing F04	118	16	2.62	3.75	0.000	1.01
Honors F04	63	26	2.91	3.36	0.033	0.46

are reported in Table 3, with statistical significance indicating that higher scores on the predictors are associated with better grades in the class. Predictor values correlate significantly with class performance in all but three cases: (i) Honors SAT verbal and (ii) math scores, and the (iii) Nursing SAT I verbal score.

We used the *effect size* for each of these measures as a standardized method of comparison. Effect size (ES) is defined as the difference between the average score of user and nonuser groups, divided by the standard deviation of the total class.

$$\mathrm{ES} = \frac{\underset{\text{user}}{\text{avg score}} - \underset{\text{non-user}}{\text{avg score}}}{\text{standard deviation of whole class}} \qquad (1)$$

A result of $ES = 0$ indicates that there is no difference between groups; values of $ES < 0$ indicate that any effects from ChemPrep participation were weaker for ChemPrep students than for nonusers; values of $ES > 0$ indicate that any effects from ChemPrep participation were stronger for ChemPrep students than for nonusers.

Effect sizes with absolute values around 0.2 are considered small, 0.5 moderate, and 0.8 large by social science researchers *(16–17)*. As shown in Table 2, the effect sizes of all of the grades are positive and range from moderate to large, indicating that there are meaningful grade differences between ChemPrep students and nonusers in all of the courses.

In order to determine whether the differences in grades were solely attributable to differences in student strength, we calculated the effect sizes for scores from the SAT I tests and departmental placement tests, our proxy measures for prior achievement and ability (Tables 4–7). Small effect sizes for these measures would indicate that there is little difference in aptitude between user and nonuser groups and would be

Table 3. Comparison of Correlation Values between Predictor Variables and Final Course Grades

Course (Number of Students)		Pearson Correlation Coefficient Values Relating Final Course Grades to These Test Results			
		SAT I: Math	SAT I: Verbal	Math Placement: Algebra	Math Placement: Trigonometry
GenChem S04	(*N* = 313)	0.540[a]	0.374[a]	0.461[a]	0.410[a]
GenChem F04	(*N* = 584)	0.218[a]	0.143[a]	0.297[a]	0.277[a]
Nursing F04	(*N* = 147)	0.316[a]	0.133	0.433[a]	0.397[a]
Honors F04	(*N* = 112)	0.070	0.060	0.222[b]	0.345[b]

[a]These correlations are significant at the 0.05 level (two-tailed); [b]These correlations are significant at the 0.01 level (two-tailed).

Table 4. Comparative Differences in SAT I: Math Scores between ChemPrep Users and Nonusers

Course	Nonuser Group *(N)*	ChemPrep Group *(N)*	Average Scores, Nonuser Group[a]	Average Scores, ChemPrep Group[a]	*P*-Value of Difference	Effect Size
GenChem S04	268	28	578	598	0.09	0.23
GenChem F04	424	59	581	585	0.71	0.05
Nursing F04	104	16	532	578	0.02	0.64
Honors F04	63	27	661	641	0.28	–0.27[a]

[a]Scores did not correlate well with grades (see Table 3) and were not used in further analysis.

Table 5. Comparative Differences in SAT I: Verbal Scores between ChemPrep Users and Nonusers

Course	Nonuser Group *(N)*	ChemPrep Group *(N)*	Average Scores, Nonuser Group[a]	Average Scores, ChemPrep Group[a]	*P*-Value of Difference	Effect Size
GenChem S04	268	28	547	575	0.08	0.35
GenChem F04	424	59	549	585	0.00	0.44
Nursing F04	104	16	518	536	0.35	0.24[a]
Honors F04	63	63	610	607	0.91	–0.03[a]

[a]Scores did not correlate well with grades (see Table 3) and were not used in further analysis.

evidence that the higher grades of users were due to participation in the ChemPrep course.

As Tables 4–7 show, GenChem and Nursing users of ChemPrep were in fact academically stronger than nonusers, demonstrating higher predictor variable scores on all measures (ES > 0). For Honors, no significant difference was found between users and nonusers in the two variables that correlated well with course grades: math placement scores in algebra and trigonometry (ES ~ 0). This result is reasonable since the group is more homogenous and academically stronger overall.

A comparison of the effect sizes of grades and prior achievement and ability measures for each class is shown in Figure 2. The SAT and mathematics placement effect size values define a range in which we would expect the value for the course grade to fall if ChemPrep had little or no influence on student performance. Because the SAT scores for Honors and SAT verbal for Nursing do not correlate well with student grades (see Table 3), we do not include them in Figure 2.

For every course, the effect size for the grade was greater than for those of the prior achievement and ability measures. While the students in GenChem and Nursing who used ChemPrep tended to be stronger than their peers (ES > 0 for SAT and mathematics placement), they also appeared to benefit beyond what would be predicted by their entry skills. The ChemPrep course appears to have had a positive effect over and above the advantage these students brought to the course.

In the Honors course, no significant difference was found between users and nonusers based on predictors of prior achievement and ability, but there is a large difference in grade performance. Here, there seems to be a substantial positive relationship between ChemPrep usage and course grades. This was a surprising result because the Honors group was stronger overall and we had expected that an increase, if any, in course grades for users would be small. We were also surprised by the fact that a much larger percentage of Honors students completed ChemPrep (23% vs 9% for GenChem and Nursing). If we assume that this group has a larger proportion of motivated students then this result is reasonable.

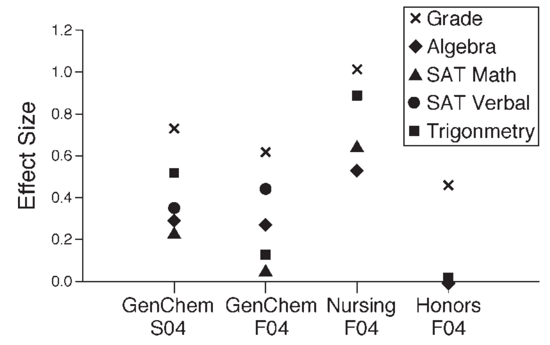

Figure 2. Effect size of final grades and test scores, by course.

While the data for effect size support the hypothesis that ChemPrep helped students over and above what would be expected from their previous work, it is notoriously difficult to tease out motivational factors and the data do not unequivocally show a cause–effect relationship. Other motivational factors, such as more time spent on task, may be contributing. We have not been able to devise a good measure of this using OWL because login time does not necessarily translate into actual study time. Anecdotal data from surveys suggest that the stronger students actually spend less time doing homework.

Table 6. Comparative Differences in Algebra Placement Scores between ChemPrep Users and Nonusers

Course	Nonuser Group (*N*)	ChemPrep Group (*N*)	Average Scores, Nonuser Group[a]	Average Scores, ChemPrep Group[a]	*P*-Value of Difference	Effect Size
GenChem S04	246	29	20.4	22.1	0.14	0.29
GenChem F04	411	62	21.4	22.8	0.05	0.27
Nursing F04	94	16	17.4	20.3	0.07	0.53
Honors F04	65	27	25.6	25.6	0.97	–0.01

Table 7. Comparative Differences in Trigonometry Placement Scores between ChemPrep Users and Nonusers

Course	Nonuser Group (*N*)	ChemPrep Group (*N*)	Average Scores, Nonuser Group[a]	Average Scores, ChemPrep Group[a]	*P*-Value of Difference	Effect Size
GenChem S04	246	28	4.7	6.1	0.01	0.52
GenChem F04	411	62	4.9	5.2	0.34	0.13
Nursing F04	94	16	3.4	5.4	0.00	0.89
Honors F04	65	27	6.9	7.0	0.95	0.02

Table 8. Gender Distribution of Introductory Chemistry Students Who Were ChemPrep Users or Nonusers

Course	Females, Total (%)	Female Users (%)	Female Nonusers (%)
GenChem S04	41	66	36
GenChem F04	53	72	46
Nursing F04	80	94	74
Honors F04	51	69	43
Overall	53	73	46

Who Benefited from ChemPrep?

The data suggest that the students who completed ChemPrep were, in general, strong academically, and the final course grades of these students in subsequent courses were positively influenced over and above what would be predicted from measures of prior achievement or ability. This is especially interesting because one would expect that these are the students who would need, or benefit from, a preparatory course the least.

We can identify three types of general chemistry student who would voluntarily choose to participate in ChemPrep:

1. Students who know they are unprepared and are likely do poorly without additional help.
2. Students who are likely to do well but lack confidence in their preparation.
3. Students who probably will do well and make use of every resource available.

The course was primarily designed for the first type of student. However, it appears that most of the ChemPrep users actually fell into the latter two categories. For these students, ChemPrep—with its detailed feedback and mastery approach to learning—appears to have helped develop or refresh the content knowledge needed to perform well. In addition, ChemPrep may also have helped these students build confidence with the technology used in the subsequent courses. These students are likely to succeed anyway and ChemPrep seems to be a tool they used to improve their performance.

Based upon our design and intent for the course, it is our expectation that students of lower prior achievement and ability levels would also benefit from ChemPrep. Our challenge is to help these students identify their deficiencies and to convince them to take advantage of this resource.

Gender Differences

ChemPrep users were more likely to be women, constituting 73% of the total users while representing a total of 53% of all students taking these chemistry courses (Table 8).

Through surveys conducted in our general chemistry classes over the past five semesters, a consistent pattern has emerged: women students rate the importance of outside resources such as textbooks, study groups, help center, Web sites, tutoring, and so forth, more highly than men do. None of the differences on individual items reached a level of statistical significance, but the pattern is consistent across all items. Thus, women are more likely to take advantage of various sources of help than are men, and their over-representation among ChemPrep users is indicative of this. This is also consistent with the idea that the students who participated in ChemPrep were from the second and third types discussed before. For these students, the online course may have helped to build a framework for success. Given the under-representation of women in the physical sciences, the ChemPrep model may point out a creative new way to reach female students.

How Can We Encourage Greater ChemPrep Usage?

It appears that we have reached many of those students who are predisposed to take advantage of preparation materials to boost their confidence, study skills, and content knowledge. However, we have not necessarily reached those students who are most unprepared and will do poorly without extra help.

In summer of 2005 we worked directly with advisors in the New Students Program, the Honors College, Engineering, and Nursing to inform incoming students about ChemPrep. We developed a brochure that has been to distributed to over 800 students. Advisors within each discipline are best positioned to encourage participation and they have received ChemPrep with great enthusiasm. We are keen to see if these steps will increase the voluntary participation rate.

As briefly described above *(5),* educators at the University of Iowa have approached the problem of identifying weaker students by creating an online chemistry exam that assesses student readiness and points out relevant Web resources. We expect that a similar approach will be effective for ChemPrep and OWL software engineers have begun work to develop an online testing capability that is able to diagnose a student's level of content readiness and assemble a curriculum subset of modules that is tailored to each student's need. As shown in Table 1, many students signed up for ChemPrep but did not complete at least half of the material. These students may have benefited from such a diagnostic instrument to help them pinpoint specific weaknesses and address them more efficiently.

As a result of feedback given on our surveys, we are also investigating whether three different versions of ChemPrep should be developed for GenChem, Nursing, and Honors courses. The main question is whether a curriculum specifically customized to each course would be more likely to encourage participation. Different versions of ChemPrep might also adapt more readily to courses at other institutions.

Conclusions

ChemPrep was developed to be a stand-alone preparatory program to help students succeed in general chemistry. Students reported that the combination of short information pages, parameterized questions with detailed feedback, tutors, and answers to questions through the OWL message system, permitted them to learn independently without the need for a textbook or lecture. Students who completed ChemPrep had higher success rates and, on average, higher grades in GenChem, Nursing, and Honors chemistry courses. The initial offerings of ChemPrep were entirely voluntary, and more women than men participated. ChemPrep appears to have helped students of high prior achievement and ability perform better than their achievement scores predicted. Students in the Honors course enrolled in ChemPrep in higher percentages than students in GenChem and Nursing. Honors users were not necessarily better students than their peers, but performed better in the course than those students who did not use ChemPrep. Weaker or less motivated students did not respond to the voluntary offerings of ChemPrep in the same numbers as stronger or more motivated students, and we are seeking alternate ways to reach this population. Further research involving the ChemPrep course as it compares to learner styles is underway.

A companion study of the preparatory course for organic chemistry showed a similar improvement in the performance of users versus nonusers in the subsequent courses. This study will be the subject of a separate paper.

The preparatory course model should be appropriate for any discipline that requires a certain amount of background knowledge, especially in the sciences and mathematics. It could also benefit students in a variety of situations, including those at two- and four-year institutions. The UMass Provost's Office has used ChemPrep as the basis for a proposal to develop a university-wide program to improve success in first-year physics and calculus courses among others. There are clear long-term benefits to helping more students successfully complete their entry-level science and mathematics studies, both in terms of reducing the number of students who take extra time to complete their degrees, and in terms of retaining more students in science-related majors. We believe the ChemPrep model holds great promise to help improve this situation for students of general and organic chemistry.

Acknowledgments

We thank the University of Massachusetts–Amherst for allowing use of the OWL infrastructure to offer ChemPrep free of charge to students. Without this support, ChemPrep would have been prohibitively expensive to develop and deploy.

Notes

1. Funding for this project was provided by the Professional Development Grant Program of the University of Massachusetts Information Technology Council.

2. A companion self-paced online preparatory course for organic chemistry has also been developed and tested. The results of this study will be presented in a subsequent paper.

3. Information about the ChemPrep courses for both general and organic chemistry can be found at *http://www.chem.umass.edu/chemprep/* (accessed Nov 2006).

4. A demonstration of the OWL system delivered through Thomson Learning can be found at *http://owl.thomsonlearning.com/demo* (accessed July, 2005).

5. Examples of the OWL courses delivered at UMass Amherst can be found at *http://owl.oit.umass.edu* (accessed July, 2005).

6. Grades are based upon a 4.0 scale with 4.0 indicating an A and 0.0 an F.

7. Correlations in the Honors class are lower due to the selectivity of the course, which resulted in a restriction of range in the predictor variables.

8. All entering first-year students take the mathematics placement exam, which is used to determine their appropriate mathematics course. It has two components: algebra and trigonometry.

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