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Importance of Academic Legacy on Student Success in First- and Second-Semester General Chemistry

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Abstract: This investigation sought to elucidate the influence of students' academic legacy on their prior knowledge and course outcomes providing crucial insights for educators who teach general chemistry. This six-semester analysis involved 6,914 students enrolled in classes across nine Texas universities. Explored were personal circumstances associated with students' successes and failures that influenced performance in on- and off-sequence, first- and second-semester general chemistry (Chem 1 and Chem 2). Students' academic legacy based on their categorization as first generation (neither grandparent nor parent/guardian with a 4-year bachelor's degree), second generation (at least one grandparent or parent/guardian with a bachelor's degree), or third generation (at least one grandparent and at least one parent/guardian hold a bachelor's degree) was investigated. Of the students in the dataset 33.8% (*n* = 2,340) self-identified as Hispanic. Results for Hispanic and non-Hispanic students indicated that first-generation students struggled more with Chem 1 and Chem 2 than students in the other two legacy groups. As students' academic legacy extended, they were more apt to succeed in general chemistry. Second- and third-generation students demonstrated stronger prior high-school chemistry backgrounds and were enrolled in more advanced mathematics courses. As expected, students with stronger academic backgrounds in chemistry and mathematics scored higher on the diagnostic MUST (Math-Up Skills Test), had greater self-efficacy relative to their preparation to succeed, and reported fewer paid work hours. First-generation students on the average entered with lower diagnostic MUST scores, felt less prepared to succeed, and disclosed a greater need to be employed.

Keywords: *Academic legacy; Ethnicity; Higher education; General chemistry; Diagnostic testing; Mathematics/automaticity*

Introduction

Background

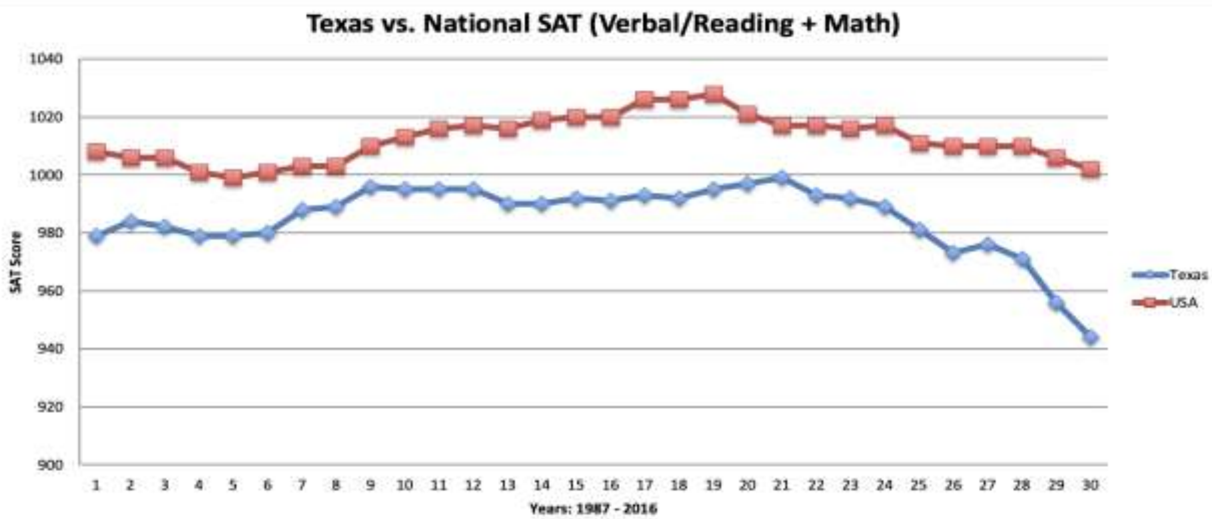
Texas is home to the second largest Latino population in the United States of America (US) with 42.5% of the total population identifying as Latino/a/x. The only other state to register a higher population percentage of Latino/a/x is California with an increase of 0.2% or 42.7% (*Excelencia*, 2021, HACU, 2023). Texas joins Hawai`i, New Mexico, California, and Nevada as the only majority-minority states in the US. At the time this study began of the 37 four-year public institutions, 18 were classified as Hispanic Serving Institutions (HSIs), 16 classified as Hispanic-emerging (eHSIs), and two qualified as Historically Black institutions (HBCU). One institution located on the border with Arkansas is the only four-year public university considered to be predominantly White, non-Hispanic. Students who participated in this study were enrolled at nine universities located across 45,000 mi^2 (about 117,000 km^2) of Texas. When this investigation began, three of the nine universities qualified as HSIs and the other six as eHSIs. (Currently, seven of the nine participating universities have increased their Hispanic student enrollment and are currently classified HSIs.)

In Texas, university degree attainment for Latinx students lags that for White, non-Hispanic students by 14% (*Excelencia*, 2021). Just over half of Texas eighth graders eventually enroll in an institution of higher education, but less than half (i.e., 40.7%) of high school graduates receive a degree or certificate and only 16% receive a bachelor’s degree or higher (THECB, 2017). Across the state, 36.7% of the enrolled undergraduate population in public institutions identified as Hispanic (THECB, 2017); the latest estimate is 39.3% (THECB, 2021). To bring an important aspect of STEM education into focus, we have explored the effects of academic legacy on students enrolled in a STEM majors' course (general chemistry) of whom many are underrepresented, under resourced minority students. In general, standardized test scores indicate that Texas secondary students are less prepared now than they have been over the last 31 years (Figure 1). In fact, over 40% of students entering college for the first time are not consider college ready (THECB, 2017). Even though not shown in Figure 1, mean SAT scores for Texas continued to fall in the academic year 2017 when scoring parameters changed. From the reporting of 50 states plus Washington, D.C., Texas ranked 45th on published SAT means. In a 2023 report from the George W. Bush Institute, "During the 2021-2022 school year, no grade level was more than 60% ready for the next grade." (Wicks & Pruneda, 2023).

The decline of the SAT scores in Texas is not simply a question of the recent influx of immigrants entering Texas. Students' language barriers and many other factors influence all students' success rate. Supported by data from the 2023 Bush Institute report, there is no grade level (elementary to high school) with over 50% of students on track in mathematics. When data are considered by economic resources and ethnicity, 70% of economically disadvantaged students, 66% of Hispanics, and 75% of Black students are not on grade level in mathematics (Wicks & Pruneda, 2023). The American Chemical Society (ACS) Blue Ribbon Advisory Panel on Minority Affairs urged getting minority students into the pipeline at the pre-college stage as the key to increasing the number of minorities in graduate programs and careers. The ACS also reported a disproportionately low number of Hispanic students are applying for scholarships expanding this discrepancy (ACS News, 2000). This six-semester study focuses on students' academic legacy and demonstrates that many factors influence the success rate of students enrolled in first-semester (Chem 1) and second-semester (Chem 2) general chemistry. In this study, the team of chemical education researchers from Texas details the importance of academic legacy on students' success in Chem 1 and Chem 2.

Figure 1

SAT scores (y-axis) over a span of 30 years.



Note. Points 1-30 collected before SAT scoring calculation changes. [This figure is a modified version of the one published in Petros et al. (2017) and is reprinted with permission of the *Journal of Chemical Education* and the authors.]

In addition to the educational challenges mentioned above, financial need pushes students to consider employment while enrolled in college, which can impact time available to study outside of class. At the time of data collection for this study, the number of full-time students with Pell grants at a one of the participating eHSI (now an HSI) was 42% and the full-time students at a participating HSI was notably different at 55.2% (THECB, 2017). The average graduation debt of the students at each institution is disturbing: debt is just under $24,000 at one of the HSIs in this study and debt exceeded $32,500 at one of the eHSI (THECB, 2017). (For comparison, THECB (2021) reported statewide percentage of students receiving Pell grants at 38.9% with over $25,000 of accumulated debt per graduate.) Over 55% of this study's HSI general chemistry students work off campus with another 9% working on campus. At a participating eHSI, one half as many students (27%) reported working off campus with only 6.5% of students employed on campus. The data from previous studies suggested that working on campus contributed positively to students' improved course averages (Weber et al., 2020). In this study it was found that fewer Hispanic students live or work on campus than do other ethnicities. A previous study determined that students at one of the participating HSIs (now considered a "super" HSI with a Hispanic population over 75%) took longer than eHSI students to complete a bachelor’s degree. Degree attainment is known to almost double one’s lifetime earnings (Habley, Bloom & Robbins, 2012). However, when students feel obligated to attend classes part-time, the debt associated with the increased number of years impacts financial and completion measures. It is projected that eighth-grade Texans may hamper their future earnings by $104 billion – with low-income students bearing the bulk of that loss – due to their lack of readiness for postsecondary education with only 22% of them earning a degree or credential within six years of high school graduation (Wicks & Pruneda, 2023). A positive completion factor is that only 64% of the degrees at the eHSI are awarded to at-risk students but this stat improves to almost 86% at HSIs (THECB, 2017). Participating university demographics sectioned by HSI and eHSI status are reported in Table 1.

Table 1

Four-year university demographics from participating HSIs and eHSIs.

	Type	Size	Texas Location	UG Enrollment	Hispanics
HSI (> 25.0% Hispanic)					
TAMUSA	Public	Mid	San Antonio	6,041	75.4%
UHCL	Public	Mid	Houston	6,582	44.9%
TSU	Public	Large	San Marcus	33,193	40.6%
eHSI (16.0-25.0% Hispanic; before classified as an HSI, need to maintain 25%+ for a year)					
ACU	Private	Small	Abilene	3,297	17.8%
TAMUC	Public	Mid	Commerce	7,962	22.6%
SHSU[a]	Public	Mid	Huntsville	18,790	25.8%
TAMU[a]	Public	Large	College Station	53,144	25.2%
UT, Austin[a]	Public	Large	Austin	40,048	27.0%
UNT[a]	Public	Large	Denton	32,694	27.9%

Note. [a]Since this study concluded, these universities have gained HSI recognition; ACU and TAMUC remain eHSIs. Statewide: *N* = 532,492 public-school undergraduates with Hispanic enrollment of 39.3%. These data were selected from the *2021 Almanac* of the Texas Higher Education College Board (THECB).

Methods

Academic Legacy

Student demographics as to their academic legacy are reported in Table 2. Students categorized as a first-generation student report no grandparent or parent/guardian held a four-year bachelor's degree. The members of the second-generation student group includ those who self-report that at least one grandparent or parent/guardian held a 4-year degree. The third-generation student reports a legacy of at least one grandparent and at least one parent/guardian holds a four-year degree. (No information was collected on where the degree was attained or the nature of the degree, only that a four-year degree was held.) In Table 2 only two schools (TAMU, R1 Carnegie research institution and private institution ACU) of the nine have greater percentages of third-generation legacy students than first-generation.

Table 2

Student's academic legacy enrollment and percentage contribution by institution in Chem 1 and Chem 2.

Institution[a]	Neither Grandparent nor Parent (%) **First generation**	Grandparent or Parent (%) **Second generation**	Grandparent and Parent (%) **Third generation**	**Participation** (percentage contribution)
TAMU-SA	176 (56.2%)	103 (32.9%)	34 (10.9%)	313 (4.5%)
UT, Austin[b]	285 (50.9%)	181 (32.3%)	94 (16.8%)	560 (8.1%)
SHSU	74 (43.5%)	65 (38.2%)	31 (18.2%)	170 (2.5%)
TAMU-C	75 (40.8%)	57 (31.0%)	52 (28.3%)	184 (2.7%)
UHCL	152 (40.4%)	145 (38.6%)	79 (21.0%)	376 (5.4%)
UNT	578 (38.1%)	584 (38.4%)	357 (23.5%)	1,519 (22.0%)
TSU	312 (38.0%)	294 (35.9%)	214 (26.1%)	820 (11.9%)
TAMU	557 (23.3%)	801 (33.5%)	1,035 (43.3%)	2,393 (34.6%)
ACU	112 (19.3%)	205 (35.4%)	262 (45.3%)	579 (8.4%)
Totals	**2,321 (33.6%)**	**2,435 (35.2%)**	**2,158 (31.2%)**	**6,914**

Note. [a]Order of the institutions is based on highest to lowest first-generation (all ethnicities) enrollment status. Schools: TAMU = Texas A&M University, SA = San Antonio, C = Commerce; UT = The University of Texas at Austin; SHSU = Sam Houston State University; UHCL = University of Houston – Clear Lake; UNT = University of North Texas; TSU = Texas State University; and ACU = Abilene Christian University.
[b]Hosted TIP (Texas Interdisciplinary Plan) class: special enrollment for first-year students admitted to the College of Natural Sciences. Given percentages do not reflect the typical enrollment at The University of Texas at Austin.

Instrument

Texas students' mathematics and verbal skills are evidently in need of improvement (Figure 1) compared to the rest of the US. Determining how students solve mathematics problems jumpstarted the Networking for Science Advancement (NSA) team formation in the Fall 2016. Since mathematics preparation is closely tied to success in the general chemistry course sequence (Chem 1 to Chem 2), the NSA team decided to first focus on students' automaticity (what they can do without the use of a calculating device). The search of the literature provided an evidence-based research instrument reported by an author from the U.S. Naval Academy and a co-author who specializes in number-sense improvement workbooks (Hartman and Nelson, 2016). This was an easy study to replicate: give a number-sense quiz named the MUST (Math-Up Skills Test) without a calculator and repeat giving the same students another version of the quiz with a calculator thereby evaluating students' numeric automaticity ability. Basic arithmetic skills and the procedures used to solve simple mathematics exercises were assessed by the diagnostic MUST, which includes multiplication of two 2-digit numbers, multiplication and division with powers of ten, zeroth power application, changing a fraction to decimal notation, rearranging algebraic equation (combined gas law), logarithms, determining the base-10 logarithm functions, square and square root of a number in scientific notation with a negative power, and balancing simple chemical equations (a form of counting the number and kind of elements on both sides of the equation). A copy of the MUST is available in Williamson et al. (2020). (In response to the NSA team's research, an online MUST is currently available from Macmillian Publishers[1].)

The NSA team published supporting evidence for the benefits of the hand-graded 20-question, 15-min., paper-and-pencil, calculator-free, open-ended MUST that can predict with a 78% accuracy whether a Chem 1 student will attain at least a 69.5% average by using coefficients from the developed LASSO regression model (Williamson et al., 2020). This publication mentions that when SAT records of students are not readily available, the MUST appears to be equally successful at identifying at-risk students. Even though the SAT issue identified above (Figure 1) is what piqued the team's curiosity, data generated from the calculator-free MUST is proving to be just as valuable (and results are immediately availabile) in identifying at-risk students making it a more useful diagnostic than the more established SAT (Williamson et al., 2020). In addition to the publication on Chem 1 students, the team published another study on Chem 2 students with even higher predictability identifying 83% of the successful students. In an organic chemistry student study, the evaluated data included student's MUST score, their first-exam score, and their prior GPA, which improved predictability to about 90% (Lee, Rix & Spivey, 2022). Results from all these studies support that students who enter with higher MUST scores statistically outperform the others as indicated by their end-of-course averages. [If you are wondering about why "calculator-free", the NSA team discovered in our pilot study (Petros et a., 2017) that final course grades produced a stronger correlation to MUST scores when students did not use a calculator (r = 0.450) than when they did (r = 0.403). Also, many general chemistry students are considering future careers in the health professions and will need to sit for the MCAT and/or other professional assessments, which consist of calculator-free sections, so the calculator-free MUST acts as an insight into their future.]

Mathematics professionals established the content validity of the MUST to ensure that the instrument measured what it was intended to measure. The unexpected higher correlation when calculators were not used led the NSA team to further investigations. As is well-documented, Chem 1 to Chem 2 courses report historically high DFW rates (students who make grades of D or F or withdraw from a course) (Martin, 1942; Hovey & Krohn, 1958; Rowe, 1983; McFate & Olmsted, 1999; Legg, Greenbowe, & Legg, 2001; Mason & Mittag, 2001; Wagner, Sasser & DiBiase, 2002; Reardon et al., 2010; Ford, Broadway, & Mason, 2023). The diagnostic used in this study goes beyond arithmetic skills. Yes, students performed better when calculators were used (Petros et al., 2017), but students who have overlearned the underlying procedures behind the MUST exercises and can correctly respond to the exercises, consistently successfully completed courses at a higher rate than those who had to rely on their calculators to obtain correct answers. Internal consistency measures (e.g., Cronbach's alpha and KR-20) have always exceeded (0.85) indicating high reliability. The MUST is psychometrically sound and has provided direct evidence that number-sense mental skills are very important to success in Chem 1 (Williamson et al., 2020) and Chem 2 (Powell et al., 2020). First-semester organic chemistry (O-Chem I) NSA team studies have also revealed that the mental skills required for successful completion of general chemistry may be similar to those required for success in O-Chem I (Bodenstedt et

[1] Macmillan Publisher developed an online version of the MUST in 2023 offered through the *Achieve* program: https://www.macmillanlearning.com/college/us/digital/achieve. Only minimal data have been collected, so no conclusions are currently available as to its effectiveness; results from a pilot study parallel those from this research.

al., 2022; Lee, Rix, & Spivey, 2022); students who understand the procedures needed to solve these arithmetic problems may also find noted chemical reactions and mechanisms easier to comprehend and retain.

Additional NSA team studies of the successes and failures of general chemistry students include several publications on the use of the MUST: Albaladejo et al., 2018 (Chem 1 and Chem 2); Mamiya et al., 2020 (environmental factors); Powell & Mason, 2021 (pre-med majors); Shelton et al., 2020 (warning signals); Alivio et al., 2020 (math review); Villalta-Cerdas et al., 2022 (personal characteristics); Dubrovskiy et al., 2022 (gender gap); Willis et al., 2022 (common questions); Ford, Broadway, & Mason, 2023 (e-homework); Shelton, Simpson, & Mason, 2023 (unsuccessful students); and Mason & Shelton, 2023 (MUST predictability). The team has yet to investigate if the MUST is also useful in characterizing first-generation students and differentiating these students from students with an extended academic legacy.

Protocol

All participating universities received IRB approval at their institution to collect data on the importance of students' academic legacy and their success in general chemistry, a key STEM course required for many areas of study and employment. All instructors gave the MUST diagnostic instrument during the first week of classes. The collected demographic data, academic performance scores on the diagnostic MUST assessment, and final course averages were compiled by the last author removing any biases that might arise in the data analyses. Pilot study data were collected in fall 2016-spring 2017 and are not included in this analysis. The reporting timeframe of this study is therefore fall 2017 to spring 2020. As is well-known, CoVID impacted how classes starting in March 2020 were conducted. At this time, many lectures were changed to an online delivery method. In this study, the diagnostic MUST, demographic information, and the Human Subjects' agreements were in place and only final course grades were needed to complete the data collection. Spring 2020 final course averages did not vary significantly from those of prior semesters so are included in the dataset analyzed.

Research Questions

This study responds to the following questions:

1. How does a student's legacy status correlate to their MUST and general chemistry course (Chem 1 and Chem 2) performance?
2. Is there a positive correlation between academic legacy and students' success in Chem 1 and Chem 2 based on their performance in high school (HS) chemistry and current level of mathematics enrollment?
3. How do student demographics (e.g., feeling prepared, gender, ethnicity, and employment) align with academic legacy and course success (grades of A, B, and C)?
4. Hispanic student comparisons:
   - Do Hispanic students show a preference towards attending HSIs or eHSIs?
   - How predictive is the MUST in determining Hispanic students' course success?

- When academic legacy groups are considered, how do Hispanic students' entering automaticity skills affect course success?
- Are first-generation Hispanic students continuing to enroll in the general chemistry sequence (Chem 1 to Chem 2) at the same rate as the other ethnicities?
- How does Hispanic student enrollment in Chem 2 compare to that of non-Hispanic students?

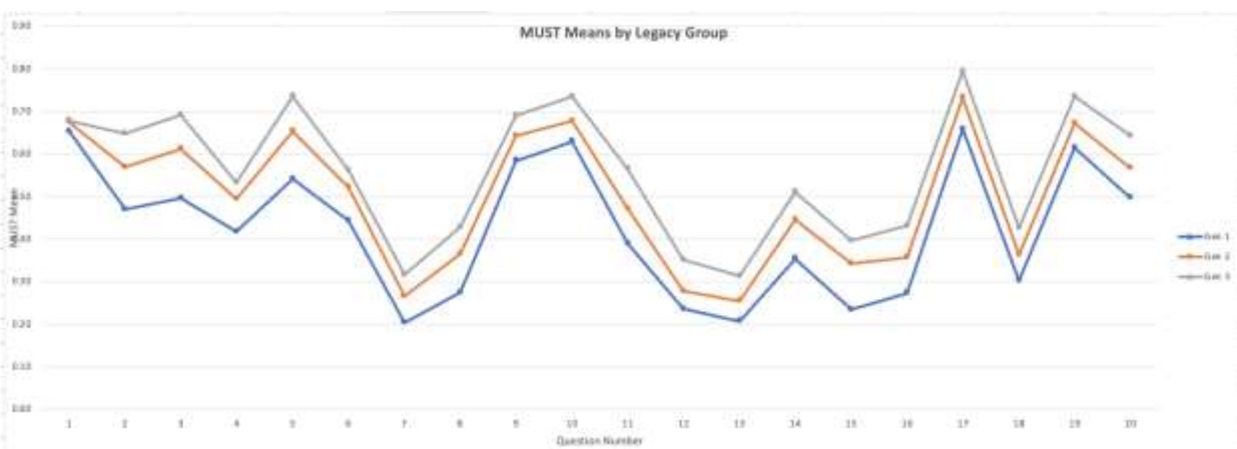
Results

Population

Over 90% of the students in this study attended a secondary school in Texas and therefore entered as students who experienced an isomorphic curriculum providing them with similar backgrounds but also holding many of the same misconceptions (Petros et al., 2017; Albaladejo et al., 2018; Williamson et al., 2020; Powell et al., 2020). Figure 2 is a line graph depicting MUST question means for the three student groups ($N = 6{,}914$) based on their family's academic legacy history. Note the similar up and down pattern of all groups and that the means of each question for first-generation students (bottom line) is the lowest of the three groups on every question asked. Generation three (top line) scored highest on average on each MUST question without overlap supporting the statistically significant differences between groups ($p < 0.05$).

Figure 2

Legacy group means on each MUST question (1-20).



Note: Legacy groups: Gen 1 = first-, Gen 2 = second-, Gen 3 = third-generation students enrolled in Chem 1 and Chem 2 (including both on- and off-semester courses).

Splitting the population into ethnic groups, the MUST means are aligned from high to low in Table 3. MUST scores are grouped by below average, middle range, and above average ranges. To determine the middle range of MUST scores, take one-half of the standard deviation (*SD*), add it to the sample population mean and then subtract it from that mean. Use the closest whole numbers for the low and high MUST range values. The below-average range is below the smaller number of the middle range and the above-average range is larger than the higher score of the middle range. The ranges for each ethnic group are in Table 2.

Table 3

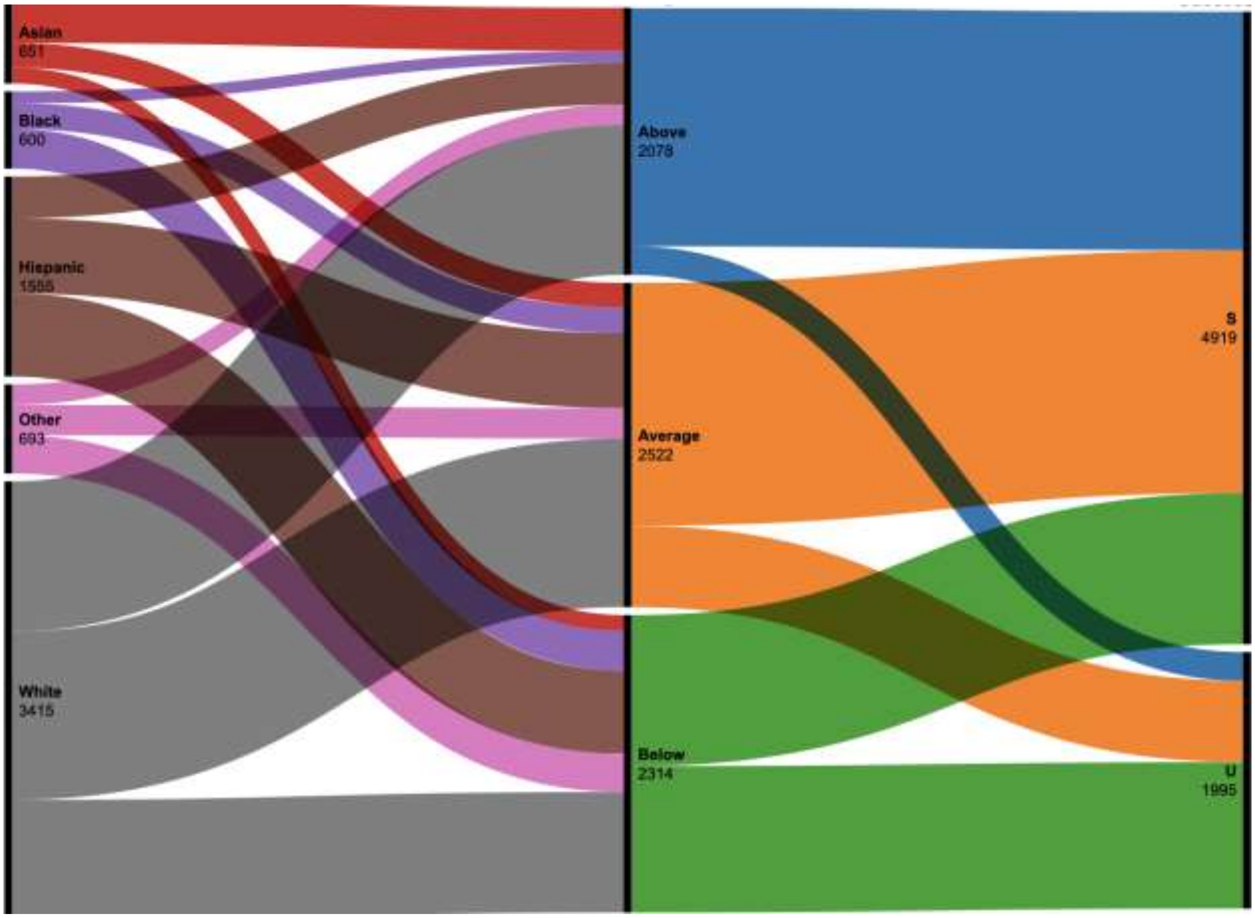
MUST ranges for each ethnic group.

Ethnicity	***N***	**Mean (*SD*)**	**Below Average**	**Middle Average**	**Above Average**
Asian	651	12.0 (5.1)	0-8	9-15	16-20
White	2,951	10.3 (5.0)	0-7	8-13	14-20
Other	393	8.7 (5.1)	0-5	6-11	12-20
Hispanic	2,340	8.2 (5.0)	0-5	6-11	12-20
Black	579	7.2 (4.6)	0-4	5-12	13-20
s	**6,914**	**9.4 (5.1)**	**0-6**	**7-12**	**13-20**

The White ethnic group omits those who indicated any other ethnicity; the Hispanic ethnic group includes students who indicated that their heritage includes Hispanic influence; Asian and Black ethnicities did not indicate any other genetic disposition; and the Other category includes Native Americans, Middle Easterners, Mixed, anyone who selected the "Other" category on their self-reported demographic survey, and those who omitted a response (n = 13) to this query. Figure 3 presents an alluvial diagram (to access how to produce your own alluvial diagrams see Mauri et al., 2017) where you can follow the various "rivers" from students' diagnostic MUST scores to course success (grades of A, B, and C) or lack of success (grades of D and F). The most interesting river (blue, top right) is the flow from students who scored in the above average range on the MUST and were S (successful) in the course as compared to those in the skinny blue river from the above MUST range to the U (unsuccessful) bar on the right side. Yes, students can score in the highest MUST range and be S or U, but the odds indicate that very few who do well on the MUST earn grades of D or F. The White ethnic group (left bar) splits into thirds for each MUST group. The Black, Hispanic, and Other groups have fewer members in the above category, and the Asians have a lower percentage of students who scored in the lowest MUST range. The data support the most obvious reason for this disparity is that Asian's MUST mean is statistically higher ($p < 0.05$) than the MUST means for all other ethnic groups (Table 3).

Figure 3

Alluvial diagram (N = 6,914) linking each ethnic group with their MUST scores and general chemistry course success groups (S = Successful and U = Unsuccessful).



Note. The left bar gives the five ethnic groups with the population size, the middle bar represents the average MUST ranges (above = 13-20; average = 7-12; below = 0-6), and the right bar indicates the S and U students. Noting the rivers from the left bar to the middle bar you can identify the contribution of the various ethnicities to each scoring range. For example, the majority of the Asian scored in the above range and a majority of the Blacks scored in the below range. The largest MUST group contributing the U students (over 50%) extends from the below average MUST group (green river, bottom right).

Table 4 highlights how academic legacy impacts student outcomes, or in other words, being a third-generation student where both a parent and a grandparent hold bachelor's degrees is advantageous to general chemistry course success. In this study, about one-third (33.6%) of the students at the nine universities evaluated consider themselves a member of the first-generation category. Also interesting about these outcomes is how frequently all the variables evaluated align. As the academic legacy of these students increases so does their self-efficacy or feeling of being prepared, which is dramatically reflected in the percentage of successful (grades of A, B, or C) third-generation students of 98.4%. There is a statistical difference ($p < 0.05$) between first- and second-generation students but there is no statistical difference between second- and third-generation students' feelings about how prepared they are for their specific general chemistry course. (All following statistical differences are reported at the $p < 0.05$ level meaning that the test hypothesis is false or should be rejected, and there is a difference between the groups examined.) Self-efficacy, MUST scores, course averages, percentage of male students enrolled, high school chemistry course background, and current mathematics enrollment are all aligned from low to high; the two categories align in the opposite direction are the percentage Hispanic enrollment and work history. The greatest percentage of Hispanic students (57.8%) belong to the first-generation student group, followed by second-generation students at 27.2%, and of the third-generation students only 15.3% report being descendants of Hispanic ethnicity. The average time worked was based on categorical ranges of 0 = no employment on- or off-campus, 1 = 1-10 h, 2 = 11-20 h, 3 = 21-30 h, and 4 = 31-40 h. First-generation students report a higher category average of time worked. Data indicate that the first-generation students (mean measure of 2.5 = 11-20 h) on average work more than students in the other two groups at 2.3 and 2.1, respectively, for second- and third-generation groups. These results are also consistent with a 2008 study, which found that Hispanic students were more likely to attend college part-time and had a greater attrition rate (Wilkerson, 2008). Statistical comparisons between groups by work-hour categories indicate that the average first-generation student must carry a heavier employment load (many working more than what is considered part-time or over 20 h/week) than students in the second- and third-generation groups, which may contribute to their academic struggles. Not included in Table 4 is the percentage of students of each legacy group who do not work. Of the first-generation group 61.9% report not to work. For second-generation and third-generation students 66.3% and 73.9%, respectively, do not work on or off campus. Data on family income were not collected, but these percentage coincide with suspected improved economic conditions as academic legacy increases.

Table 4

Student demographics (N = 6,914) based on Gen (generation) group.

Academic Legacy	*N*	% [a]Suc	Feeling Prepared	MUST max 20	Course Average	% Male	% Hispanic *n* = 2,336	[b]HS Chem	Current Math	Work
No Parent/ Grandparent (First Gen)	2,321	64.3	3.04	8.1	72.9	37.3	57.8	1.86	2.78	2.5
Parent or Grandparent (Second Gen)	2,435	71.0	3.12	9.5	76.0	38.9	27.2	1.88	3.08	2.3
Parent and Grandparent (Third Gen)	2,158	98.4	3.18	10.9	81.1	40.2	15.3	1.92	3.36	2.1
Overall	**6,914**	**71.1**	**3.11**	**9.4**	**75.9**	**38.8**	**33.8**	**1.89**	**3.07**	**2.3**

Note. [a]Suc = successful; [b]HS Chem = high school chemistry

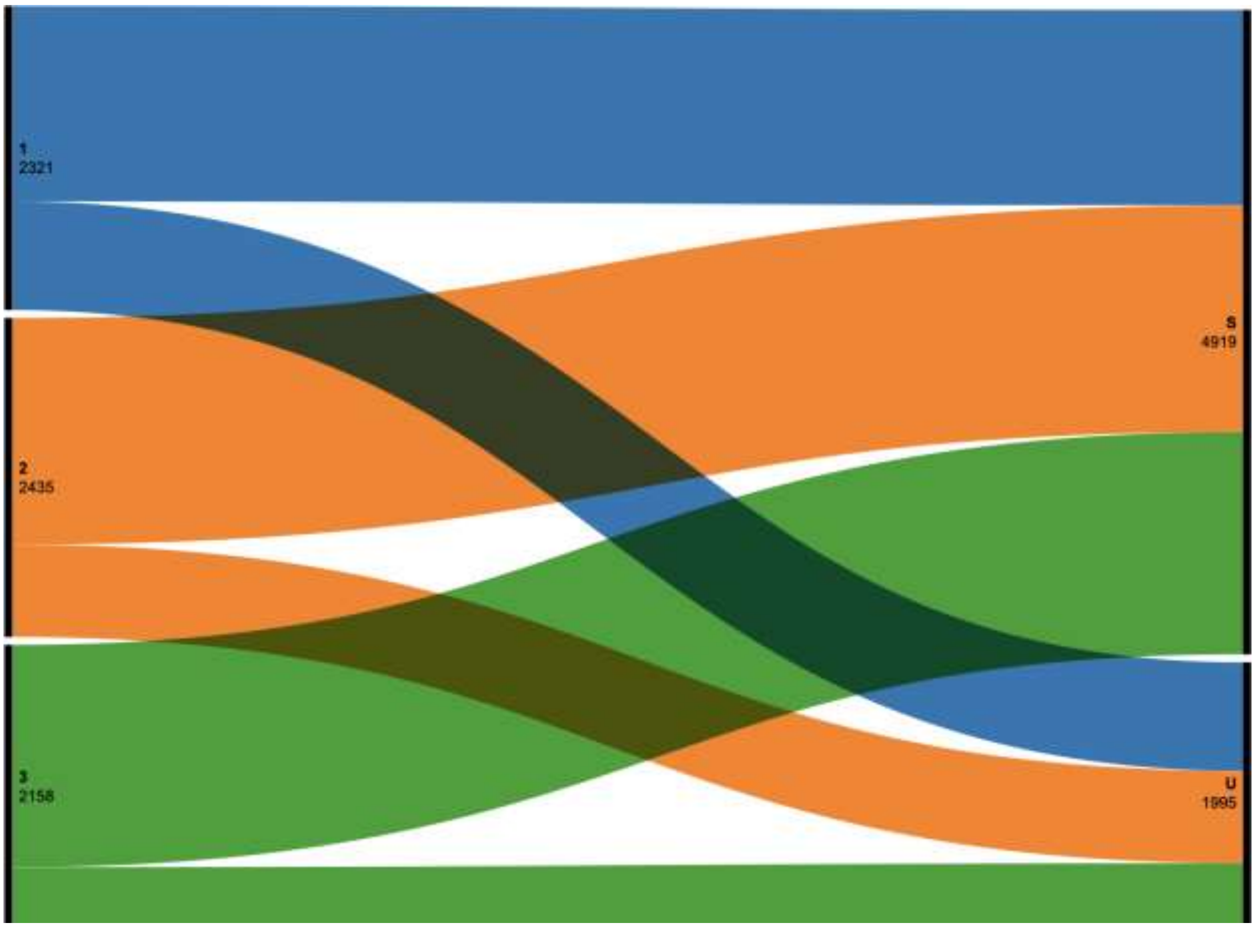
As the academic legacy extends, the mean of students' final course averages improves. There is a statistical difference in MUST averages and course averages between each legacy group ($p < 0.05$). Third-generation students entered with higher diagnostic MUST scores and completed the courses with higher course averages. Statistically more high school (HS) chemistry students completed an AP (Advanced Placement) chemistry course (0 = no HS chemistry; 1 = regular; 2 = pre-AP, and 3 = AP chemistry) if they were in the third-generation group than if they were in the first-generation group, but the only statistical difference is between first- and third-generation students. Students' current mathematics course enrollment also improves as the legacy the group increases with a statistically different comparison of all groups. This result is consistent with Mittag and Mason (1999) who reported that the best predictor for success in basic chemistry for non-Hispanic students was their prior mathematics level completed; prior mathematics level completed was the third best indicator for Hispanic students.

First-generation students enter their general chemistry course with the lowest MUST average of the three legacy groups evaluated and are the least prepared for their general chemistry courses due to having completed fewer (or only low-level) high school chemistry courses and having completed fewer (or only low-level) college-level mathematics courses. On average, first-generation students complete their course with a lower average (see Table 4) than do second- and third-generation students. In Figure 4 focus on the S/U bar (right side) for the unsuccessful students and note that a smaller percentage of these students come from academic legacy group 3 (third-generation students, green river) and that a larger percentage of the U group is from group 1 (first-generation students, blue river). Table 5 provides the data to support the various ethnic populations. The largest percentage of first-generation students is the Hispanic group, and the smallest is the White, non-Hispanic group. The chosen order for the ethnicities is based on high to low MUST means (purple font). The MUST means align by ethnicity without exception from low to high depending on legacy generation expansion. Course averages match the trends of the MUST means except for the Black ethnicity (yellow highlight) where the Black's second-generation average is higher but not statistically different than the Black's third-generation group. Also of interest is that the Asian group's first-generation population percentage is only exceeded by the Hispanic first-generation percentage but yet Asians have the highest overall MUST mean (Table 3) and this trend continues with each legacy population (Table 5). This is a curious finding and supports acceptance of a college-going culture as a very important contribution to student success. It is also possible that Asian students might have misunstood the demographic question regarding academic legacy and thought that the family's education had to be from a four-year institution in the US.

Interestingly, the alluvial diagram (Figure 5) shows that very few students from group 3 are enrolled in Chem 1 and Chem 2 off-sequence courses compared to students who enroll in the on-sequence courses but there are fewer third-generation students in the off-sequence courses. Taking these data to the course completion outcomes (S = successful; U = unsuccessful), about 50% of both off-sequence course students are U. In both on-sequence courses, there is a greater percentage of S students than U students with this trend being greater for Chem 2. About 50% of each of the off-sequence courses, students are U, but in the on-sequence courses, about 2/3 of the Chem 1 completers are S, and over 3/4 of the Chem 2 students are S.

Figure 4

Academic legacy groups 1 (first generation), 2 (second generation) and 3 (third generation) and links to successful (S) and unsuccessful (U) outcome groups.



Hispanic Students (*n* = 2,340) Results

Do Hispanic students migrate towards attending HSIs or eHSIs?

A majority of the Hispanic students in this study (*n* = 1,344/2,340 = 57.4%) self-report that they are first-generation students (Figure 6, top blue river on left). As can be seen on the right bar of Figure 6, more Hispanic students in this study are enrolled at eHSIs than HSIs with over 50% of enrollees at each of the HSIs and eHSIs being from the first-generation group. The distribution of the academic legacy groups is similar for the Hispanic student population at both HSIs and eHSIs in the studied cohort. These data probably indicate that Hispanic students are more likely to remain closer to home than purposefully attend an HSI institution that might be farther away and require hours of commute.

Table 5

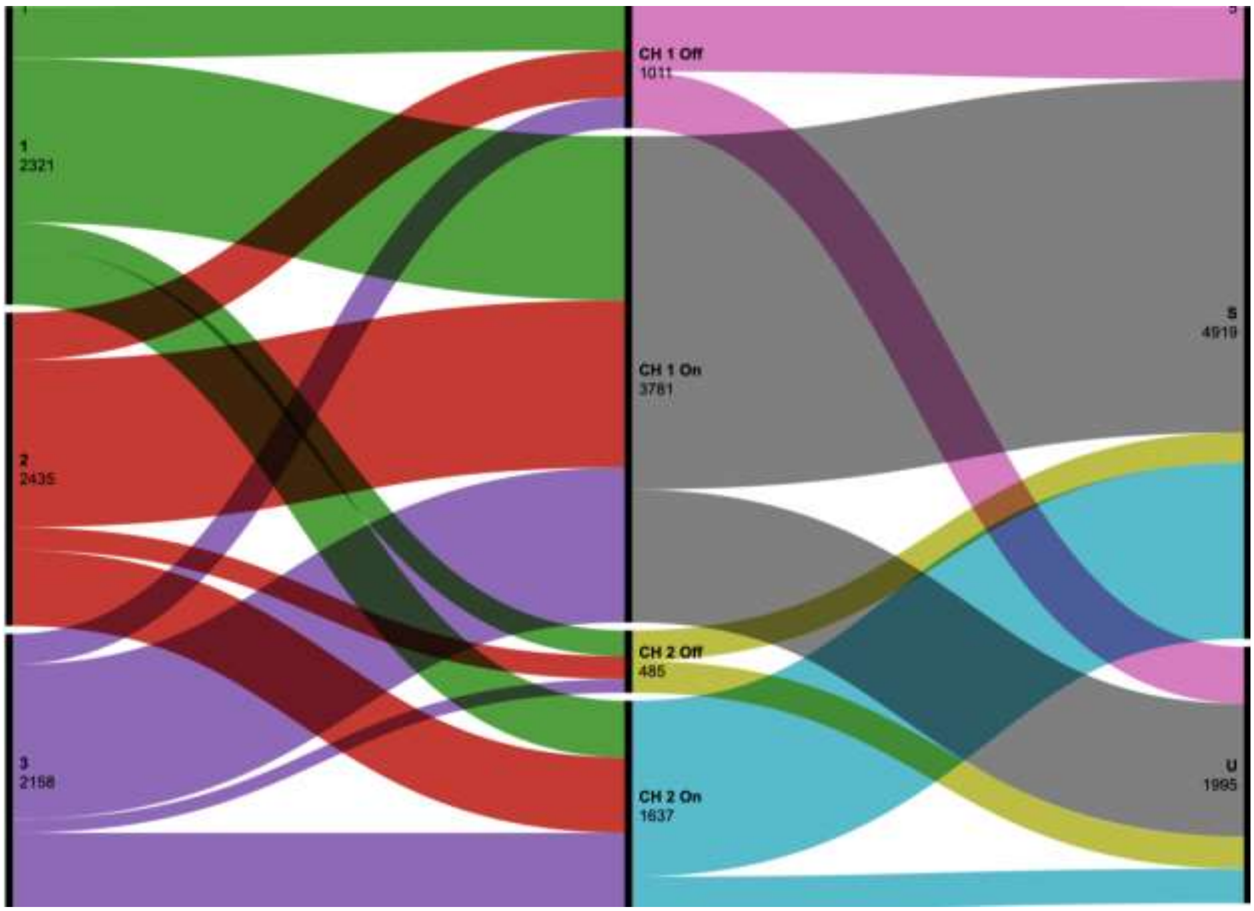
Ethnicity population data (N = 6,914): participation (red), MUST means (purple), and class averages (black) by legacy generation.

	Asian	White	Other	Hispanic	Black	
***n* 1st gen (%)**	209 (32.1)	488 (16.5)	99 (25.2)	1344 (57.4)	181 (31.3)	
***n* 2nd gen (%)**	292 (44.9)	1038 (35.2)	151 (38.4)	665 (28.4)	289 (49.9)	
***n* 3rd gen (%)**	150 (23.0)	1425 (48.3)	143 (36.4)	331 (14.1)	109 (18.8)	
Overall (%)	**651 (9.4)**	**2,951 (42.7)**	**393 (5.7)**	**2,340 (33.8)**	**579 (8.4)**	**6,914**
MUST Mean (max = 20)						
1st gen	10.9	8.8	7.7	7.6	6.6	
2nd gen	12.1	10.1	8.8	8.5	7.4	
3rd gen	13.3	10.9	9.4	9.9	7.9	
Overall	**12.0**	**10.3**	**8.7**	**8.2**	**7.2**	**High to low**
Class Avg %						
1st gen	78.7	74.2	70.7	72.2	68.9	
2nd gen	81.3	77.4	75.9	74.2	70.1	
3rd gen	82.9	80.0	76.7	77.4	69.7	
Overall	**80.8**	**78.1**	**74.9**	**73.5**	**69.7**	**High to low**
Grade	**B**	**C**	**C**	**C**	**C**	

Note. Highlights: blue—MUST means and class averages are not aligned; green—MUST means and class averages are aligned even though not in the same numerical order as 1st and 2nd generations; yellow—not in numerical order from low to high for Black's generational status but not statistically different.

Figure 5

Academic legacy groups (1, first generation; 2, second generation; and 3, third generation) (left bar) and the courses in which students (N = 6,914) are enrolled (middle bar) linked course completion results (right bar) (S, successful and U, unsuccessful).

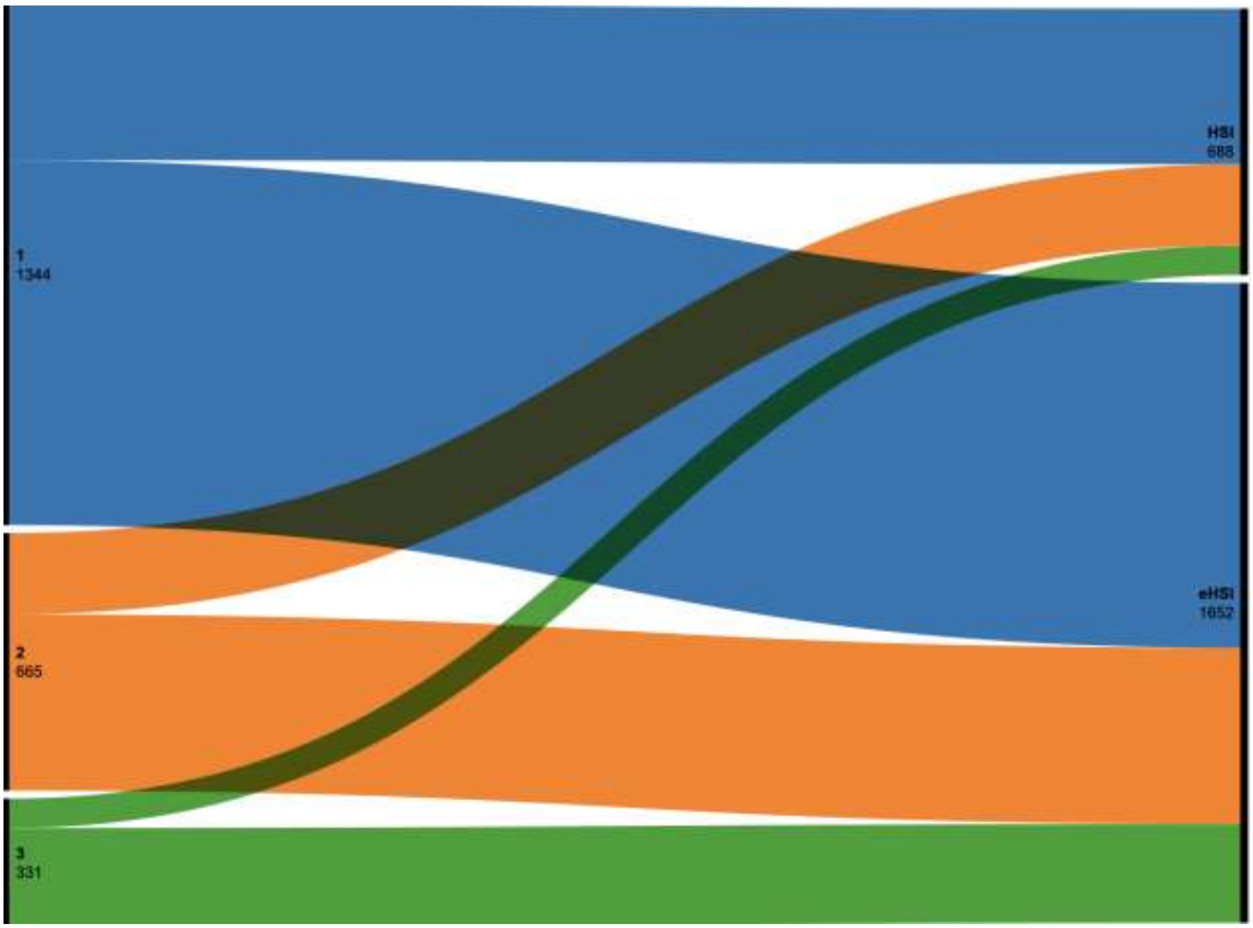


How predictive is the MUST in determining Hispanic students' course success?

The left bar of Figure 7 represents the score ranges from Table 3 for Hispanic students' MUST results. Consistent with the overall results for the *N* = 6,914 (Figure 3), if a student scores in the above MUST average range, there is only a small chance that they will be in the U section of the right bar of Figure 7. The Hispanic students in this study totaled 2,340/6,914 = 33.8% of the study's population. Of the Hispanic students, 808/2,340 = 34.5% are unsuccessful in their general chemistry course (earned a D or F). For the total population (all ethnicities included), about 29% are unsuccessful. Removing the Hispanics students from the overall population, the U rate for the other ethnicities combined falls to 26.0% based on 1,187 U non-Hispanics/4,574 non-Hispanic population (a drop of 8.5%). Table 3 gives the MUST mean for the overall population of (9.4/20 = 47.0% correct) and the MUST mean for the Hispanic students in the study of 8.2/20 = 41.0%. It is not surprising that students who enter with poorer automaticity skills complete the courses with a larger percentage of U students.

Figure 6

Hispanic students (n = 2,340) legacy groups of first-, second-, and third generation (left bar: 1, 2, and 3) and their university HSI and eHSI groups (right bar).

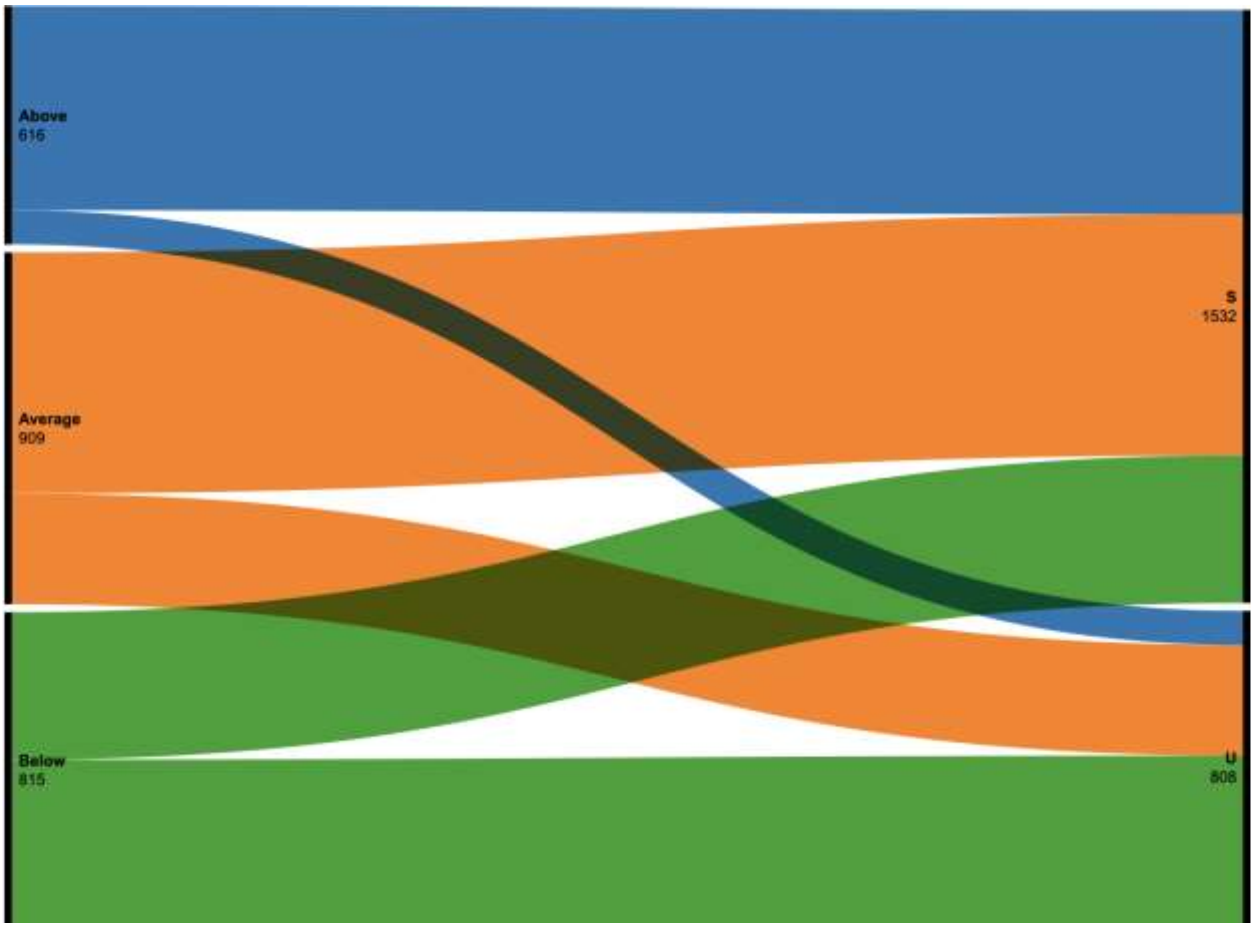


When academic legacy groups are considered, how do Hispanic students' entering automaticity skills affect course success?

Figure 8 depicts that of the first-generation students (almost 60% of *n* = 2,340), only a small percentage score above average on the MUST (middle bar). For those who do score above average on the MUST, very few are unsuccessful (right bar) in their course. Most of the D and F students are students who score below the average range on the MUST with most of these students being first-generation students and less than 10% being from academic legacy group 3 (third-generation students).

Figure 7

Hispanic students (n = 2,340) MUST ranges (left bar: above, average, and below) and course success (right bar: S = successful, U = unsuccessful).

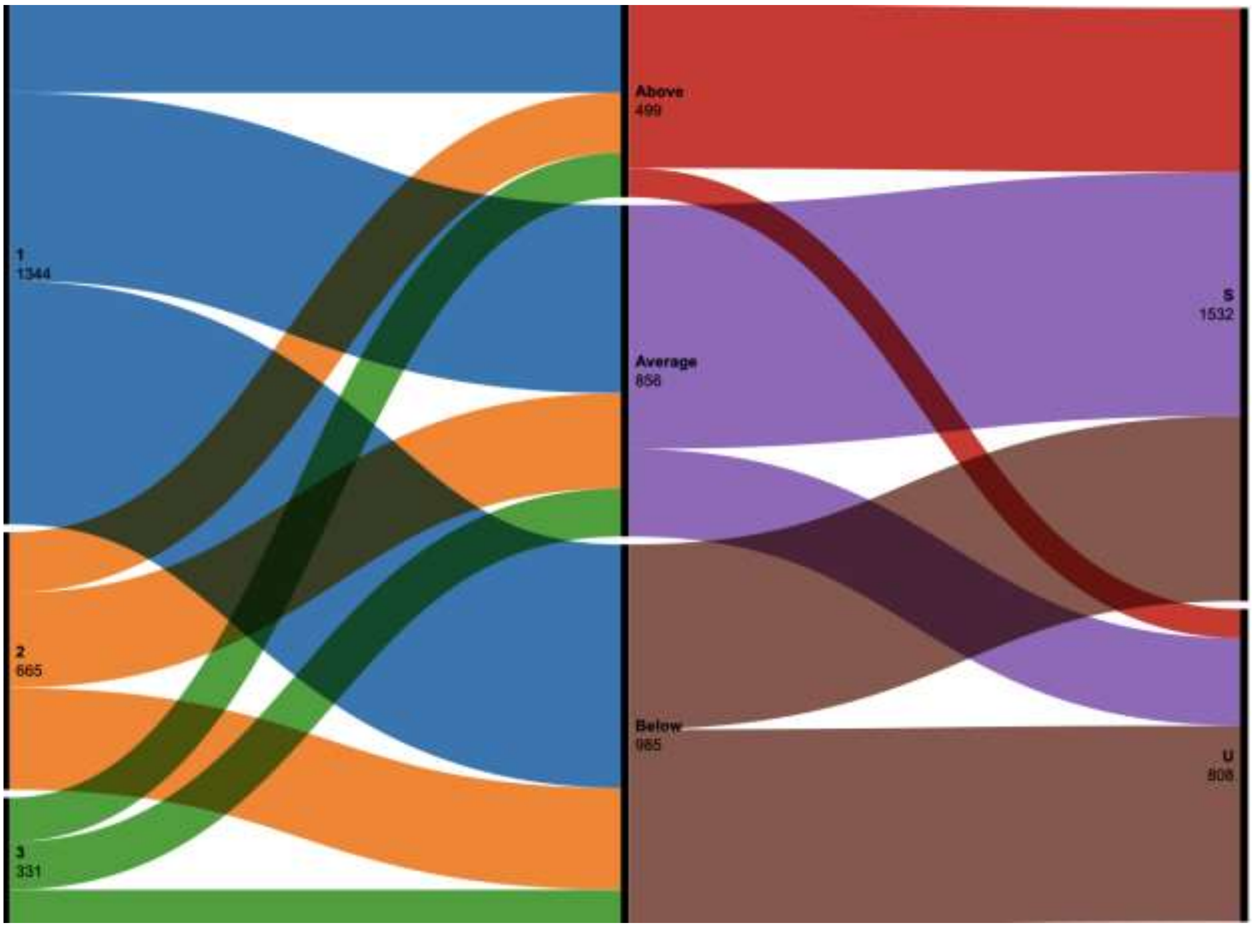


Are first-generation Hispanic students continuing to enroll in the general chemistry sequence (Chem 1 to Chem 2) at the same rate as the other ethnicities?

Comparing Figures 5 and 9, it is obvious that the Hispanic student group has a larger percentage of first-generation students than the overall population reviewed (1,344/2,340 = 57.4% *vs.* 2,321/6,914 = 33.6%, respectively). Removing the Hispanics from the overall population (*n* = 4,526), first-semester general chemistry (on- and off-semesters) supports virtually the same large enrollment percentages ([2,486 + 672]/4,526 = 69.8% and [1,295 + 339]/2,340 = 69.8%, respectively), but second-semester general chemistry (on- and off-semesters) indicates that the Hispanic students are not continuing with the suggested sequence [1,138 + 278]/4,526 = 31.3% (non-Hispanic) vs. [499 + 207]/2,340 = 25.8% (Hispanic). As previously mentioned, the ACS has noted the decline of URM continuing with chemistry courses and has expressed concerned about this lack of progress in the suggested pipeline towards undergraduate STEM degrees and graduate school enrollment.

Figure 8

Hispanic legacy groups (left bar, 1-3), MUST score ranges (middle bar), and course completion success (right bar, S and U).

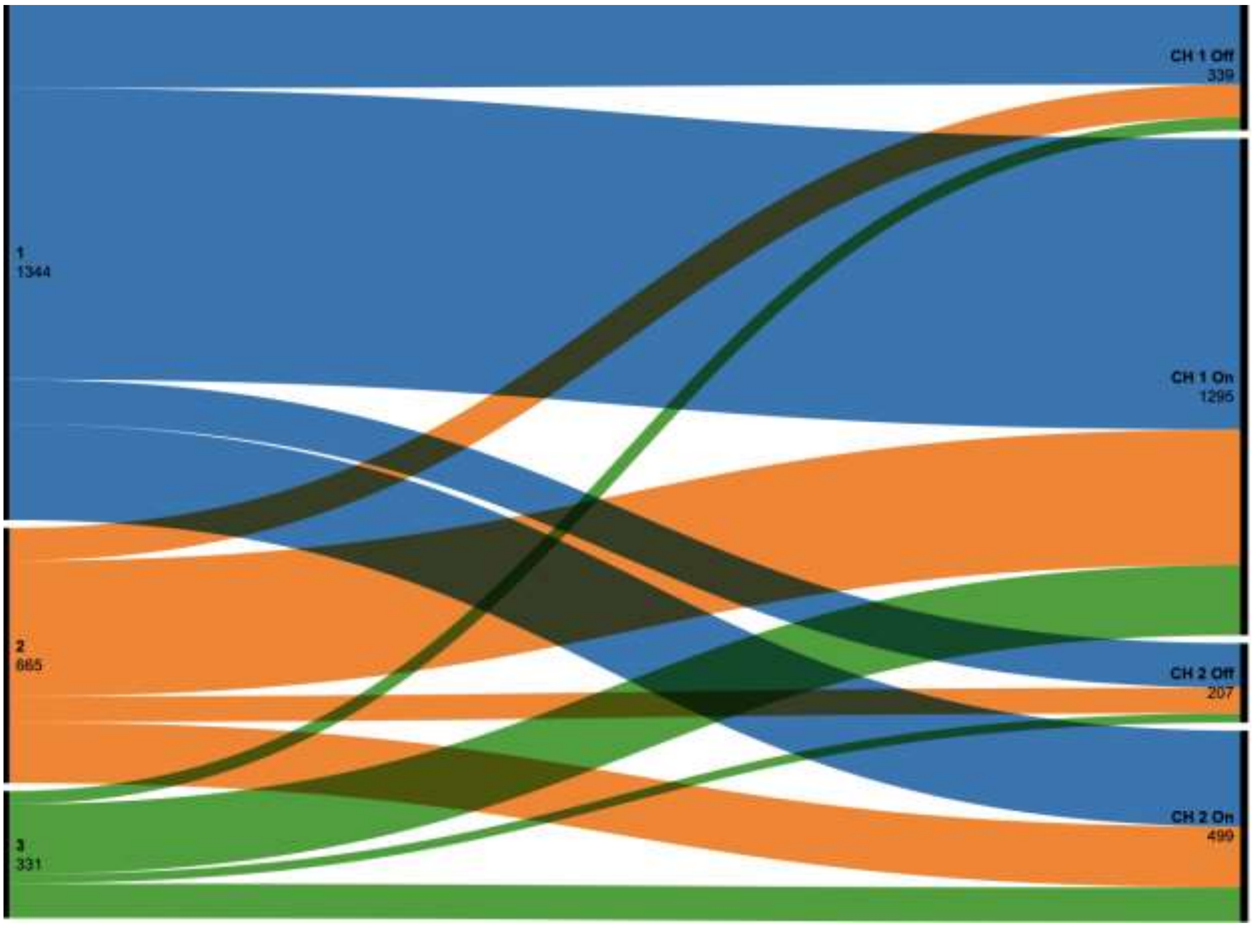


How does Hispanic student enrollment in Chem 2 compare to that of non-Hispanic students?

The enrollment of Hispanic students attending HSIs vs. eHSIs and which general chemistry course they attend is displayed in Figure 10. Students from an HSIs and eHSIs (left bar) enroll 1,295 + 339/2,340 = 69.8% in Chem 1 on- and off-sequence general chemistry (right bar). Hispanic student enrollment in Chem 2 on- and off-sequence courses falls to ([499 + 207]/2,340) or 30.2%). The overall non-Hispanic population starts with (2,486 + 672)/4,526 students = 69.8% and supports relatively the same number of students (1,138 + 278)/4,526 = 31.3% continuing to Chem 2 on- and off-sequence courses. These data continue support that Chem 1 is considered to be a "killer" course (Rowe, 1983) for future STEM majors regardless of ethnicity.

Figure 9

Academic legacy groups 1-3 (first – third-generation students) and their matriculation through completing Chem 1 and Chem 2 on- and off-sequence courses.



Discussion

This study aims to establish relationships between students' academic legacy as influenced by their prior knowledge and their final course averages. The 15-min. MUST provides educators insight into students' potential struggles and outcomes the first week of classes. The correlation between the MUST and course averages is moderate ($r = 0.450$). Still, the data reflect a significant consistent pattern reported in multiple studies as previously noted. The advantage of using the MUST as an assessment is that results are produced as soon as the assessments are graded unlike the national standardized entrance exams more commonly used as measures of academic preparedness. As more colleges become entrance-exam optional, the MUST may fill a void in assessing incoming student readiness for chemistry coursework. Of course, the exact underlying causation is not possible to discern, but from the authors' experiences many students have become too dependent upon calculating devices limiting the number-sense mental skills needed for attaining STEM degrees and subsequently careers in today's global market. Students' lack of math-fact automaticity begins in elementary school with the major contributor to this problem being the use of a calculator. Our data support that of Wicks and Pruneda (2023), who prognosticated that "Too many Texas students do not have the knowledge and skills to succeed in their next grade, much less in the workforce".

Figure 10

Hispanic students enrollment in HSIs and eHSIs (left bar) and general chemistry course enrollment (right bar).

The students' "circle" of influence (social network) comes from peers, parents, social media, bosses, etc. Choosing a course of study in chemistry, noting that there is a significant decrease in enrollment between Chem 1 and Chem 2, is a daunting academic path for many students especially when they do not see the value of getting a STEM degree. Faculty need to develop methods for communicating with students to make learning more culturally responsive (Gay, 2018). One of the current national programs is the use of systems thinking, where in addition to teaching the standard content information related to chemistry (still a major part of the whole) other connected parts are brought into the curriculum to emphasize chemistry's broader influence. Other programs being used by instructors in this study are smaller special classes of TIP scholars at an R1 university (mentioned above), removing calculators at predetermined times, and teaching students about acquiring an open mindset (like that promoted by Carol Dweck). A more in-depth discussion is warranted to determine how to create deeper-learning models based on Dweck's open-mindset to encourage and challenge students to learn to evaluate their answers to exercises before accepting them as correct.

Life beyond academia will grow with personal communication between students and other circle influencers. Students who have college-educated grandparents and parents are more likely to have access to more educational resources (e.g., books and technology) and have greater access to personal and institutional advising that can encourage success. They are also more likely to have significant financial resources that offer multiple advantages including having feelings of being more prepared to succeed (Table 4). Feelings of preparedness stem from individual factors that may be the result of modeling other family members' behavior such as: holding cultural value in attaining an education as a positive outcome, an improved motivation to succeed, a better grasp of the need of good study habits, and a healthy level of self-esteem. Supportive social networks provide students with persuasive role models, access to internships and employment opportunities after graduation, and if bilingual may provide employers with unique toolboxes. Language skills and language barriers are more common among Hispanic students and may affect students regardless of legacy group membership. In a state like Texas, all students should be encouraged to become bilingual in both English and Spanish. Studies predict that by 2050, 50% of the US population will be populated by many under-resourced minority students who speak Spanish as a first or second language (McGee, 2019). Predictions also include that more than half the jobs in Texas by 2050 will require some type of postsecondary education (Reardon et al., 2010) and others project that even sooner, 70% of the jobs in Texas will require postsecondary credential(s) by 2036 (Wicks & Pruneda, 2023).

Another reason the data presented in this report are important is in response to the latest Supreme Court of the United States (SCOTUS) decision that race and institutional legacy cannot be part of a university's application process. Yes, the data in this study are reported in terms of the various ethnicities, but they also reflect how academic legacy of students accepted to Texas universities mirror the population of the state. If this study was repeated in other states, the expectation is that the percentages of that state's minority population would also be adequately reflected simply by asking all students about their parents'/guardians' and grandparents' four-year degree accomplishments. Over 90% of the students surveyed for this study, attended high school in Texas and continue their Texas residency for their post-secondary education. The query in this study gathered data on whether close relatives held a four-year degree and not where the degree(s) were from. This legacy-question probe differed from the one ruled on by SCOTUS because where grandparents/parents attended was not important, only that one or more generations held a completed four-year university degree was of interest to this line of research and all ethnicities were equally impacted.

General chemistry is considered a high-risk course due to having a high DFW rate that may be as high as 50% (Reardon et al., 2010) and many studies have reported an over 30% DFW rate for many years as mentioned above. Chemistry is a gateway course for most all STEM majors. College graduates earn higher salaries, live longer, have better health care, and have an overall better quality of life, which is required in a globally competitive world (Habley, Bloom & Robbins, 2012). Post-secondary education needs to be prioritized because degreed students develop valuable new skills and attain better critical problem-solving abilities, gain experience as leaders, and increase the likelihood of success after graduation because they become more competitive (Johnston, 2017).

Totally removing calculators from K-12 grade classes in today's world is impractical, but this study adds credence to the findings of Baker and Cuevas (2018). According to these authors, the popularity and dependence on the use of calculators in grades 3, 5, and 8 lessens the likelihood of retaining and committing mathematics facts to memory placing their future success in jeopardy. High school teachers need to encourage students to learn to judge their solutions to exercises without focusing on the numerical answers to their problems—in other words, it is key for high school students to understand the functions behind the calculators, the procedures behind the numbers, and not just blindly memorize processes to attain a numerical answer.

Limitations and Strengths

The major limitation of this study is that it reflects the preparation of only Texas students and their success in general chemistry courses. Data collection was limited to the students who signed the IRB release and completed their respective courses—students who withdrew for any reason including failing grades and students who received incomplete grades were not included in the data analyses. Texas is one of the largest states in the United States and hosts a larger minority population than most states. The strengths of this manuscript lie in the facts that compiled data are from a six-semester study with almost 7,000 general chemistry students who attended multiple universities characterized as large to small, private and public, hold various Carnegie classifications of R1, R2, etc., and are located in a range of locations from small rural towns to major metropolitan areas. The margin of error is always inversely proportional to sample size. Because this report is a multi-year study and serves a large population, the margin of error should be small and reflective of a larger whole. Results are expected to be more reliable and generalizable than those drawn from a single class, single institution, or single semester. Survey data are self-reported, but these data are reported the first week of classes before biases created by class experience might impact responses. Students mature and change over a semester, so these data only reflect a "snapshot" of the first days of class before any content examinations have been administered.

Conclusions

In this study, students are characterized as to their academic legacy based on whether their grandparents and/or parents held four-year degrees. The results of the diagnostic MUST clearly differentiated between first-, second-, and third-generation students' academic legacy and are aligned with students' final course averages. There appears to be a strong correlation between students' academic legacy and their success in general chemistry with students of the third generation (grandparents and parents hold four-year degrees) significantly outperforming traditional first-generation students. The results clearly support that the MUST is a good assessment tool to use to identify students who will succeed in lower-division chemistry classes. The research that remains is how do students enrolled in other STEM and non-STEM courses perform. The students who performed in the above average range on this 20-question, calculator-free, open-ended quiz for the most part succeeded in their courses (Chem 1, Chem 2, and O-Chem I). The students who performed in the below average MUST range had a much greater chance of not being successful. First-semester general chemistry students across the board continue the course sequence to second semester at a rate of only about 30%, but when the legacy status of the Hispanic students (n = 2,340) is considered, first-generation Hispanic students continued the course sequence at a lower rate of about 25%.

Success in general chemistry is the gateway to many careers. With declining SAT scores (Figure 1) and showcased lack of automaticity skills, the overall population needs better secondary preparation for university-level courses and calculators need to be removed from most secondary-school courses until basic arithmetic skills have been overlearned. In this study, the Hispanic students entered general chemistry courses with below average MUST scores compared to the Asian, White, and "other" student populations with the major influence being the lack of success of first-generation students who entered with weaker prerequisites from high school chemistry and current mathematics enrollment that influenced their completion of the courses with a statistically lower average ($p < 0.05$) (Table 4). Prior knowledge is and will also be the greatest influencer of the students' success in their next course (Shell et al., 2010). It is also of note that more first-generation students, the ones who need the most help of all ethnicities discussed have the greatest feeling of being unprepared to succeed and are the students who have the highest outside employment record supporting the need for more funding to support these students, so they do not have to work to remain in class. Texas Higher Education funding is considered discretionary as based on “formula funding” decreed by the lawmakers as to allocations based on what remains after the required payments are covered. These decisions impact students pursuing STEM degrees who must work and contribute to their higher risks to retention (Wilkerson, 2008).

Digital natives (those who have grown up with technology) are changing how information is transmitted, perceived, and shared, but this change may also be a source of students' lower automaticity ability and their inability to retain the well-known procedures behind basic arithmetic calculations. More funding is needed to support students' financial needs and students should be given opportunities to overlearn known basic arithmetic procedures with deliberate practice of the number-sense skills needed to succeed in chemistry. The MUST can serve as a measurement tool for identifying students who may be at risk for lower scores in lower-level chemistry courses. The MUST results allow the instructor to identify students of all ethnicities and academic generations who are in the greatest need of additional help on the first day of class in only 15-min. for the cost of one sheet of paper.

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