



## Is the STEM Gender Gap Closing?

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**Abstract:** The Networking for Science Advancement (NSA) team's institutions consist of nine universities located in one large southwestern US state. This study evaluated students enrolled from Spring 2017 to Fall 2019 in first- and second-semester general chemistry. Over 90% of the students ( $n = 6,694$ ) have been exposed to a secondary school isomorphic curriculum. The population studied, Chem I ( $n = 4,619$ ) and Chem II ( $n = 2,075$ ), met entry-level criteria and are therefore expected to succeed (i.e., earn grades of A, B or C). This study's focus is to disaggregate data based on binary gender (M/F) in hopes of revealing patterns that might remain hidden when studying an undivided population. In Chem I, the female population was 59.6% and increased to 64.5% for Chem II. The 15-min., diagnostic Math-Up Skills Test's (MUST) scores identified about half of all students who were unsuccessful (grades of D and F). Results from the study support that males enter Chem I and II with better automaticity skills (what can be done without using a calculator) than females. However, females outperformed males on course averages in Chem I but not Chem II. Our data provide supporting evidence that the gender gap may be closing.

**Keywords:** *Arithmetic Automaticity Skills; Diagnostic Assessment; Diversity Issues; Gender; General Chemistry.*

### Introduction

Differences in science achievement between males and females until adolescence are virtually

nonexistent, but then the gap appears to widen as students age (Yeziarski & Birk, 2006). The collective concern is that we lose competent STEM-oriented

girls in middle school fundamentally impacting their future career choices. The lack of strong academic K-12 preparation, particularly in mathematics, is a reported detriment to STEM success (Carver et al., 2017; Yager, 1988). Another stumbling block reported for students to become a STEM major is success in general chemistry courses where unsuccessful grades of D, F, and withdrawals many times exceed 30% (Blanc et al., 1983; Rowe, 1983). Part of tackling this complex problem is developing a clear profile of females and males who successfully continue along a STEM-career path. Innumerable studies have addressed the demographic of gender, but rarely do studies disaggregated on specific STEM disciplines (Sax et al., 2017) or on gender or ethnicity to investigate their possible effects on variables (Cooper & Snow, 2018; Habley et al., 2012). The focus of this study concerns the success of students who identify as male and female in general chemistry I and II (Chem I and II), two of the most prominent and career-determinant gateway courses required for most STEM majors (Cohen & Kelly, 2019). While some students self-identified as non-binary for gender, this group was too small to report on while maintaining confidentiality. Previous studies by the Networking for Science Advancement (NSA) team have reported that students' automaticity ability (what can be done without the aid of a calculating device), as measured by an easily administered diagnostic test named the MUST (Math-Up Skills Test), correlates well with students' success in general chemistry courses (Albaladejo et al., 2018; Mamiya et al., in press; Petros et al., 2017; Powell et al., 2020; Villalta-Cerdas et al., in press; Weber et al., 2020; Williamson et al., 2020). In this study from a majority-minority state, the MUST is used to highlight male and female students' entering automaticity ability and understand how these skills

are linked to Chem I and II course success when data are disaggregated on gender.

## Literature Review

Gateway classes can be critical to students' success. They are intended to help improve students' basic preparation, provide a foundation for and persistence in an intended major, and affect transfer and graduation rates (Cohen & Kelly, 2019). For typical science majors, general chemistry (a challenging STEM gateway course) is considered a freshman-level course, although enrollment may be delayed due to inadequate background preparation, fear of registration due to its reputation, or improper enrollment due to lack of suitable advising. Additionally, general chemistry courses are typically high-enrollment courses, usually made up of an eclectic group of students with non-homogeneous socioeconomic, cultural and educational backgrounds. Perhaps linked to the issues, general chemistry is often associated with declining retention and persistence in STEM-related fields (Cohen & Kelly, 2019). Poor performance in introductory STEM courses (like general chemistry) may lead to a student changing to a non-STEM major or completely withdrawing from post-secondary education (Cohen & Kelly, 2019). STEM persistence is an important issue, especially in the context of underrepresented groups based on race and gender (Srinivasan, 2017). According to Villafaña-García (2015), it is important to study factors that could influence students' decision to stay in STEM. As such, identifying at-risk students at the beginning of the semester who are likely to have difficulties in such a course is an important yet challenging task (Wagner et al., 2002), which undoubtedly necessitates the development of directed intervention mechanisms to help struggling students.

GPA is a strong indicator of persistence (Sonnert & Fox, 2012). Low GPAs tend to affect the retention of men more than women (Perez-Felkner et al., 2019) but women with low GPAs reportedly simply switch to a non-STEM major (Sonnert & Fox, 2012).

Typically, underrepresented minority groups in STEM are members of the first generation in their families seeking a degree and female (Carver et al., 2017). The loss of talented women from the STEM pipeline has been widely recognized within science education as an important issue, particularly in the physical sciences (Harsh et al., 2012). In Cohen and Kelly's (2019) study, none of the demographic factors evaluated (gender, socioeconomic status, ethnicity) showed to be significant predictors of degree change. Still, they did find that the better a selected student did in chemistry, the less likely he/she would be to change to a non-STEM major (or in other words, the more likely to persist as a STEM major). Chemical engineering studies revealed that male students were more likely to retake a failed course while female students were more likely to seek a new major when they failed a chemistry course (Srinivasan, 2017), being consistent with the STEM research analysis of Sonnert and Fox (2012). Fink et al. (2020) identified that a student's sense of belonging in a learning environment, particularly for women in the physical sciences, can be used as a predictor of Chem I and II performance. In agreement with Cohen and Kelly (2019), Rüschenpöhler and Markic (2019) did not find gender to play a significant role in chemistry students' self-concepts. However, Halder et al. (2015) found that females performed better than males on factual knowledge questions and males outperformed females when comprehension (measured rules and principles) was tested; no statistical difference was found between

genders when conceptual knowledge (e.g., a terminology test) was evaluated.

Women and Hispanics withdrew at higher rates than men and non-Hispanics even though the course grades of women who completed the course were significantly higher on all exams grades than their male counterparts (Mason & Mittag, 2001). In 2009, National Center for Education Statistics (NCES) reported about 57% of college students were female (Habley et al., 2012) and in 2017, NCES continued to report that 57% of the total were female. Women and minorities remain underrepresented in chemistry bachelor's degree attainment in the United States despite efforts to improve their early chemistry achievement through supplemental academic programs and active-learning approaches (Fink et al., 2018). For example, in 1998, women accounted for 39% of the conferred US bachelor's degrees in the physical sciences (e.g., chemistry, physics, and astronomy), and by 2008, the percentage improved, albeit only to 41% (Harsh et al., 2012). Carver et al. (2017) surmised that even moderate increases in retention nationwide could generate enough needed STEM professionals to fill the current STEM openings, but this has yet come to fruition. In fact, over the past 40 years efforts to improve women's representation as research scientists have only led to modest increases in graduate degrees, and employed males still dominate STEM careers with less than 10% of science careers being occupied by females from minority backgrounds (Villafaña-García, 2015). Performance results revealed a degree-achievement gap between underrepresented minorities and white students in the control group, but with a population of 60% female, no gender-based gap was reported (Fink et al., 2018). The same study documented that in 67

countries/regions considered more gender-equal societies, the gender gap in bachelor-degree attainment was even larger (Fink et al., 2018). Perez-Felkner et al. (2017) reported that women attained more degrees in physics, engineering and computer sciences but remained highly underrepresented in these careers.

Early prediction of student performance in the classroom is an important educational research area (Cohen & Kelly (2019). The logistic regression model developed in a study by Cohen and Kelly (2019) predicted about 67% of the cases as to whether a student would remain a STEM major or seek a non-STEM degree and, importantly, students' performance in chemistry explained about 58% of the variance to change degree plans. Interestingly, the other sciences (e.g., biology and physics courses) did not have the equivalent impact on degree preference changes. In a study by Wagner et al. (2002), approximately 80% of the students who failed the first exam in general chemistry failed the course, but the most predictive background variable was found to be mathematics performance, followed by chemistry performance and age. The research by Carver et al. (2017) identified calculus as a "choke point" barrier to STEM success. Mathematics level completed was a powerful determinant for success in an introductory chemistry class in other research studies as well (Mason & Mittag, 2001; Petros et al., 2017; Powell et al., 2020; Williamson et al., 2020), where the higher the mathematics level completed, the higher the student's course average. Sax (2017) reported the top explanatory gender-gap variable for computer science students was mathematics skills where women rated themselves lower than men but this gap was weakening over the period of the study (1976-2011).

Other researchers confirm that women's mathematics ability is lower than men's and this lack of perceived ability along with a closed mindset hinders them from pursuing degrees in the highly sex-segregated physical, engineering, mathematics, and computer sciences (Perez-Felkner et al., 2017; Perez-Felkner et al., 2019).

Solutions to these difficult problems have been proposed by many. On their website, Hartman and Nelson (n.d.) reminded readers that beginners are not simply "little experts" and what is necessary is to return to prior education norms (before 1990s) like memorized arithmetic/mental-math facts (automaticity), memorized algorithms to circumvent working memory overload, along with employing chunking strategies when appropriate. They reported that learning mathematics and chemistry are especially difficult for many students and suggested that vocabulary and arithmetic basics need to be "overlearned" by students to help guarantee success. Some authors suggest institutional offerings of summer gateway courses to improve the high school background for students entering college for the first time (Fox, 1994). Fink et al. (2020) reported an almost 12% attrition from Chem I to II and noted that the students who persisted had better college-preparatory experiences (e.g., AP courses) and were the students who were less likely to leave after one semester. Other researchers suggested providing gateways for women interested in careers in chemistry and physics by offering more undergraduate research experiences (Harsh et al., 2012). Some researchers feel that appealing to providing women with higher levels of self-efficacy and improved outcome expectations will be the most beneficial to students (Miller, 2006; Srinivasan, 2017). Villafaña-García (2015) found that

black and Hispanic males have a negative chemistry course self-efficacy sense of self compared with white males. Fink et al.'s(2020) research found that female students, especially those from underrepresented minority groups, reported that feelings of lower belonging and higher uncertainty within the first weeks of the chemistry course impacted their course grades in mathematics and physics and had a marginal effect on Chem I grades. Even when women have positive attitudes toward fields like mathematics, negative stereotypes can hurt their interest and performance and influence all students' decisions about whether or not to continue the general chemistry course sequence (Fink et al., 2020). STEM course grades influence persistence (Perez-Felkner, Nix, & Thomas, 2017; Perez-Felkner et al., 2019; Sonnert & Fox, 2012).

## Methods

### Institutions

There are 38 public universities located in Texas with a total undergraduate enrollment of 658,219 where the female population exceeds male by 14.6%; 37.5% are considered of Hispanic descent and 12.2% of African American descent. Hispanic Serving Institution (HSI) designation is possible when the undergraduate population enrolls at least 25% Hispanic students. Six universities that participated in this investigation are considered Hispanic-emerging (e-HSI) institutions having a minimum of 16% Hispanic enrollment with the other three institutions recognized as HSIs (see Table 1). One of the HSIs is a large institution with an enrollment of more than 38,000 students. Two others are medium-sized schools with enrollments over 6,000; small schools have enrollments below 5,000 undergraduates (Tai et al., 2005) like the private school identified in Table 1. Given the wide variety of

institutions and the Hispanic-student population considered, the data evaluated give a representative view of a large majority-minority U.S. state and lend credibility to this study.

### Population

The population evaluated in this study consists of students enrolled in Chem I and II at nine Texas universities. The data contributors are all members of the NSA (Networking for Science Advancement) team from one of three Hispanic-serving or one of six Hispanic-emerging institutions. The population evaluated ( $n = 6,694$ ) studied enrolled students in Chem I ( $n = 4,619$ , 69.0%) and Chem II ( $n = 2,075$ , 31.0%). The female student population in Chem I and Chem II were  $n = 2,753$  (59.6%) and  $n = 1,339$  (64.5%), respectively. Some of the larger population of females in general chemistry can be accounted for by students' performance on the Advanced Placement (AP) Chemistry exam. It is typical for more women than men to be enrolled in Chem I because AP Chemistry exam results indicate that males are almost twice as likely to place out of Chem I and perhaps Chem II for performing at the highest score level of 5 (Perry, 2019), but scores on the AP Chemistry exam do not account for all of the approximately 60:40 split.

The demographic indicators collected were: gender, ethnicity, pre-college academic preparation (i.e., participation in one or more high school chemistry courses), mathematics course(s) concurrently enrolled or degree-requirement completed, parents' education, where students had lived during high school based on the first two digits of their reported zip code, and employment status. Over 92% of the students in this IRB-approved study who agreed to participate attended Texas schools before admittance into one of

the nine universities. The students evaluated were enrolled in Chem I and Chem II in both fall and spring semesters over a period of six semesters (Spring 2017 to Fall 2019). Students are considered to be on-sequence if enrolled in Chem I in the fall and Chem II in the spring semesters and off-sequence when enrolled in the opposite setting. In all cases, as expected, on-sequence students outperformed off-sequence students. Thus, data presented view how male and female students succeeded in each course regardless of semester chosen. The majority of the

participants in this study experienced an isomorphic high school curriculum as mandated by the state's education agency, so it is presumed that the majority of the students have similar academic classroom experiences when enrolled in equivalent classes and should be adequately prepared to enter Chem I. All Chem II students successfully (grades of A, B or C) completed Chem I and are therefore considered prepared for Chem II.

**Table 1**

*Description of Participating Institutions (THECB 2019 Report and Common Data Set info)*

Institution	Undergrad Enrollment	Hispanics Enrolled	STEM Undergrad Degrees (%)	6-year Graduation Rate (%)	Degrees awarded to Hispanics (%)	Accountability Group
Medium, public HSI	6,616	72.3%	16.0	n/a	67.9	Master's, PUI
Medium, public HSI	8,961	40.7%	13.0	n/a	35.7	Master's, PUI
Large, public, HSI	38,644	38.5%	13.3	64.2	34.4	Emerging R2
Small, private, e-HSI	3,538	16.6%	10.1	60.0	13.4	Doctoral
Large, public, e-HSI	12,072	21.8%	9.6	49.0	18.9	Doctoral
Large, public, e-HSI	21,025	24.2%	7.5	59.2	21.6	Doctoral PU
Large, public, e-HSI*	38,087	26.5%	14.7	59.5	22.6	Emerging R1
Large, public, e-HSI	51,684	24.5%	15.8	85.8	21.9	Research, R1
Large, public, e-HSI	63,694	24.2%	13.3	86.3	21.3	Research, R1

*Note.* \*Designated as an HSI in Fall 2020. Abbreviations: HSI = Hispanic Serving Institution, e-HSI = emerging Hispanic Serving Institution, Carnegie classifications: R1, R2 = Research university and level with "emerging" indicating that the full status has yet to be obtained, PU = Professional University, n/a = not available due to relatively new standing, PUI = Primarily Undergraduate Institution.

### Diagnostic Instrument

The original quiz that became what the NSA team named the MUST (Math-Up Skills Test) was generated by Hartman and Nelson (2015). The updated and current MUST is a 15-minute, calculator-free, hand-graded assessment with 20 open-ended

questions. It has a very large Cohen's *d* effect size of 1.43 and 1.20 for Chem I and II, respectively. The NSA Team has published the advantages of using the calculator-free MUST assessment to identify students early in the semester who potentially might struggle with the content of Chem I (Williamson et al., 2020) and Chem II (Powell et al., 2020). Items on the open-

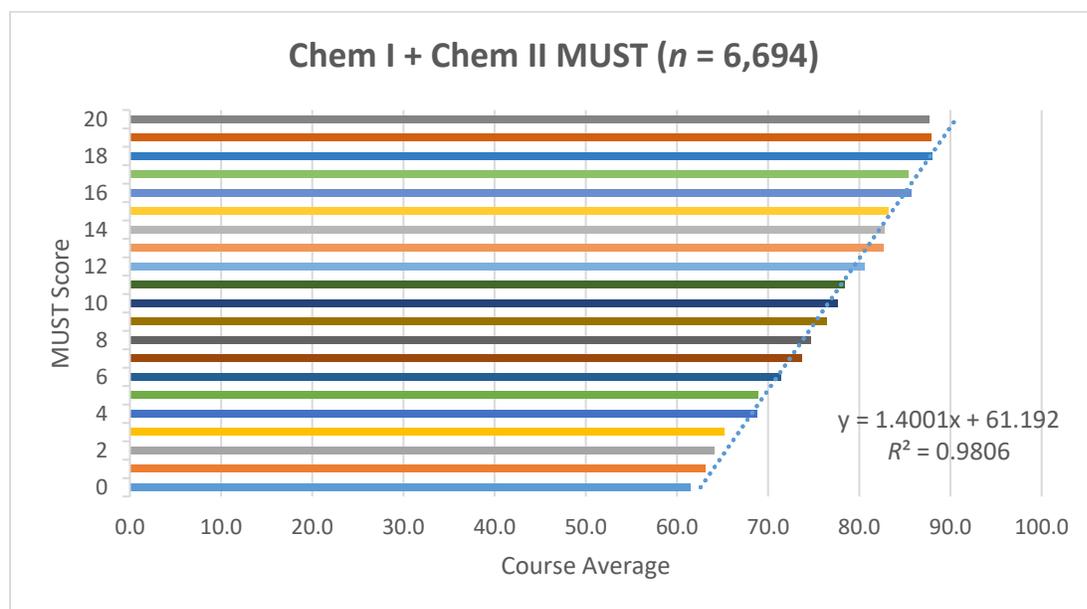
response MUSTs were scored on a binary scale as either correct (1) or incorrect (0). Since each response on the MUST has only one correct answer (the assessment is not multiple choice), the Kuder-Richardson formula 20,  $r_{KR20}$  (similar to Cronbach's alpha) is appropriate to determine the reliability of the MUST. Also, the MUST has consistently reported good reliability as it does in this study of 0.874. The practical use of the MUST has been well-established by the NSA Team (Petros et al., 2017; Albaladejo et al., 2018; Williamson et al., 2020; Powell et al., 2020), and its use in these research studies documents that students' entering-automaticity skills are valid predictors of how successful they will be in Chem I and Chem II. Each student's MUST score was a sum of the correct items on a scale of 0 to 20. The questions on the 20-item MUST can be grouped into five question categories: multiplication (questions 1, 2, and 3), division (questions 4, 6, 7, 8, and 16), fraction simplification (questions 9, 10, 17, and 18), logarithms

and exponents (questions 5, 12, 13, 14, and 15), and symbolic manipulation like balancing chemical equations, which is a form of counting (questions 11, 19, and 20).

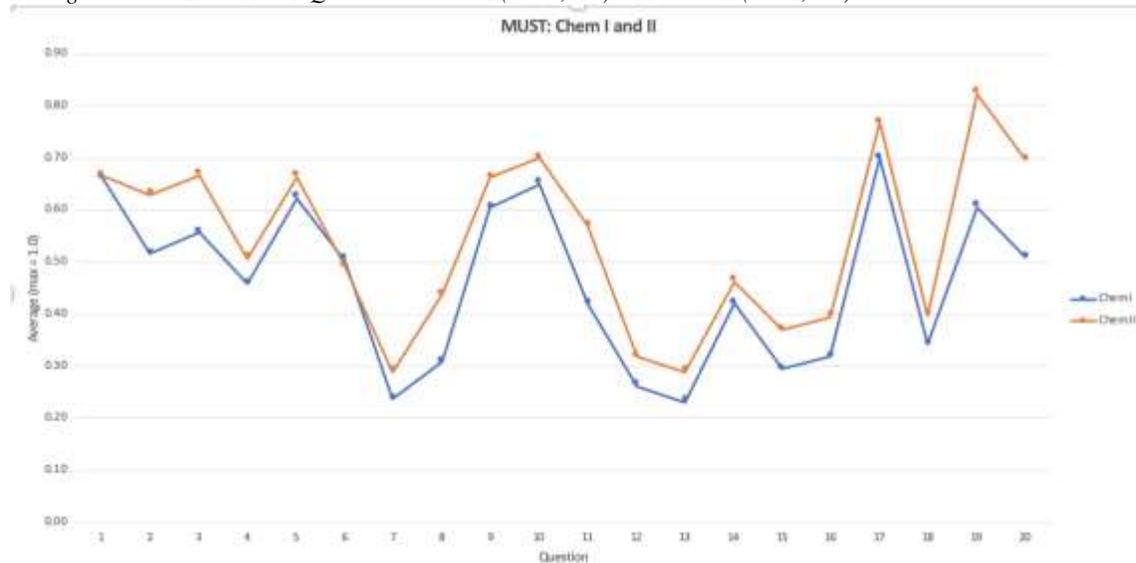
Figure 1 depicts the linear relationship between MUST scores and course averages for  $n = 6,694$ . In Figure 2, note the similar up and down flow of the averages on this diagram: students, independent of their institution, struggle with the same problems on the MUST diagnostic instrument indicating students bring similar understandings and misconceptions reflective of their pre-college backgrounds to Chem I and II. Figure 2 also illustrates that Chem II students perform at a higher automaticity level than Chem I students, but many of the same misconceptions still exist. Comparing group mean scores of Chem I and II students, in all cases males statistically outperformed females at the  $p < .05$  level (see Figure 3).

### Figure 1

*Course Averages Calculated for each Possible MUST Score (0-20 points) Illustrate a Linear Trendline*



**Figure 2**

Average Score on Each MUST Question in Chem I ( $n = 4,619$ ) and Chem II ( $n = 2,075$ )

Note. On all questions the Chem II mean was higher and on all questions except #1 (multiplication of two, 2-digit numbers) and #6 (dividing a fraction by a fraction), Chem II students statistically outperformed Chem I students ( $p < .05$ ).

### Research Question

At the end of the semester, final course grades (determined as a percentage of points earned out of total points possible) were collected for students from each class as an output measure (dependent variable) of course completion. The key inputs of concern in this study were gender, students' MUST score, and their relationship to final course averages.

How do students' entering arithmetic automaticity abilities as measured by the MUST correlate with their performance in Chem I and Chem II courses when examined by gender?

### Results

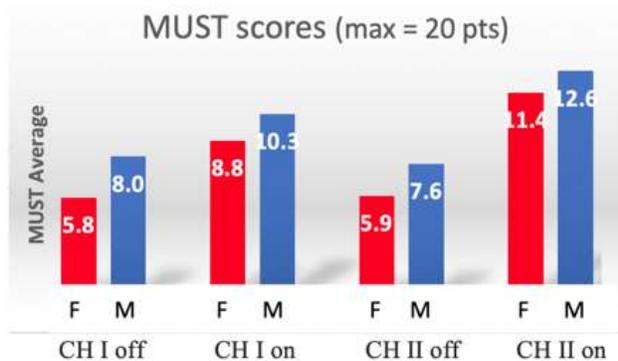
Figure 3 displays the performance on the MUST by gender for Chem I and II students separated into on- and off-sequence sections. Consistently, the on-sequence groups are statistically better ( $p < .05$ ) than the corresponding off-sequence groups. Data analysis shows that the Chem I and Chem II off-sequence

female students have the lowest mean MUST scores at 5.9/20 and 5.8/20, respectively. On average, female students in on-sequence Chem I scored 3.0 points higher than off-sequence female students and male students in on-sequence in Chem I scored 2.3 points higher than the off-sequence males. In on-sequence Chem II, the average score for female students was 5.5 points higher than that for off-sequence female students and the average score for male students was 5.0 points higher than the average MUST score for their off-sequence counterparts. Overall, male students who enrolled in Chem II during a spring semester (i.e., on-sequence males) had the best arithmetic-automaticity skills as measured by the MUST. Even though it might be anticipated that Chem II students would always have better automaticity skills than Chem I students regardless of enrollment semester, these data did not support this. These data show that those enrolled in Chem II off-sequence had substantially lower number-sense abilities as measured by the MUST where the off-sequence males

had a lower MUST average score of 7.6/20 points compared to the off-sequence Chem I males who averaged 8.0/20 points.

**Figure 3**

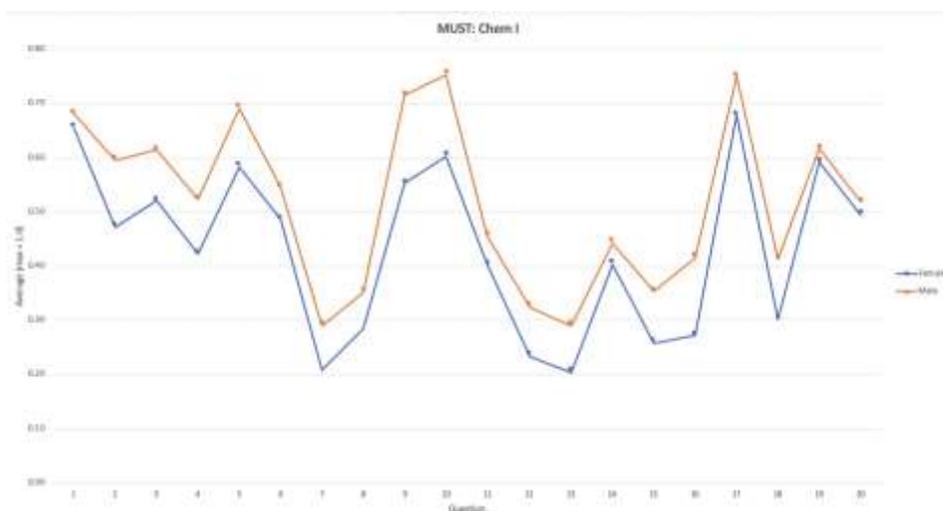
*Gender Differences in on- and off-Sequence in Chem I and Chem II*



*Note.* In Figure 3 each group males statistically outperformed females.

**Figure 4**

*Average Score on Each MUST Question for Chem I (n = 4,619)*

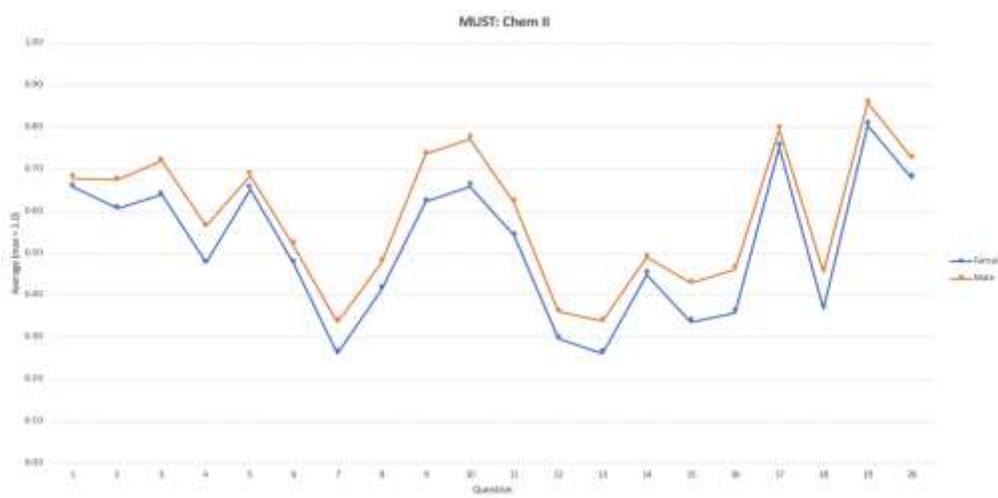


*Note.* On each question, the males' average exceeded that of the females' average.

Figures 4 and 5 compare male and female performances when the on- and off-sequence data are combined. When evaluating the difference between males and females in Chem I (Figure 4) and Chem II (Figure 5), the means for males were higher than for females for each question. The differences are statistically significant at the  $p < .05$  level for all questions except #1, #19, and #20. Q1 requires students to multiply two 2-digit numbers and Q19 and Q20 require students to balance chemical equations. For Chem II, statistical differences at the  $p < .05$  level exist on all but questions #1, #5 and #6. Q1 requires students to multiply two 2-digit numbers, Q5 requires raising a number to the zeroth power and Q6 requires simplifying a complex fraction and reporting the answer as a decimal equivalent.

**Figure 5**

Average Score on Each MUST Question for Chem II (n = 2,075)



Note. On each question, the males' average exceeded that of the females' average.

Table 2 is aligned by the groups' MUST scores from low to high and reports the means, standard deviations (*SD*) and standard errors of the mean (*SEM*) for the MUST scores (maximum = 20.0 points) of Chem I and II students by gender. Each group (Chem I males and females, Chem II males and females) are statistically different from each other on the MUST and course averages. Chem I and Chem II males outperformed the corresponding female classmates on the MUST, and Chem II students outperformed Chem I students on the MUST and course averages. The italicized course average for Chem I males is the only mean not in alignment with the others but it also has the largest *SD*. In Chem I, 59.6% of the population was female and this percentage increased to 64.5% for Chem II enrollment. The retention of females being about 5% higher may be a reflection of the fact that their course averages in Chem I were also higher providing them with a stronger "belonging attitude" as discussed above.

Most students (98%) report to have taken at least one high school chemistry course; according to the state's curriculum for college-bound students, physics may also be taken to satisfy the science requirement. One of the most striking demographic characteristics collected from the students was the mathematics course in which they are currently enrolled. Table 3 lists these data aligned by the percent of students who have met the mathematics prerequisite. The universities composing the NSA team are not consistent with required prerequisites and some do not have specifically published requirements. It was agreed upon by the NSA team that completion of college algebra was the appropriate prerequisite for Chem I and completion of pre-calculus was appropriate for Chem II. The students' self-reported data indicate that males were at least 10% more likely to have met these prerequisites than female students. The percentages of first-generation students (i.e., those whose parents have not earned a 4-year degree) were close to 30% in each course group with the exception of Chem I female students who comprised 35.3% of

the population. Approximately a third of the population in each group is comprised of students of Hispanic heritage, with comparable numbers of male and female Latinx students, but the decline in the

percentage of Latinas from Chem I to II of 3.1% compared to the percentage 1.8% increase of Latinos is of interest.

**Table 2**

*Diagnostic Assessment Means (low to high) and Course Averages*

Groups <sup>a</sup>	<i>n</i>	Percent (%) female	MUST ( <i>SD</i> ) ( <i>SEM</i> )	Course ( <i>SD</i> ) ( <i>SEM</i> )
Chem I Female	2,753	2,753/4,619 = 59.6%	8.3 (4.95) (0.094)	75.4 (16.3) (0.310)
Chem I Male	1,866	1,866/4,619 = 40.4%	9.7 (5.18) (0.120)	74.4 (18.1) (0.418)
Chem II Female	1,339	1,339/2,075 = 64.5%	10.1 (5.11) (0.140)	77.3 (14.5) (0.397)
Chem II Male	736	736/2,075 = 35.5%	11.5 (5.03) (0.185)	79.8 (15.3) (0.564)
Chem I (M & F)	4,619	4,092/6,694 = 61.1%	8.8 (5.09) (0.062)	75.0 (17.0) (0.250)
Chem II (M & F)	2,075		10.6 (5.12) (0.010)	78.2 (14.8) (0.326)
Overall	6,694		9.4 (5.16) (0.063)	76.0 (16.4) (0.201)

*Note.* <sup>a</sup> $p < 0.05$  Chem I females outperformed Chem I males on course averages but entered with lower MUST scores. Chem II males outperformed Chem II females; Chem II students outperformed Chem I students.

**Table 3**

*Selected Demographics*

Groups	<i>n</i>	Math Requirement	% No Prior	% First	Percentage
		Met (%)	Chemistry	Generation	Latinx
Chem II Male	736	67.9	0.8	28.3	33.3
Chem II Female	1,339	55.6	1.3	29.1	33.3
Chem I Female	2,753	56.4	1.2	35.3	36.4
Chem I Male	1,866	66.9	1.6	31.8	31.5
Chem II (M & F)	2,075	60.6	1.6	28.8	33.3
Chem I (M & F)	4,619	60.0	1.4	33.9	34.4
Overall	6,694	60.4	1.5	32.3	34.1

Prior knowledge is a strong indicator of student success (Shell et al., 2010). For the students who enter Chem I and II, the highest-level high school chemistry courses completed and the university-level mathematics course currently enrolled are displayed in Table 4. The data are distributed according to the course performance from high to low (bottom portion of Table 4). For every course/gender group (highest level of high school chemistry taken and whether or not the appropriate level of mathematics has been accomplished), the MUST and course averages are in alignment without exception. The population evaluated did not include those who had not taken high school chemistry (or failed to report their background), leaving  $n = 4,525$  (Chem I) and  $n = 2,027$  (Chem II). The results indicate that prior knowledge really does make a difference. In all MUST cases, as student exposure progressed from Regular to Pre-AP to AP high school chemistry, male scores (Table 4's outside columns) were consistently higher than their corresponding female counterparts, but course averages differed. In all Chem I cases, male course averages were lower than their corresponding female classmates' averages. The reverse trend was seen in Chem II. The same trends exist when evaluating whether or not students have met the suggested mathematics completion course (i.e., college algebra for Chem I and pre-calculus for Chem II). The students were again culled for those who chose not to report or were not enrolled in a mathematics class providing  $n$

$= 3,320$  and  $n = 1,549$  for Chem I and Chem II, respectively. In all MUST cases, males outperformed the corresponding female group, but when it came to Chem I course averages, females did better than males.

One of the observations that can also be made (Table 4) is that all course averages regardless of the group were above 69.5% (i.e., successful). Observable trends when MUST scores grouped into three groups: below average (B = bottom), average (M = middle) and above average (U = upper) ranges (see Tables 5 and 6) are worthy of note. To form these groups we took the average MUST score out of 20 maximum points and use one standard deviation (*SD*) around the mean to give an average MUST range of 6-11 for Chem I students (Table 5) and 8-13 for Chem II students (Table 6). Tables 5 and 6, together with the supporting alluvial diagrams (Figures 6 and 7), provide evidence of the predictability power of the MUST. Only a small percentage of the students in either Chem I or II who score above average (U = Upper) on the MUST are unsuccessful in the courses (12.2% in Chem I and 9.0% in Chem II). More important are the statistics for the students who fall into the below average (B = Below) category. After devoting only 15 minutes of class time to the MUST assessment, almost 52% of the Chem I at-risk students and 47% of the Chem II at-risk students can be identified, and their respective course averages are in the unsuccessful range,  $< 69.5\%$ .

**Table 4***Prior Coursework in High School Chemistry and Post-Secondary Mathematics*

MUST Mean ( <i>SD</i> ) ( <i>SEM</i> ) (max score = 20)				
	Chem II Male	Chem II Female	Chem I Female	Chem I Male
Regular	9.5 (5.0) (0.34)	8.2 (5.3) (0.26)	6.7 (4.6) (0.16)	8.0 (4.9) (0.20)
Pre-AP	11.9 (4.6) (0.26)	10.5 (4.8) (0.20)	8.6 (4.8) (0.13)	9.8 (5.0) (0.17)
AP	13.5 (4.6) (0.33)	12.0 (4.6) (0.26)	10.3 (4.9) (0.21)	12.2 (5.0) (0.26)
Not Met	10.9 (5.1) (0.31)	9.8 (5.2) (0.23)	7.8 (4.6) (0.17)	8.6 (4.7) (0.21)
Met Math	12.7 (4.6) (0.27)	11.0 (4.9) (0.23)	9.5 (5.1) (0.15)	10.9 (5.2) (0.17)
Course Average ( <i>SD</i> ) ( <i>SEM</i> )				
	Chem II Male	Chem II Female	Chem I Female	Chem I Male
Regular	75.2 (17.1) (1.15)	72.9 (15.8) (0.781)	71.9 (17.0) (0.584)	70.5 (18.4) (0.746)
Pre-AP	80.3 (13.5) (0.780)	77.9 (13.5) (0.560)	76.1 (15.6) (0.431)	74.8 (16.9) (0.588)
AP	85.0 (13.9) (1.01)	82.3(12.6) (0.708)	79.9 (15.2) (0.654)	79.8 (18.3) (0.938)
Not Met	78.4 (14.9) (0.896)	75.3 (14.7) (0.650)	74.0 (16.0) (0.585)	70.4 (18.0) (0.795)
Met Math	82.1 (15.3) (0.883)	80.9 (13.3) (0.621)	78.0 (16.0) (0.474)	76.8 (18.0) (0.592)

**Table 5***Chem I targeted MUST Score Ranges: Below < 6 (B), Average = 6-11 (M), Above > 11 (U)*

MUST range <sup>a</sup>	<i>n</i> (%)	Course ( <i>SD</i> ) ( <i>SEM</i> )	Number of Successful	Number of Unsuccessful	Grades D + F (Unsuccessful)
Below average: B	1,420 (30.7)	66.0 (16.6) (0.440)	685	735	51.8%
Average: M	1,752 (37.9)	75.0 (16.0) (0.382)	1,247	505	28.8%
Above average: U	1,447 (31.3)	83.9 (13.7) (0.360)	1,271	176	12.2%
Total	4,619	75.0 (17.0) (0.250)	3,203	1,416	30.7%

*Note.* <sup>a</sup>Significant difference at  $p < .05$  level: upper outperformed medium, medium outperformed low, and upper outperformed low. Abbreviations correspond to those in the alluvial diagram: U = upper, M = middle, B = bottom

**Table 6**

*Chem II Targeted MUST Score Ranges: Below < 8 (B), Average = 8-13 (M), Above > 13 (U)*

MUST range <sup>a</sup>	n (%)	Course (SD) (SEM)	Number of		Grades D + F (Unsuccessful)
			Successful	Unsuccessful	
Below average: B	632 (30.5)	69.3 (15.7) (0.626)	336	296	46.8%
Average: M	746 (36.0)	79.1 (13.1) (0.478)	597	149	20.0%
Above average: U	697 (33.6)	85.3 (11.3) (0.427)	634	63	9.0%
Total	2,075	78.2 (14.8) (0.326)	1,567	508	24.8%

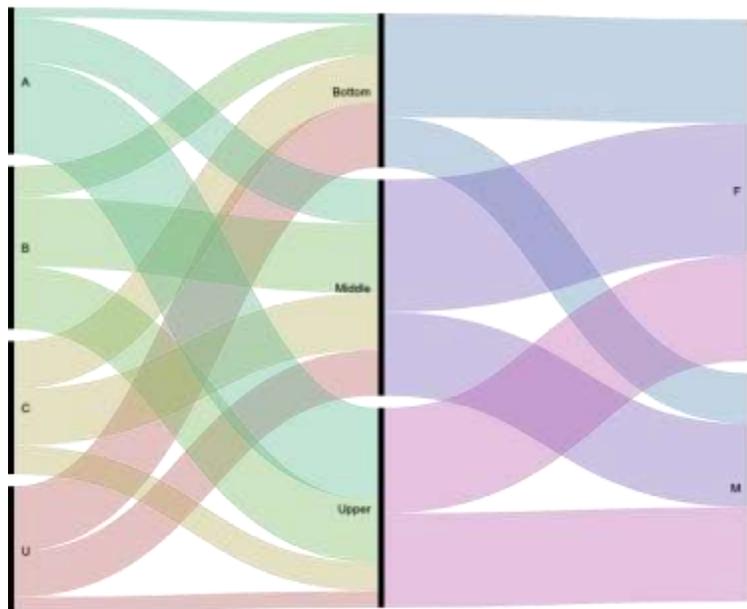
*Note.* <sup>a</sup>Significant difference at  $p < .05$  level: upper outperformed medium, medium outperformed low, and upper outperformed low. Abbreviations correspond to those in the alluvial diagram: U = upper, M = middle, B = bottom

The alluvial diagrams below (Figures 6 and 7 for Chem I and II, respectively) depict where the various splits occur. There are a couple of notable aspects to contemplate. Considering that the MUST is given at the beginning of the semester, its results reflect what students bring with them to Chem I and II. The far-right band indicates gender. By comparing Figures 6 and 7, it is evident that more females enroll in Chem I and II than males. To interpret Figures 6 and 7, start

on the bottom of the leftmost side (unsuccessful (U) students in the classes). The “rivers” of the left-hand side of the diagrams connect to the middle bar (MUST ranges). In both Chem I and II, very few students who finished the course with grades of D or F (Unsuccessful = U, bottom river on the left) scored above average (Upper) on the MUST, and very few A grades (upper river on left) enter the course with below average (Bottom) MUST scores.

### Figure 6

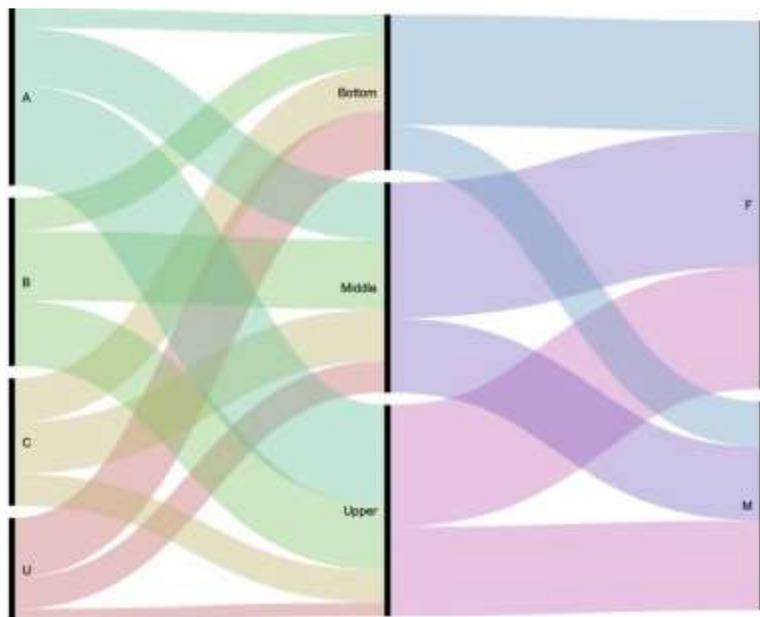
*Alluvial Diagram Illustrating Chem I MUST Groups (middle) Linked to Grades (far left) and Gender (far right)*



*Note.* The MUST scoring groups (Bottom, Middle, and Upper) are linked to the course grades (A, B, C, and Unsuccessful averages below 69.5% or grades of D and F combined) on the far-left bar and gender male (M) and female (F) distributions on the far-right bar. Source: <https://rawgraphs.io/learning/how-to-make-an-alluvial-diagram/#01-paste-your-data>

**Figure 7**

*Alluvial Diagram Illustrating Chem II MUST Groups (middle) Linked to Grades (far left) and Gender (for right)*



*Note.* The MUST scoring groups (Bottom, Middle, and Upper) are linked to the course grades (A, B, C, and Unsuccessful averages below 69.5% or grades of D and F combined) on the far-left bar and gender male (M) and female (F) distributions on the far-right bar. Source: <https://rawgraphs.io/learning/how-to-make-an-alluvial-diagram/#01-paste-your-data>

In both Chem I and II, the percentage of the top middle rivers flowing to the right (blue in color) are devoted to students who scored below average on the MUST. In Figures 6 and 7, females in the bottom MUST range more than doubles that for males; females also make a greater contribution to the middle-MUST ranges for Chem I and Chem II (violet in color). The percentage of Chem I and II males and females starting with MUST scores in the upper range (lavender in color) appear to be about equal with the majority of these students successfully completing the course with grades of A, B, or C.

Tables 7 and 8 provide more data for the alluvial diagrams. In both Chem I and II courses each performance group is supported by distinct differences between MUST scores and course averages for both genders. There is at least a 10% difference in course

averages in Chem I (equivalent to a letter-grade improvement) for both males and females as their respective MUST averages climbed by about 25% between performance categories based on every gain of 2 MUST points being equivalent to 10%. Each female category in Table 7 has lower MUST scores with higher course averages. The only gender comparison that did not show a statistical difference was the course averages for the upper-performance group (in italics). The Chem II MUST gaps (about 30%) between performance categories is even wider than in Chem I for both genders. The Chem II course averages in the average and above average categories have narrowed to about 7 points for male students and 5 points for female students emphasizing the need for better automaticity skills. In Chem II statistical differences at  $p < .05$  for gender comparisons exist in all MUST cases, except for the average student

category but only for the course averages for the upper tier of students. Males outperformed females in both entering MUST scores and final course averages for Chem II. Also, the male course average of 63.7% in Chem I and the female course averages of 67.2% in Chem I and 68.9% in Chem II are the first times in the data presented that an average placed into the unsuccessful category (i.e., < 69.5%). From all the data produced from this evaluation, the only groups in

Tables 5-8 to show unsuccessful course averages corresponded to below average MUST scores. The only group that was able to compensate for low automaticity ability were the below average Chem II males who completed the course with a 70.1% average. The males who entered Chem II with above-average automaticity ability also statistically outperformed ( $p < .05$ ) Chem II females.

**Table 7**

*Gender Similarities and Differences in Chem I by Performance Category (n = 4,619). Overall MUST average = 8.8/20; Overall Class Average = 75.0%*

Chem I	Male <sup>a</sup>			Female <sup>a</sup>		
	<i>n (%)</i>	MUST	Course Avg	<i>n (%)</i>	MUST	Course Avg
Below average	482 (25.8)	3.2	63.7	939 (34.1)	3.0	67.2
Average	696 (37.3)	8.6	73.0	1,056 (38.4)	8.3	76.3
Above average	688 (36.9)	15.3	83.2	758 (27.5)	14.8	84.6
Overall	1,866 (40.4)	9.7	74.4	2,753 (59.6)	8.3	75.4

*Note.* <sup>a</sup>All MUST and course averages between males and females show  $p < .05$ , except in the above average category with no statistical difference (italicized values). In each case, males entered with higher MUST scores but completed the course with a lower average.

## Discussion

The gender gap has essentially closed in secondary mathematics and science courses when compared to results obtained from post-secondary institutions (Perez-Felkner et al., 2019). Students from many backgrounds are successful in general chemistry. Barriers to success are not limited to prior academic knowledge but may also include emotions and the scope of a growth mindset (Dweck, 2006). Student engagement and motivation are also key as is students' self-efficacy, attitude, and career goals, which all play roles in persistence to attain a STEM degree that leads

to a STEM career. However, previous research has shown that prior knowledge is correlated with performance and students who enter general chemistry courses with greater arithmetic automaticity have an increased chance of success. This early success is important to maintaining the STEM pipeline because poor performance negatively impacts STEM persistence (Cohen & Kelly, 2019).

**Table 8**

*Gender Similarities and Differences in Chem II by Performance Category (n = 2,075). Overall MUST Average = 10.6/20; Overall Class Average = 78.2%*

Chem II	Male			Female		
	n (%)	MUST	Course Avg	n (%)	MUST	Course Avg
Below average	181 (24.6)	4.6 <sup>a</sup>	70.1	451 (33.7)	4.2 <sup>a</sup>	68.9
Average	264 (35.9)	10.6	79.2	482 (36.0)	10.5	79.1
Above average	291 (35.5)	16.6 <sup>a</sup>	86.4 <sup>b</sup>	406 (30.3)	16.2 <sup>a</sup>	84.4 <sup>b</sup>
Overall	736 (35.5)	11.5 <sup>a</sup>	79.8 <sup>b</sup>	1,339 (64.5)	10.1 <sup>a</sup>	77.3 <sup>b</sup>

*Note.* <sup>a</sup>MUST averages: Below and above average categories and overall,  $p < .05$  <sup>b</sup>Course averages: Above average category and overall,  $p < .05$

In this study, about 57% of the unsuccessful Chem I females and 45% of the unsuccessful Chem I males fell into the below-average (bottom) category on the MUST. About 30% of students of each gender are first-generation students. The percentage of students who reported that they worked while enrolled in classes (42% of female students and 47% of male students) has been addressed in Weber et al. (2020). Unsuccessful females tended to be those who earned a below-average MUST score, had not completed pre-calculus (or their current mathematics enrollment was not reported) and were also more likely to be employed as compared to their male classmates. Any one of these descriptors might only have a minimal influence on a student's ability to succeed, but the synergy of all of these factors undoubtedly increases challenges to the success for these students.

What does students' entering automaticity ability tell us about students' performance in Chem I and II?

When Chem I male MUST groups are compared to the corresponding female groups, in general, males enter Chem I with greater number-sense skills than females, but it is females who have higher final course averages over the males – are Chem I females simply better classroom students? If so, then this attribute might explain why Chem II classes include a slightly larger percentage of females than males, and maybe this is the beginning evidence to suggest that females' "belonging attitude" is prospering and the gender gap is leveling. Even though the Chem I evidence is encouraging, Chem II males tend to outperform females on both their automaticity ability and course averages. Even when Chem II females enter with above-average MUST scores there remains a statistical difference ( $p < .05$ ) in final course averages. Similar to the Sax et al. (2017) computer science study, positive signs that the gender gap is closing exist but there is still a long way to go!

### Study Limitations

The noted limitation is that the demographic data included in this study were self-reported by the students. Students were aware that they were participating in an IRB-approved study so it is assumed that all data points were accurately reported. The sample included students enrolled in general chemistry classes from eight public and one private

### Conclusion

The allotted time for the MUST is only 15 min. and it consistently reflects (and predicts) students' overall performance in Chem I and II. Many colleges and universities suggest chemistry should be taken in high school by all applicants regardless of intended major (Fox, 1994). At the post-secondary level, chemistry is a foundational course required for many STEM majors. General chemistry is identified as a high-risk course where the D/F grade rate is often reported to be over 50% compared to other science courses, where the DF grades are around 33% (Cohen & Kelly, 2019). This study supports the results of Bloodhart et al. (2020) who found that undergraduate females in STEM outnumber and are outperforming males in the physical sciences even though they entered this study with a lack of numeracy skills that are paramount to success in more advanced chemistry pursuits. In every other case, males entered with higher MUST scores but females finished with higher course averages. By the time we got to these data, men entered with higher MUST and completed the course with higher course averages. Training students to limit the use of calculators is necessary to re-energize needed

university of the possible 38 public and 53 private universities in this diverse education setting spanning over 45,000 square miles region, which is much larger than many US states combined. Thus, the sample population is reasoned to be a good representation of general chemistry students enrolled throughout this state.

quantitative skills. One carrot is that many of the students who enroll in general chemistry are on a path to obtain a STEM degree and become a health professional. Many will at some time in their future take the calculator-free MCAT. Some members of the NSA Team have untethered their students from their calculators during certain parts of the courses. Hartman and Nelson (n.d.) suggest making sure that students overlearn the basics necessary for each chemistry lesson before students start the material. Closely linked to students' arithmetic skills are their quantitative-literacy and quantitative-reasoning abilities. In our data-driven world, it is ones' prior knowledge that is and will also be the mainstay of how much effort will be needed to take the next step. Perez-Felkner et al. (2019, p. 4) reported, "we do not yet know to what degree precollege and college ability and achievements predict postsecondary gender gaps in STEM," but maybe this study provides some insight into this mystery. What would the story be if females entered Chem I with improved number-sense skills and a better growth mindset toward entering STEM career fields? Progress towards these goals is slow, but there are indications that the gaps are closing.

### Declaration of Interest Statement

The authors declare no conflict of interest concerning this IRB-approved study.

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