Research Article

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Effects of Texas' Isomorphic Curriculum on Readiness for Post-secondary Gateway Courses in Chemistry

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Abstract

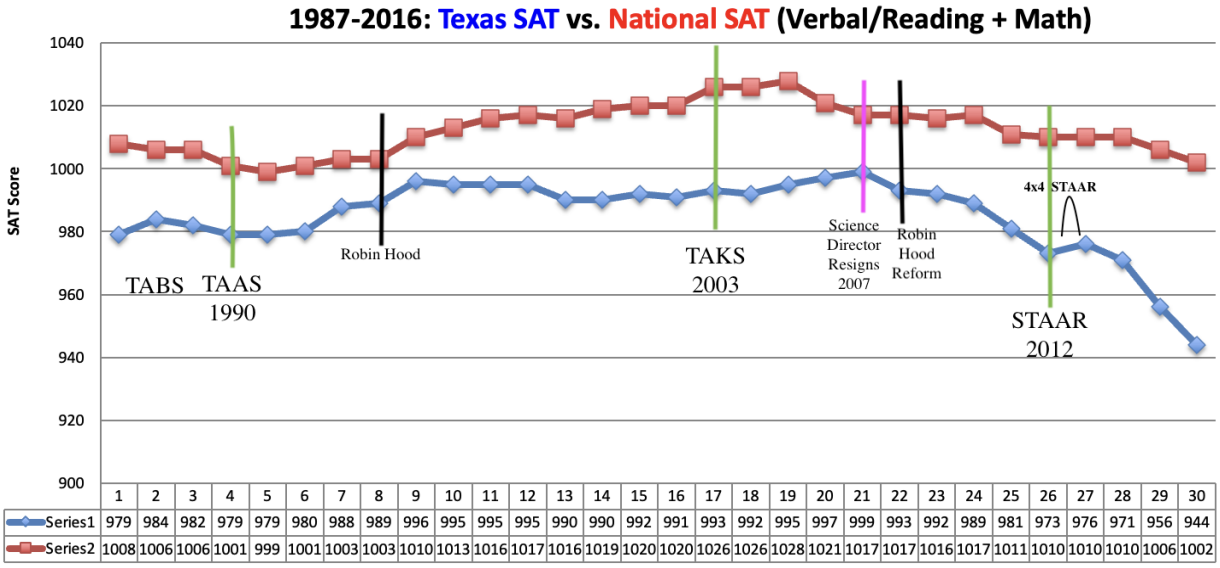
This study analyzed six years of data from nine universities in the state of Texas. Compared were assessment averages reflecting in-state and out-of-state students' preparation for a major STEM gateway course sequence, general chemistry I and II (Chem I/II). Students' preparation was evaluated by calculator-free diagnostic instruments covering a broad range of prior knowledge. The MUST (Math-Up Skills Test) assessed procedural skills in basic arithmetic, the QL/QR (Quantitative Literacy/Quantitative Reasoning) evaluated students' ability to draw conclusions from data presented in images, and the DAT (Diagnostic Algebra Test) assessed algebraic skills deemed appropriate for success in general chemistry. Combined Chem I/II data and Chem I only data suggested that students from Texas were not as prepared for success as their out-of-state peers. Texas-educated students who continued with the sequence to Chem II realized improvement and no longer performed at a statistically lower level than their out-of-state peers.

Keywords: *pre-college preparation, retention, diagnostic instruments, general chemistry, automaticity*

Introduction

This report is written in response to the 2023 George W. Bush Institute report "The State of Readiness: Are Texas students prepared for life after high school?" [1]. The authors are chemical education researchers (CERs) in the state of Texas who are members of the Networking for Science Advancement (NSA) team formed in the Fall 2016 and directed by the last author. The formation of the NSA team was in response to the SAT data displayed in Fig. 1 where the last author noticed that Texas students' SAT averages were plummeting rapidly and wanted to try to understand *why*. The contributing educators are faculty at Texas A&M University – Commerce, Sam Houston State University, Texas A&M University – San Antonio, The University of Texas at Austin, Abilene Christian University, Texas State University, University of North Texas, and Texas A&M University. This study undertook the task of evaluating

Texas university students' automaticity (what can be done without the use of a calculator) ability who either experienced in-state and out-of-state secondary education. Three diagnostic instruments were used to assess their prior knowledge, the most predictive variable of future academic success [2]. Completers' final general chemistry I and II (Chem I and II) course average was considered as the dependent variable. Removing calculators from students tests their personal mental-mathematics fluency and number-sense ability reflecting their understanding of overlearned mathematical facts and procedures.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Series1	979	984	982	979	979	980	988	989	996	995	995	995	990	990	992	991	993	992	995	997	999	993	992	989	981	973	976	971	956	944
Series2	1008	1006	1006	1001	999	1001	1003	1003	1010	1013	1016	1017	1016	1019	1020	1020	1026	1026	1028	1021	1017	1017	1016	1017	1011	1010	1010	1010	1006	1002

Figure 1. SAT scores (x-axis) over a span of 30 years (points 1-30, ending when SAT scoring calculation changed) with demarcations indicating changes to state-adopted curriculum standards. The acronyms are TABS = Texas Assessment of Basic Skills, TAAS = Texas Assessment of Academic Skills, TAKS = Texas Assessment of Knowledge and Skills, and STAAR = State of Texas Assessment of Academic Readiness. Black bars (points 8 and 22): Robin Hood plans target budgetary issues addressed by the Texas Legislators, which in 1994 showed a positive change after 2008 the downward spiral began. Hot pink (point 21): Texas Education Agency (TEA) Science Director resigned in 2007. In 2008, the Texas 4×4 (4 years of science, mathematics, English and social studies) STAAR was fully implemented producing a short-lived slight tick upward. In 2013, the exit-level 4×4 STAAR was reduce to English I and II, US History, Algebra I, and Biology assessments as part of the state's accountability system. [Figure 1 was published by the NSA team [3] and is reprinted with permission of the Journal of Chemical Education and the authors.]

Literature Review

The Texas Education System specifies an isomorphic curriculum known as the TEKS (Texas Essential Knowledge and Skills) for all students enrolled in public schools; accredited private secondary schools are directed to adopt similar curricula. The state's Education Commissioner suggested that the significant decline in mean SAT scores over the past few years was due to many more Texas students being encouraged to take the SAT including those who had not previously considered going to college. As the "college-going culture" increased, the number of under-resourced students, many of whom are also minority students, impacted the state's performance, because as reported by Stutz [4] minorities typically score lower on the SAT than non-minority students. According to the 2023 Bush report [1], 60% of all students in Texas are not on grade level in mathematics. In fact, 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 [1]. These pre-college data are very concerning since prior knowledge is and will also be the greatest influencer of the students' success in their next course [2]. The NSA team therefore decided to follow-up with Texas university-level data collected over the past six years. A study of students' preparatory background is warranted to understand whether students who attended Texas secondary schools are or are not more academically prepared for general chemistry, a major gateway course required by many STEM (science, technology, engineering, and mathematics) degree plans, than their out-of-state peers.

A search of the literature provided an evidence-based research instrument reported by a professor from the U.S. Naval Academy and a co-author who prepares mathematics workbooks for STEM majors [5]. Their study evaluated students' automaticity (what students can do without a calculator). The protocol was first to evaluate what students can do without a calculator and then using a similar quiz evaluate what students can do with a calculator. As a retired professor, the last author of this study thought that she could corral her CER friends in Texas and provide a pathway to repeat this study. Mathematics preparation is closely tied to success in the general chemistry sequence (Chem I to Chem II), which are courses with historically high DFW rates (students who make grades of D or F or withdraw from a course) [6-14].

The final version of this 15-minute, calculator-free, open-ended, pencil-and-paper, hand-graded number-sense quiz, named the MUST (Math-Up Skills Test), was given to students the first week of classes. This diagnostic was designed to evaluate students' basic arithmetic skills, 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 numbers of elements). A copy of the MUST is available in Williamson et al. (2020) [15], and Macmillan Publishers currently provides an electronic version of the MUST on *Achieve*[1]. Results from the pilot study [16] even though the mean when calculators were used was higher, surprisingly the statistical analysis produced a higher correlation of the MUST means to final course grades when students didn't use calculators than when they did, prompting further investigations into the cause(s).

The other two diagnostics used to evaluate students' prior knowledge were the QL/QR and the DAT. Each semester in an attempt to discover reasons behind students' low performance in Chem I and II, students were given the MUST and at times one of the other diagnostic instruments under agreed-upon research protocol for that semester for exploratory reasons. All three diagnostics assessed students' automaticity ability and have high reliability, large effect size, good internal consistency, and reproducibility. The MUST's internal consistency measures (e.g., Cronbach's alpha and KR-20) have always exceeded (0.85) indicating high reliability. The MUST has a large effect size and has shown very good predictability of final course grades. Chem I predictability produced a 78% accuracy that a student will attain at least a 69.5% average by using coefficients from the developed LASSO regression model [15]. The LASSO regression model was also used in a Chem II study giving an even higher predictability identifying 83% of the successful students [17]. 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% [18]. Its use has provided instructors at the beginning of the semester with diagnostic information about who will probably struggle with the course so that additional support can be offered. A few out-of-state CERs report to have recently used the MUST in their classes but they have yet to publish.

The QL/QR assessment is part of an NSF research grant of Eric Gaze's database of questions (NSF DUE 1140562 project) and a few questions from those suggested by Peter Brown. The NSA team developed the QL/QR quiz making sure that all multiple-choice questions were answerable without the use of a calculator. The current QL/QR was compiled by the NSA team. The first version contained 20 questions, but it was decided that given the time constraints of the general chemistry class, this diagnostic needed to be shortened. In response a 10-question version was developed from the most frequently missed basic arithmetic and algebra questions on the 20-question version and all questions with charts, tables, graphs, and other images included. The QL/QR produced a KR-20 = 0.738 (acceptable reliability). Strong correlations ($r > 0.60$) were determined to exist between the MUST and the QL/QR quizzes [19]. The DAT is a well-established diagnostic test used to assess the algebraic skills of general chemistry students [20].

Additional NSA team studies of the successes and failures of general chemistry students include several publications on the use of the MUST: environmental factors [21]; pre-med majors [22]; math review [23]; careers [24]; personal characteristics [25]; gender gap [26]; organic chemistry [27]; common questions [28-29]; e-homework [14]; identifying unsuccessful students [30]; MUST predictability lower-level chemistry [31]; and academic legacy [32].

The Bush Institute report [1], described several interesting facts about current Texas K-12 students. These results on Texas students' pre-college education together with the NSA team's research data promoted the need for the NSA team to respond. Published in the Bush Institute 2023 report some the following facts regarding pre-college education in Texas include:

1. Students who moved to Texas are better educated than those who grew up here.
2. Math proficiency of the graduating class of 2023 is at the 44% level, a 14% drop in proficiency since the 8th grade (largest decrease of any US state).
3. All Texas ethnicities consistently underperform the national average on the SAT.
4. In response to the decline in the academic readiness of Texas students, jobs are being filled from talent found out of state
5. who hold almost twice as many 4-year degrees as the native Texan workforce.

Where the Bush Institute report addressed the issues at the pre-college level, the NSA team followed some of these pre-college students to the university level and evaluated the relationships between students MUST, QL/QR, and DAT diagnostic scores and students' final course averages. Enrollment in general chemistry, a freshman-level STEM course and gateway course to many careers usually has a prerequisite of completion of college algebra (or equivalent) or documented readiness for pre-calculus but this requirement is dependent upon the institution. Of major importance to this study is how the NSA's research data support the observations provided in the Bush Institute report.

Research Protocol

Chem I and II are required by many STEM degrees. Most of the enrolled students seek biological science degrees and of these most report plans for future careers in the health professions. The NSA team instructors gathered data for six years on general chemistry students, looking for patterns and noted repeatable outcomes leading to conclusions supported by the empirical data. All instructors received IRB-approval for this research under the rules of their university. Participating general chemistry students signed IRB-consent forms, completed a demographic survey to collect personal information, and then over one or two days responded to various diagnostic assessments. One of the questions on the demographic survey was: what was your zip code where you attended high school? The first two digits of a US zip code provides the information needed for the identification of their home residence. Texas supports zip codes starting with 75, 76, 77, 78 and 79 with an additional code (99) used for students on the international border around El Paso who may attend US schools. All other reported US zip codes and international mail codes were amassed into the subgroup of "out-of-state" students. After several face-to-face

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

group meetings in Waco, it was decided to use modified versions of the MUST (15 min.) and QL/QR (20 min.) instruments and the DAT (20 min.) to evaluate enrolled students' automaticity ability the first week of classes at each university. At the end of the semester, final course grades were matched to the diagnostics. Each practicing instructor emailed an Excel data file to the last author who compiled the data for analyses and interpretation of outcomes. Students who did not complete the courses, were considered post-baccalaureate, completed the courses with an average of less than 10%, and those who did not have a MUST score were deleted from the population pool evaluated.

Institutions

As is evident from Table 1, the participating universities are from a broad range of types, sizes, and accountability groups. These institutions are small, medium, and large; private and public; located in major metropolitan areas and small rural towns; Hispanic Serving Institutions (HSI) and emerging HSIs; and span from major research institutions to those who's highest degree offered is a masters providing an excellent representation of the universities in Texas. Most of the educators in this study are not from Texas (supporting that Texas imports a substantial number of out-of-state employees). Most of the NSA instructors are considered White, non-Hispanic, with other ethnicities of Native American, Hispanic, and Asian/Pacific Islander.

Table 1. Four-year university demographics from participating institutions.

Institution	Type*	Size	Texas Location	UG Enrollment	Accountability	Instructors
Abilene Christian	Private	Small	Abilene	3,297	Emerging HSI	TX, White
TAMU-SA	Public	Medium	San Antonio	6,041	Super HSI	IL, White
UH-Clear Lake	Public	Medium	Houston	6,582	HSI	Russian, White
TAMU-C	Public	Medium	Commerce	7,962	Emerging HSI	Asian
Sam Houston	Public	Medium	Huntsville	18,790	HSI	Costa Rica, Hisp
North Texas	Public	Large	Denton	32,694	R1, HSI	PA, White
Texas State	Public	Large	San Marcus	33,193	HSI	HI, Asian
UT, Austin	Public	Large	Austin	40,048	R1, HSI	TX, White
TAMU	Public	Large	College Station	53,144	R1, HSI	OK, Native Am

*Public school data are selected from the *2021 Almanac* of the Texas Higher Education College Board (THECB). Abbreviations: HSI = Hispanic Serving Institution; R1 (very high) is a Carnegie classification for universities' research productivity; Hisp = Hispanic, Am = American; US state approved abbreviations (HI, IL, OK, PA, and TX).

Research Data and Results

Table 2 provides the data used by the NSA team to evaluate consenting Chem I and II students (N = 6,948) from semesters considered on-sequence (Chem I in fall and Chem II in spring) and off-sequence (Chem I in spring and Chem II in fall). Sections on Table 2 display data for in-state (In) and out-of-state (Out), Chem I and II students combined, all Chem I and Chem II students separated, and Chem I and II data separated into on- and off-semester classes. The last column provides information on t-tests used to indicate if the data points were likely to have occurred randomly in the normal population or if there is a distinct difference between the two groups (pre-college education outside of Texas or in Texas) at the alpha level of $p < 0.05$.

Table 2. Diagnostic data for Chem I and II students (N = 6,948, unless otherwise stated).

Courses	N	%	Class Avg	% Suc	MUST	QL/QR	DAT	$p < 0.05$
Combined (*n*)						**2702**	**2579**	
Out	438	6.3	77.4	73.7	50.3	61.1	79.9	Statistical differences (means): Class Avg, MUST, QL/QR
In	6510	93.7	75.8	70.8	46.5	57.7	77.9	
Chem I (*n*)	**4817**					**2047**	**1583**	
Out	303	6.3	76.9	73.9	49.4	61.4	77.9	Statistical differences (means): Class Avg, MUST, QL/QR
In	4514	93.7	74.7	68.7	43.9	56.2	74.6	
Chem I on (n)	***3797***					***1422***	***1191***	
Out	*212*	*5.6*	*77.7*	*74.5*	*51.6*	*61.0*	*80.5*	*Statistical differences (means): MUST & QL/QR*
In	*3585*	*94.4*	*76.4*	*72.3*	*46.7*	*54.9*	*77.2*	
Chem I off (n)	***1020***					***625***	***392***	
Out	*91*	*8.9*	*75.2*	*72.5*	*44.3*	*63.6*	*72.5*	*Statistical differences (means): Class Avg & MUST*
In	*929*	*91.1*	*68.3*	*54.7*	*33.0*	*59.1*	*66.1*	
Chem II (*n*)	**2131**					**655**	**996**	
Out	138	6.5	78.6	73.3	52.6	60.3	84.3	Means have no statistical difference
In	1993	93.5	78.1	75.6	52.5	62.5	83.1	
Chem II on (n)	***1646***					***422***	***846***	
Out	*102*	*6.2*	*82.1*	*81.4*	*58.7*	*67.3*	*87.4*	*Means have no statistical difference*
In	*1544*	*93.8*	*81.3*	*83.5*	*58.6*	*67.5*	*86.7*	

Chem II off (n)	***485***					***233***	***150***	
Out	*36*	*7.4*	*68.7*	*52.8*	*36.3*	*49.2*	*67.5*	*Means have no statistical difference*
In	*449*	*92.6*	*66.9*	*47.9*	*31.6*	*53.5*	*62.3*	
Out: out-of-state; In: in state; % = percentage; Avg = average; Suc = successful students (grades of A, B, or C); MUST = Math-Up Skills Test; QL/QR = quantitative literacy/quantitative reasoning: DAT = Diagnostic Algebra Test.								

Since the NSA team's first study, one of the most interesting results is that there is strong alignment between MUST scores and course grades that has been repeatedly reported. This trend is repeated in Table 2, where final class averages and the corresponding MUST means are perfectly aligned. Regardless of which semester (Chem I or Chem II), whether on- or off-sequence, or if the students' pre-college experience was in Texas or not, the higher-class average is paired with the higher MUST mean and *vice versa*.

From the combined data (top rows in Table 2), the out-of-state students outperformed the in-state students on class average, percentages of successful students, MUST (20 questions), QL/QR (weighted average of some 20-question assessments and some 10-question assessments) and DAT (20 questions) scores. This result is consistent with a pilot study where out-of-state students' MUST average of 59.5% was statistically higher than MUST averages from all zip code regions in the state of Texas ranging from 22-35% (Author, 2018). *T*-test results indicate a statistical difference ($p < 0.05$) for the overall course average, and MUST and QL/QR means. Yes, out-of-state student results do reflect what is stated in the Bush Institute report (2023) that Texas students are not as academically prepared as their out-of-state peers. It is interesting that when Chem I and Chem II results are compared separately, the only statistically different values appear in the Chem I section. These results continue to support the Bush Institute report (2023) in that Texas students are not prepared as well as their peers who were educated outside of Texas in procedural algorithms (MUST), quantitative literacy/reasoning (QL/QR), and basic algebraic performance (DAT). However, the positive is that when the Chem II students are evaluated, no statistical differences are found between out-of-state and in-state Texas students. In several Chem II data points in Table 2, the out-of-state average is higher than the in-state average, but there is no longer a statistical difference in the means after students advance to Chem II.

There are a couple of reasons for the Chem II observations. The most obvious divergence is that only 2,131 (44.2%) of the 4,817-student population from Chem I continued to Chem II, but there is only a minor difference between continuing populations of Out and In state. Some of the decline is to be expected since some degree plans only require one semester of general chemistry, which should affect both out-of-state and in-state students equally. The other side is that a large percentage of Chem I students do not earn a grade high enough to continue to Chem II (grades of A, B, or C). Looking closer at the Chem I population, note that there is no proportional change between out-of-state vs. in-state percentages (i.e., 6.3 and 93.7) as compared to the combined population but by Chem II there is. Enrollment in Chem II produces a slightly higher percentage of out-of-state students (6.5) indicating that more Chem I students from out-of-state continue with the course sequence than those from Texas, which is probably due to out-of-state students having a higher success rate of 73.9% compared to 68.7% for the in-state Chem I students. The good news for Texas students is that once enrolled in Chem II, many of the diagnostic differences disappear and in certain cases (like success rate in Chem II on-sequence students, and all the QL/QR score means) Texans slightly outperformed out-of-state students.

Limitations

The results presented in this study only reflect the influence of students enrolled in general chemistry, a major gateway course with a consistently reported high DFW rate. Expanding this research to include other STEM and non-STEM disciplines is strongly encouraged. Also, expanding the use of the MUST as a diagnostic instrument to all higher education institutions in Texas would serve to strengthen our results.

Conclusions

From the Bush Institute 2023 report, "Instead of focusing on strategies to improve the readiness rates of young Texans, Texas lawmakers are being asked to roll back past progress and weaken how Texas measures readiness." The empirical data reported in this study dispute the "past progress" premise and hope that readers will pass these results onto all lawmakers. The one thing that has been consistent from the NSA-team study is that the calculator-free MUST is very indicative of students' success in general chemistry I and II, on-sequence and off-sequence courses. The MUST provides a proven alternative to the use of SAT scores, requires only 15 min. of class time to complete, results are available as soon as they are graded, and the cost is that of one sheet of paper (unless you choose the Macmillan Publishers version).

The most challenging observation from this analysis is that overall out-of-state educated students outperform students educated in Texas in all number-sense areas assessed. One practical solution might be to remove calculators from students at the pre-college level at least until high school enrollment in chemistry or physics so that students will not exploit this very valuable tool before they have overlearned basic arithmetic facts and are very knowledgeable of appropriate procedural skills. Compared to the out-of-state students, Texas students are simply not getting the practice required to have basic arithmetic facts and procedures at hand, so that they can succeed at the same level as their out-of-state peers.

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Data Availability Deidentified student data are available from the corresponding author upon written request.

Declarations Ethical approval all procedures performed in these studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The research used large-scale secondary datasets. No data are traceable to individual participants.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Conflict of Interest The authors declare no competing interests.

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