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The STEM Center to Promote Undergraduate Education and Research at Sam Houston State University

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Abstract

The STEM Center at Sam Houston State University (SHSU) has received funding from the National Science Foundation (NSF - IUSE) and was established in 2017. The STEM Center seeks to increase the number and quality of STEM graduates by establishing a strong foundation for learning using innovative teaching practices, supporting students in finding research and internship opportunities, and building lifelong skills needed for advancement and leadership in STEM careers. The center is in one of the STEM buildings with two fully equipped classrooms and office space for full-time staff members. The center staff collaborates with university-wide programs to promote STEM education and contribute to the university's quality enhancement plan (QEP). The paper shares details regarding faculty and student involvement, the development of preparatory courses, institution-wide resources, and student outcomes from the project with the academic community.

Introduction

The STEM Center at SHSU seeks to increase the number and quality of STEM graduates by establishing a strong foundation for learning using innovative teaching practices, supporting students in finding research and internship opportunities, and building lifelong skills needed for advancement and leadership in STEM careers. In 2012, the President's Council of Advisors on Science and Technology (PCAST) determined a need for an additional one million STEM graduates over the next decade [1]. In order to help accomplish this worthy but formidable goal, the council recommends a strategy to increase recruitment and retention of STEM students in the first two years of their undergraduate education. In fact, the PCAST report states that increasing the national retention rate of STEM majors from 40% to 50% would produce 750,000 more STEM graduates, effectively accomplishing three-fourths of the council's goal.

Significant initiatives have been ongoing that aim to improve the quality of undergraduate STEM education and learning experiences. The initiatives vary on the levels of national, multi-institution collaborations, corporate, and individual campuses [2-6]. A STEM education 5-year strategic plan was developed by the National Science and Technology Council's inter-agency council committee on STEM education [7]. This report identified improving the experience of undergraduate STEM students as a priority area for federal investment reporting four priority areas: (a) promoting evidence-based instructional practices; (b) improving STEM experiences in community colleges; (c) expanding undergraduate research experiences; and (d) advancing success in key gateway courses of introductory mathematics.

Legislators and the scientific community have emphasized the crucial need to improve undergraduate STEM education in a series of reports, and many reforms and improvement efforts are currently underway [8-10]. According to the National Center for Science and Engineering Statistics (NCSES) recent report, the science and engineering (S&E) enterprise continues to advance along several dimensions [11-12]. "*The U.S. continues to perform the largest share of global research and development, generate the largest share of research and development*

intensive industry output globally, award the largest number of S&E doctoral degrees, and account for significant shares of S&E research articles and citations worldwide. However, other nations, particularly China, are rapidly developing their science and technology (S&T) capacity. The changing global landscape affects the position of the United States relative to the other major global players. For example, the United States has seen its relative share of global S&T activity remain unchanged or shrink, even as its absolute activity levels have continued to rise".

To aid in these efforts, the leadership of STEM Center created a comprehensive strategy for increasing STEM retention by improving the learning outcomes of students in several STEM disciplines through broadening the capacity for STEM learning at our institution. In addition, the success of the STEM Center provides an affordable and replicable model for increasing STEM capacity at the more than one thousand similar regional, comprehensive 4-year institutions across the country. Half of all bachelor's and master's degrees earned in the United States are obtained from an institution of this type [13]. The STEM Center integrates and expands the use of research-based practices across several STEM disciplines, providing 4-year comprehensive institutions similar to … with a strategy for long-term intervention to be adopted at early stages of their university experience. The STEM Center at SHSU is one of several initiatives to promote systemic change [14] in higher education as it has significantly fostered a vibrant conversation on active learning methods on campus, and refocused energy on thinking about the challenge of improving student success in the STEM disciplines [15].

Project Goals

The goals of the STEM Center are consistent with the goals stated in the PCAST report: contribute to the effort to increase the number and quality of STEM graduates [1]. The main goals of the project are to (a) equip incoming STEM students with adequate preparation and tools for success in those courses traditionally difficult for first- and second-year STEM students; (b) aid students in developing skills to maximize performance in math, engineering and science classes, and create positive attitudes required to acclimate to college life and succeed academically; (c) connect undergraduates with faculty members and graduate students to facilitate research experiences for undergraduates; (d) provide research-related networking and internship opportunities in addition to advising students about graduate school preparation and career opportunities; (e) improve the quality of STEM undergraduate education by expanding the use of active learning techniques such as Inquiry-Based Learning [16] and Process-Oriented Guided Inquiry Learning (POGIL) [17] across STEM disciplines. To meet these goals, several major activities promote the engagement of students and faculty via (a) preparatory bridge courses; (b) incentivizing undergraduate research; and (c) improving STEM undergraduate education. None of these activities will be possible without the faculty, staff and facilities of the STEM Center.

Personnel and Facilities

The STEM Center is supervised by the project team composed of five STEM faculty members from math, chemistry, and engineering technology fields. One permanent staff member oversees the STEM Center physical space and everyday administrative tasks. Additionally, the STEM Center is supported by an advisory board composed of university faculty from the College of Science and Engineering Technology, and one external evaluator to the project. The faculty and

staff have been essential for the fulfillment of the objectives of the center and related activities. The general responsibilities of the advisory board members are: (a) provide context-specific to their department when developing student research opportunities; (b) assist with recruiting faculty members to be involved with active learning efforts; (c) answer questions regarding curriculum in a particular department; and (d) help recruit student teaching assistants for either summer prep courses or active learning courses in the long semesters. There are currently nine advisory board members serving from various STEM Departments; Physics, Biological Sciences (2), Computer Science, Geology and Geography, Engineering Technology (2), Chemistry, and School of Agriculture. The external evaluator has been a valuable resource in collecting participants' data and reporting the STEM Center's progress on the set goals.

Undergraduate student assistants were hired to assist developing summer bridge course modules and assisting during summer bridge course period. Student candidates were interviewed and selected from Chemistry, Mathematics, and Engineering Technology majors. Student assistants were only offered up to 2-month of work and paid hourly for their service. The summary of student worker duties is a) assist developing summer bridge course modules, b) offer tutoring sessions for each field after the main sessions in the morning, c) help grading, d) take attendance, e) help leading breakout sessions, f) help mentoring student participants g) go through the course themselves first and evaluate. Their pay rate was usually $10/hr and typically hired for a two month period. The following is the job ad for the students interested in the position.*"Tutors will join in the STEM Center Bridge Workshop along with student participants and provide assistance virtually one-on-one, or occasionally organize group activities for students. In addition, help students reach their full potential by guiding them toward study practices and aides that can help them excel. We expect tutors to offer compassionate, motivating assistance to students.*"

In 2019 the STEM Center established a physical space (more than 1500 sq. ft.) in collaboration with the Office of the Provost. The space consists of two active learning rooms with a capacity of 30 students per room, and one permanent office space for the center administrator. The figure below showcases the distribution and organization of the space. This space is equipped with essential materials for active learning strategies such as Inquiry-Based Learning and Process-Oriented Guided Inquiry Learning. The active learning space is made available for faculty, staff, and students to meet for classes, workshops, or study sessions. During such meetings, the room equipment and furniture are easily adapted to fit the event's needs as the tables and desks can be moved around the rooms. For example, to promote small group discussion (Figure 1, left room) and panel or round table discussions (Figure 1, right room).

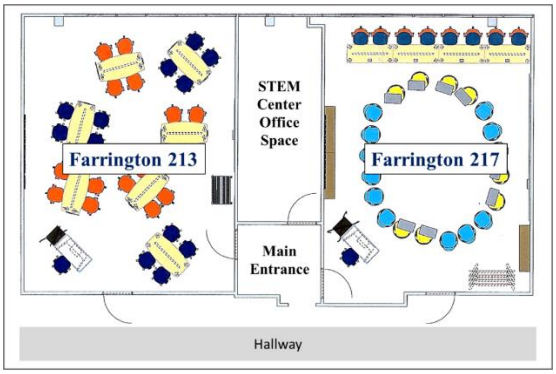

Figure 1. Layout of the STEM Center Active Learning Space.

Major Events

A - Preparatory Bridge Courses

It should not be surprising that improvements to the academic potential of STEM students may be obtained through early intervention in first- and second-year courses. But some recent programs have discovered evidence that suggests such early intervention may be essential for all but the most prepared STEM students. For example, a four-year study [18] of 1800 STEM students at Boise State University concluded that students who receive an A in their first-semester math course (either calculus or pre-calculus) were many times more likely to graduate with a STEM degree than those students who did not receive an A. These odds ranged from an impressive multiple of 4 times more likely for STEM majors to an incredible seven times more likely for engineering students. Moreover, those students who required remediation in mathematics are about half as likely to remain in a STEM discipline by graduation. This study indicates that enabling success in early math courses may be imperative to increasing national STEM graduation rates.

Additionally, a three-year study [19] of 1500 first-year STEM students at the University of New Mexico found that many students are discouraged away from STEM majors very early, with pre-calculus and calculus courses playing the largest role. Those students who earned an A in their so called "killer courses" (including pre-calculus, calculus and general chemistry I and II) experienced a very high STEM graduation rate of almost 80%. These studies provide evidence for what faculty have suspected all along: doing well in traditionally difficult mathematics and chemistry courses – completed early in college – and especially doing very well, all but ensures graduation in a STEM discipline. But the challenge of providing students the means to perform well in these courses remains, especially if they have not yet entered our campus community. Furthermore, regional, comprehensive 4-year public institutions similar to … State University welcome many first-year students with widely varied preparatory backgrounds (transfer or dual-credit courses, for example) which compounds this difficult challenge.

Bridge courses are implemented to impact students' academic success by revising fundamental concepts and skills necessary to successfully complete discipline-specific courses. The bridge courses are often short (one to three weeks) and highly dense in content (commonly mathematics or math-related applications). With the support of the NSF-funded (DUE - Division of Undergraduate Education) STEM Center at SHSU, we designed a course for upcoming engineering majors (i.e., first-year students and transfer students) that consists of a two-week-long pre-semester course organized into two main sessions. The first sessions (delivered in the mornings) were synchronous activities focused on strengthening student academic preparedness and socio-academic integration and fostering networking leading to a strong STEM learning community. The second sessions (delivered in the afternoons) were asynchronous activities focused on discipline-specific content knowledge in engineering.

The STEM Center has focused many of its resources to fulfill this critical task of improving students' preparation for introductory STEM Courses. Starting with math preparation, moving into chemistry and more recently engineering technology course content. In the first summer of the STEM Center's existence, we developed a 2-week summer course, free to students enrolled in pre-calculus the following fall. Spring 2018 was spent developing the course and recruiting students.

In late July, the first course consisted of pre-calculus mathematics content and material designed for skill development (Table 1). Using the *Foundations & Frameworks* courses developed by the Charles A. Dana Center at the University of Texas as a model [20], the approach relies on active learning techniques, inquiry, and exploration to foster a growth mindset for incoming first-year students.

While the course was very well-developed, enrollment was lower than we had hoped (Table 1). We had planned and hoped for much more than the 20 students who began the 2-week course. Feedback on the effectiveness of the course was positive, and the course plan was decided to maintain the content moving forward. After speaking with student participants, the reason for low enrollment was determined to be a combination of time (2 weeks was deemed too long) and convenience (driving to and from campus). This feedback was received, and adjustments were made. First, a shorter three-day course was developed for January, just before the Spring semester. Classes typically begin on a Wednesday in January, with residence halls open on Saturdays. This will provide three days that students can spend on campus preparing for their spring math course.

Table 1: Student enrolment by offered Summer Bridge Courses since 2018.

Preparatory Pathway to Target Course	**Summer 2018**	**Summer 2019**	**Summer 2020 – Online Instructions**	**Summer 2021 – Online Instructions**
Pre-Calculus or Trigonometry (MATH 1314 & 1316 & 1410)	10	13	29	33
Calculus (MATH 1420)	--	14	21	7
General Chemistry I (CHEM 1411)	--	--	60	67
General Chemistry II (CHEM 1412)	--	--	--	32
Engineering Technology (ETEC 1010)	--	--	--	9
Totals	**10**	**27**	**110**	**148**

Second, in early Spring 2019, the STEM Center decided to alter the design of the summer prep course from a commuter model to a residential one. Using the model of Summer Camps as a model, the STEM Center held its first STEM Camp for incoming first-year students and returning students from July 15 – July 19. We were able to host 27 students who stayed in one of the residence halls on campus and ate at the campus dining facility. During the day, they attended the Foundations and Frameworks course. During the evenings, they participated in several social events (e.g., planetarium visits, campus scavenger hunt, bowling) to inspire community engagement and campus familiarity.

Due to the COVID-19 pandemic all the face-to-face instructions in both spring and summer 2020 sessions moved to remote instructions and all planned summer residential camps were canceled. The PI team pivoted to design and created a totally remote, two-week Summer Bridge program to deliver the learning frameworks and the foundation of content in both mathematics and chemistry to students choosing to engage and complete the experience. While this was labor-intensive in time and effort to the curriculum developers and instructors, the result was a program that reached over triple the number of students as in previous iterations (Table 1). Similarly, in the summer of 2021,

the PI team convened that it was best to deliver the summer bridge courses remotely with no face-to-face sessions on campus.

For the four years of implementation, the bridge courses have supported 295 students with a focus on Mathematics, Chemistry, and Engineering Technology. Table 2 shows the demographic information of the participants over time. The participants in the courses have passed target introductory STEM courses in more significant percentages (from 70% to 86% ABC letter grades) than their peers in the same semesters (around 40% to 65% ABC letter grades). The majority of the bridge course participants commented that the interactions with faculty and staff during the summer had provided appropriate guidelines for a successful first semester of college and thus helped promptly integrate them into their dynamics of college life.

Table 2: Demographic information of summer bridge participants since 2018.

Demographics		**Summer 2018**	**Summer 2019**	**Summer 2020**	**Summer 2021**	**Total**
Gender	Female	30%	57%	76%	74%	72%
	Male	70%	43%	24%	26%	28%
Race	White	50%	46%	38%	36%	38%
	Hispanic	30%	32%	33%	31%	32%
	African American	10%	21%	22%	22%	22%
	Multiple Races	10%	0%	1%	6%	4%
	International	0%	0%	3%	2%	2%
	Asian	0%	0%	3%	2%	2%
	Native Hawaiian	0%	0%	1%	0%	0%
	Unknown	0%	0%	0%	1%	1%

The student academic performance results provide an optimistic view of the designed bridge course's impact. The participants that fully engaged in the courses were motivated by the content and the learning experiences. Courses were delivered in a hybrid fashion at our institution, with classes help in-person and remotely for most of the 2020 and 2021 academic years. The bridge course participants experienced first-hand what remote instruction was before the academic year started. Thus, they had an excellent opportunity to develop remote learning strategies, which helped them benefit from this instruction method. Therefore, the summertime experience could explain the observed performance results in the target courses.

B - Incentivizing Undergraduate Research Resources

Increasing the retention of STEM majors to the levels indicated by the PCAST report [1] will almost certainly require programs that are not limited to better student preparation and improved learning techniques in first-and second-year courses. Sustained and more varied interaction between students and faculty beyond the classroom provides mentoring opportunities that retain students in their respective majors and better prepare these students for STEM careers. It is an accepted fact that research performed at the undergraduate level is beneficial to students and faculty [21-23]. Because of the often smaller class sizes and more focused attention we can provide

to our undergraduates, comprehensive regional universities such as SHSU are particularly well-suited to promote research at this level.

In Fall 2018, the center offered a pilot version of an undergraduate research course, cross-listed across several STEM departments. Its target audience was second-year STEM majors with no experience with laboratory work or research. Twelve students registered for the course from several STEM departments (i.e., math, physics, engineering technology, chemistry). The course was designed to introduce students to the benefits and diversity of STEM research, requiring each student to identify a potential research mentor and research topic. The development and implementation of the course were previously reported [24]. For Fall 2019, we planned to repeat the pilot course, but it was canceled due to low enrollment. This happened because departments preferred to handle research preparation at the departmental level rather than in an interdisciplinary course. This is due to two primary factors: (1) students are already constrained to take fewer courses than departments would like in their majors because of financial aid restrictions. When taken, the interdisciplinary course further reduces the number of courses taken in the major; (2) different departments value different approaches for developing ramps into research.

The STEM Center then moved from a single research course to avenues that can support all department content areas to meet our goal best to "strengthen student research and internship opportunities" for students at SHSU. The current approach is a non-course-based model for collaboration focused on developing adequate ramps into STEM research for students. This collaborative effort includes research training, communication, and community built around a framework to include a web gateway through the STEM Center site, establishing an LMS organization to develop and share research training resources, and encouraging STEM community collaboration. This has started a campus-wide conversation on building ramps into research and led to the idea of supporting multiple research entry courses in the future, which will be tailored by discipline.

Undergraduate research has been linked to post-secondary success and graduate school success and has aided student retention in the STEM disciplines. A key constraint in research mentoring and teaching is faculty time. To reduce faculty time spent on basic training while improving student learning in research courses, we will present the progress of a pilot project aimed at developing reusable active-learning modules for shared chemistry research instruments. The modules are housed in Blackboard. They contain initial training materials, simple experiments designed to get students on the instruments the first time, examples of the type of data, formative assessments, and cumulative assessments. The vision is to gradually build a community of interested faculty who collaborate in using and developing shared training resources. This pilot project is focused on chemistry instruments but can be expanded with appropriate modifications to other disciplines and cross-disciplinary collaborations. This pilot project is part of the STEM Center efforts to improve learning in the STEM disciplines at SHSU.

There are many challenges to conducting effective research and research training in an academic environment. These include the challenge of training each new cohort of students, procuring funding to support scholarship, maintaining instruments, assembling collaborations for broader scope projects, obtaining access to resources and equipment external to the investigator's laboratory, and accurately and compellingly describing institutional resources on grant proposals.

The primary goal of the *Ramps into Research Initiative* is to collaboratively build a student-friendly gateway to research at SHSU, and a repository of reusable interactive modules for training students in the methodologies most relevant to their research; in a manner that supports wise and efficient use of both the faculty mentor's and the student researcher's time. In the long run, the hope is that the *Ramps-into-Research* hub will also provide a structured platform for research collaboration and efficient safe instrument/method sharing and usage. Many undergraduate students even in their second year don't know that their professors are conducting great research. Being able to tell students could facilitate getting students involved early and effectively in research. Since, different labs have different requirements for participation, the hub will make these clear to students so that they know how to meet the criteria to line up research in an area of interest to them.

The faculty who initiated The STEM Center *Ramps into Research* (RintoR) collaborated with the Office of Research and Sponsored Program (ORSP) to establish campus-wide research collaboration and establish a research hub where researchers can share their research expectations for those undergraduate students who would like to be part of undergraduate research. The collaboration led to the creation of *Ramps-into-Research Learning Module Proposal Form* where faculty develop modules with undergraduate students.

The STEM Center has provided students opportunities to attend invited speaker series in more recent years. The speakers are selected to cover a range of fields and diverse backgrounds in STEM to open the opportunity for a variety of unique paths into the STEM workforce. The seminars provide student participants with STEM career options and guidance from the invited interdisciplinary speakers. Additionally, the STEM Center organizes workshops with information on admittance to graduate programs and opportunities available for Research Experiences for Undergraduates (REU) at the home institution and other external resources.

C - Improving STEM undergraduate education

STEM Center Mini-Grant Initiative: The STEM Center offers Teaching Enhancement Grants to STEM faculty members interested in working with students and improving teaching capability. The goal of the STEM CENTER Teaching Enhancement Grants is to incentivize the College of Science and Engineering Technology faculty to enhance their courses and related instructional activities, particularly for introductory courses of STEM majors.

Since 2019, proposals are solicited in three programs: (a) STEM Course Enhancement, these awards support enhancements in teaching and learning practices in introductory STEM courses (1000 or 2000 level) STEM Course; (b) STEM Active learning space, these awards support projects that directly utilize the available active learning rooms to innovate their teaching practices; and (c) STEM Scholarship of Teaching and Learning, these awards support educational research projects being conducted within COSET courses by the faculty. Since 2019, 37 total applications have been received, and 33 were funded. Funds have a maximum of $2,000 per academic year for faculty or students' materials, equipment, and salary.

Active Learning Resources: The project team created a Professional Development website in 2020 for Remote Active Learning tools to support and promote innovation in teaching through active

learning after surveying CoSET faculty. The STEM Center has researched, vetted, and compiled a list of tools and resources that help faculty adopt active learning for remote and hybrid teaching approaches [25].

STEM Center partners: The STEM Center at SHSU has partnered with the following organizations to enhance essential aspects of our program. Specifically, it has collaborated with:

- First Year Experience program, to co-sponsor two STEM Center Learning Communities for incoming students.
- Career Services, to jointly offer presentations and assistance to help students prepare for a future transition toward employment or advanced study.
- Office of Research and Sponsored Programs, Online Programming Staff, and the departments of Agricultural Sciences, Physics, Forensic Science, Engineering Technology, and Chemistry to collaborate on expanding the Ramps into Research initiative for improving retention and success in STEM through better on-ramps into undergraduate research.
- Professional and Academic Center for Excellence to present two seminars on STEM Center programs in the Annual Teaching and Learning Conference.
- Visitors Center, and Student Support Services, and the Office of the Dean of the College of Science and Engineering Technology to disseminate information on orientation events, publicity and recruiting of new students into the STEM Bridge Course.

Conclusions

The STEM Center has increased the number and quality of students successfully completing a STEM undergraduate degree by implementing a plan consisting of three major components intended to improve the learning experience of undergraduate STEM majors. First, the preparatory bridge courses equip incoming STEM students with adequate tools for success in traditionally difficult first- and second-year STEM courses. Secondly, the STEM Center broadens participation in STEM disciplines through offering and enhancing the resources for students to participate in research experiences at the institution. Finally, the STEM Center incentivizes faculty to improve the quality of STEM undergraduate education and provides resources for them to utilize in their projects like active learning spaces and information on research-based tools and strategies for effective teaching. So far, The STEM Center has broadened the capacity for STEM learning at … State University by adopting proven strategies previously used in a more limited setting to a more varied set of STEM disciplines. The STEM Center presents a strategy for increasing the quality and quantity of STEM graduates. Although more work is necessary, the project team is confident that the current model is sustainable beyond the funding period, and the approach can be smoothly transferred to institutions similar to SHSU.

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