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Comparative Analysis of the Impacts on Students' Interests in STEM through Implementation of Different Types of Learning Modules

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Abstract

With STEM jobs increasing by about 10% over the last few years, it is expected that "demand for skilled technologists will exceed the number of qualified applicants by 1 million". Hispanics make up 18.2% of the US population, however, they make up only 7% of the STEM workforce. The White House Initiative on Educational Excellence for Hispanics addressed the educational disparities faced by the Hispanic community and has helped to increase the number of Hispanics getting a high school diploma or a bachelor's degree. About 66.7% of Hispanics age 25 or more have a high school diploma or some post-secondary training, however, the corresponding percentage of those with associate degree or higher drops to 22.7%, while the percentage of those with bachelor's degree or higher drops to 15.5%. These drops in percentages as one progresses toward higher levels of education among Hispanics are quite alarming and do not bode well, especially if there is to be a representative distribution of participants in the future STEM workforce. In this project, different types of learning modules have been designed to increase students' interest in STEM, especially Aerospace Engineering. Seven different types of learning modules with a total of 12 options were developed. These learning modules were shared with high school teachers and community college faculty in settings where the majority of students are Hispanics. The instructors then chose the best options for their classes. In this paper, the authors will introduce the designs of 12 learning modules and discuss feedback from course instructors and more than 200 students collected through post-surveys. Survey data from instructors and students confirms that all modules have been used at least twice and in at least two semesters, even the two for which no input has been received from instructors. Six modules received sufficient counts of instructor responses for the input to be reliably interpreted. Eight of the 12 modules have reached a volume of student submissions that would limit the impact of intervening variables. Student ratings regarding how interesting the module was, the helpfulness of instructions, the learning they achieved, ability to apply the content, impact on interest in STEM and aerospace study and careers, and whether they would recommend the module to other students is considered module by module. Student and faculty ratings of the value of the modules differed at some points with both perspectives contributing valuable insight regarding the materials.

Project Background

In the United States, the number of STEM graduates lags behind the number of skilled technologists needed to maintain technical superiority from a global perspective [1]. There is also a significant underrepresentation of minorities (URMs) in the STEM workforce, especially Hispanics and women [1] [2]. With STEM jobs increasing by about 10% over the last few years [3], it is expected that "demand for skilled technologists will exceed the number of qualified applicants by 1 million" [4]. Every 3 out of 4 STEM jobs require at least a bachelor's degree [3]. Two major challenges in STEM education are that students who pursue STEM degrees often drop out and fewer of those who complete are women or minorities [5]. Studies [6] [7] observed that the URMs are disadvantaged in STEM. On average, these URMs are 16 times less likely to be ready for credit-bearing STEM coursework in college than their majority peers. The

Committee on STEM Education of the National Science and Technology Council in its 2018 report [8] identified goals to “increase diversity, equity, and inclusion in STEM”, and “prepare the STEM workforce for the future” for the US to be the global leader in STEM literacy, innovation, and employment. Rendón et al. [10] reported several perceived challenges that precluded the success of Latinx (gender neutral term) STEM students, which are the same as observed by several other social scientists [11], [12]. These are: “(1) Lack of culture of support, (2) Lack of educational resources, (3) Academic deficiencies, (4) Poor sense of belonging, (5) Lack of faculty support for Latinx STEM students, (6) Lack of STEM information to enter STEM fields, and (7) Limited utility of standardized test scores.” All but one of these areas denote challenges that go beyond academic preparedness [8], [12].

South Texas, though rich in natural resources and economic growth opportunities, remains historically underserved and economically disadvantaged with a majority (>68%) Hispanic population [13]. Coupled with a lower participation rate in STEM education (<4.8%) and a faster population growth (>21%), the gap in Hispanics’ higher education in STEM majors will continue to grow [14]. More specifically, there is a lack of a diverse and STEM-capable workforce that leverages the creativity and talents of all society to send humans again to the Moon and on to Mars. There is a strong need for aerospace-related employees in South Texas, and the number of available jobs keeps growing. Since there currently is no undergraduate program offering an Aerospace Engineering major available in South Texas, various intervention activities are required to motivate and support students to pursue studies in Aerospace Engineering and its related STEM fields [15], [16], [17]. Texas A&M University-Kingsville has worked closely with school districts and community colleges to implement different learning modules related to Aerospace Engineering in the last several years. Through testing various learning modules involving aerospace-related concepts and contents, this paper reports the findings of the impact of different learning modules on students’ interests in STEM and aerospace engineering.

Project Design

The project team developed different learning modules with NASA-relevant content for both high school students and community college students. The list of modules was shared with high school teachers and community college faculty. Each teacher/faculty selected at least one option from the list and implemented it in their classrooms. Each learning module involves hands-on activities and includes detailed instructions for teachers and students. The teachers selected the modules from the list to best aligned with their students’ needs. The project team provided the supplies needed to implement the modules in the classrooms and provided video instructions for selected hands-on activities.

There were seven different types of learning modules that, with opportunity to select different engagement patterns, resulted in a total of 20 options. They are as follows.

- Design Artemis 2 patch in a 2D CAD Drawing.
- Space Launch System with 3D CAD drawings (two options of different rocket systems).
- Recycled Bottle Rocket with household items.
- A real representation of the Solar System with household items.
- Commercially available kits with additional hands-on activities (13 options ranging from paper airplanes to drones and from rocket to robot cars).
- Aerospace Engineering Video Report (16 different videos provided).

- Aerospace Engineering Magazine Report (5 different magazines provided).

In the Laredo area, the implementation of learning modules by instructors at both the community college and local school district level formed an integral part of project-based learning initiatives within courses. At the college level, modules were implemented in courses such as College Physics, Physical Science, Introduction to Engineering, College Algebra, Calculus I, Calculus III, and General Biology. At the high school level, participating courses included Principles of Applied Engineering, Robotics, Aerospace Engineering, and Engineering Design.

The recruitment of high school instructors began with outreach to local school district supervisors, who recommended suitable candidates for participation. For instance, in a high school Principles of Applied Engineering class, 21 students participated in designing individual paper rockets. Upon completing their designs, students launched their rockets to evaluate which design achieved the greatest distance, fostering hands-on learning and critical thinking.

At Laredo College, instructors were recruited from the Mathematics, Natural Sciences, and Engineering, Design, and Construction Management departments. Selection was conducted on a voluntary basis and was contingent upon the ability to effectively integrate the learning modules into their curriculum. Instructors were provided with a list of learning modules tailored to their course objectives. For example, learning modules were successfully integrated into an undergraduate college physics course. In mathematics courses, the bottle rocket module was implemented, enabling students to calculate velocity and distance based on different rocket designs. Meanwhile, engineering classes focused on creating aerodynamic rockets, challenging students to optimize their designs for maximum launch distance. These examples highlight the diverse application of learning modules across courses.

In the Corpus Christi area, a total of nine instructors participated in the projects, who have backgrounds and experiences in Engineering, Engineering Technology, Computer Science, Geographic Information System, Artificial Intelligent, and Math. The instructor selected the learning modules to best fit the course subjects and the curriculum at the beginning of each semester. The on-site coordinator made sure there were no duplicated projects for the freshman level and sophomore level classes. Most learning modules are considered part of the required coursework in participating classes at Corpus Christi's Del Mar College. Students received extra credits if the learning module was optional in the classes. In addition, most of hands-on learning module activities were offered as group projects, while video or research-based activities were offered as individual projects. The groups' projects included building and launching water powered rockets and the solid-fuel powered rockets, building and programming robot cars, and building and flying model planes or drones. The individual projects included designing a patch logo for Artemis mission using AutoCAD, NASA Space Facility Mapping, integrating the new ChatGPT AI bot into research colonizing Mars, and watching different Aerospace Engineering related videos then writing a summary and reflections.

Project Results

A series of survey questions about the modules was developed. One set was for instructors while a second and similar set was for community college students who were taught using the modules. High school students who might have used the modules were not surveyed. This decision was taken due to the multiple forms and levels of informed consent necessary to complete such an undertaking (i.e., from school administration, district personnel, parents, and students) and the difficulty in coordinating and completing these. In the surveys, respondents were first asked to answer some demographic questions and identify the learning modules they experienced (for students) or used (for instructors). In this paper, the authors present the results based on the responses to the following questions related to the identified modules. Most questions below were asked for each learning module identified by either students or faculty:

- Overall rating of the learning module (1 representing "not valuable to students" and 10 representing "very valuable to students").
- Recommending the learning module to other students (only on student survey).
- Number of students used the learning module (only on instructor survey).
- Recommend the learning module to other faculty (only on instructor survey).
- Is the learning module of interest to students.
- Does the learning module help students learn STEM.
- Does the learning module help students increase their interest in STEM.

In the last three years, twenty-three of the 27 instructors who submitted ratings for the modules were community college faculty members. The other four were three high school teachers and one faculty member at a four-year college/university. There were between two and eleven instructors who provided survey responses for ten of the modules. Table 1 provides the list of modules with the number of instructors who submitted ratings following use of each, a crosswalk of the topics addressed on the instructor and student surveys illustrating where there is input from both groups (e.g., value for students) and topics about which one group was asked (e.g., number of students in the course, recommend to other faculty). To date, only four modules have achieved a volume of instructor feedback that can support interpretation; from most to least, paper airplane (n = 11), robot car kit (n = 7), rocket launch (n = 5), and the video report module (n = 5). The evidentiary standing of instructor ratings is summarized in Table 2.

Table 1: Number of Instructors Who Submitted Ratings Following Use of Each Module

Module	Number of Instructors responded		
	High School	Community College	4-yr University
2D CAD Drawing	1	3	
3D CAD Drawing		2	
Recycled Bottle Rocket		3	
Paper Airplanes with motors		10	1
Rocket Launch	1	4	
Circuit Drone Builder		2	1
Water Bottle Rocket Launcher		3	
Robot Car	1	6	
Cardboard Jets		2	1
Video Report		4	1

Table 2: Instructor Ratings: Evidentiary Standing of Each Module

Module	Evidence	Conclusion
2D CAD Drawing	Four informants (HS and CC); mixed evidence HS = moderate ratings, CC = high ratings	More evidence required due to mixed ratings

3D CAD Drawing	Two CC informants; maximum ratings	More evidence required
Recycled Bottle Rocket	Three CC informants; high ratings	More evidence required
Paper Airplanes with motors	Eleven faculty informants; YR1 = moderate ratings, YR2 = high ratings, YR3 = highest ratings possible	Adequate evidence of quality
Rocket Launch	Five CC informants; maximum ratings	Adequate evidence of quality
Circuit Drone Builder	Three CC informants; high ratings	More evidence required
Water Bottle Rocket Launcher	Three CC informants; partial submissions without ratings	More evidence required
Robot Car	Six CC informants and one HS; high to maximum ratings	Adequate evidence of quality
EZ Jets	Three faculty informants; maximum ratings	More evidence required
Video Report	Five faculty informants; high to maximum ratings	Adequate evidence of quality

The modules were employed with at least 199 students in the project's first year, at least 265 students in the second year, and at least 255 students in the third year. Among the student respondents, 79.1% identified as Hispanic and there were five racial identities present in the informant pool (2.3% African American, 3.25% Asian, 72.6% Hispanic/Latinx, 3.25% Other, 18.6% White). A minimum count is given as several of the faculty who provided ratings did not respond to the question regarding the number of students who had experienced instruction with the module. There may, also, be some duplication in the student head count each year and across years as no limitations were placed on whether more than one module could be offered to the same student group. Table 3 summarizes evidentiary standing of student ratings similar to the pattern used in Table 2.

Table 3: Student Ratings: Evidentiary Standing of Each Module

Module	Evidence	Conclusion
2D CAD Drawing	45 informants, 3 w/ all low ratings (depresses means, incrss SDs); min. 4 semesters of input	Adequate evidence of quality and impact
3D CAD Drawing	50 informants, same 3 w/ all low ratings (depresses means, incrss SDs); minimum 4 semesters of input	Adequate evidence of quality and impact
Recycled Bottle Rocket	33 informants, no outliers but scattered low ratings; minimum 4 semesters of input	Adequate evidence of quality and impact
Paper Airplanes with motors	26 informants, 1 w/ mostly low ratings (depresses means, incrss SDs); min. 4 semesters of input	Adequate evidence of quality and impact
Rocket Launch	47 informants, 1 w/ all low ratings (outlier depressing means, incrss SDs) other scattered low ratings; min. 4 semesters of input	Adequate evidence of quality and impact

Circuit Drone Builder	8 informants, no outliers; 2 semesters of input	More evidence required
Water Bottle Rocket Launcher	36 informants, 1 w/ all low ratings (depressed means, increases SDs); 4 semesters of input	Adequate evidence of quality and impact
Robot Car	50 informants, 2 w/ all low ratings and other scattered low ratings (depresses means, increases SDs); 6 semesters of input	Adequate evidence of quality and impact
EZ Jets	11 informants, 1 w/ all low ratings (depressed means, increases SDs); 2 semesters of input	More evidence required
Video Report	87 informants, scattered low ratings (related to ind. exp./pref.); 5 semesters of input	Adequate evidence of quality and impact
Magazine Report	4 informants, no outliers but scatter low ratings; 3 semesters of input	More evidence required
Solar System	5 informants, no outliers; 3 semesters of input	More evidence required

The authors combined data points from instructor and student surveys to arrive at parallel columns of top rated modules. Table 4 shows the average ratings of each module, where 10 represents the highest rating while 1 represents the lowest rating. The instructor column is shorter as there were ties in ratings at three points, for the top rated, eighth, and the unrated modules.

Table 4: Rank Ordering of Modules: Instructor and Student Ratings

Instructor Ratings	Student Ratings
1. 3D CAD Drawing $\mu = 10$ ($n = 1$) Rocket Launch $\mu = 10$ ($n = 5$)	1. 3D CAD Drawing $\mu = 9.15$ ($n = 50$)
2. Circuit Drone Builder $\mu = 9.75$ ($n = 3$)	2. EZ Jets/Space Flite Test $\mu = 9.0$ ($n = 11$)
3. EZ Jets/Space Flite Test $\mu = 9.67$ ($n = 4$)	3. Solar System: Real Representation $\mu = 9.0$ ($n = 4$)
4. Robot Car Kit $\mu = 9.0$ ($n = 9$)	4. Recycled Bottle Rocket $\mu = 8.90$ ($n = 33$)
5. Video Report $\mu = 8.90$ ($n = 1$)	5. H_2O Bottle Rocket Launcher $\mu = 8.67$ ($n = 36$)
6. 2D CAD Drawing $\mu = 8.67$ ($n = 5$)	6. Rocket Launch $\mu = 8.63$ ($n = 47$)
7. Paper Airplane with Motors $\mu = 8.51$ ($n = 11$)	7. Circuit Drone Builder $\mu = 8.62$ ($n = 8$)
8. Recycled Bottle Rocket $\mu = 8.50$ ($n = 3$) H_2O Bottle Rocket Launcher $\mu = 8.50$ ($n = 3$)	8. Paper Airplane with Motors $\mu = 8.46$ ($n = 26$)
9. Solar System: Real Representation N/A as $n = 0$ Magazine Report N/A as $n = 0$	9. 2D CAD Drawing $\mu = 8.37$ ($n = 45$) 10. Robot Car Kit $\mu = 8.03$ ($n = 50$)
	11. Video Report $\mu = 7.76$ ($n = 87$)
	12. Magazine Report $\mu = 7.50$ ($n = 4$)

The ratings submitted by instructors and students come from different perspectives and must, as a result, be weighted differently. The instructors are professionals who may have idiosyncrasies, preferences, and their actions shaped by local circumstances but who are expected to be able to transcend those to a significant extent to apply academic and disciplinespecific standards when assessing curriculum. Their ratings should be considered in this light, although there are three or fewer responses for all but four of the modules. Student ratings reflect personal perspectives and, in a voluntary response set like that being gathered, can be influenced by bias toward the material or instructor. They can also be influenced by factors the instructors would consider as ancillary, the setting, and even the peer group with whom the experience occurred to provide examples. There is also no means of controlling for prior experience with a process or topic that would make the content of the module less novel and appealing. However, a higher volume of ratings decreases the potential for pronounced impact from factors like these. Thus, eight of the 12 modules have or are approaching a volume of submissions that would limit the impact of intervening variables, twenty or more responses.

Another data point gathered that can serve as an indicator of quality is whether the informant would recommend the module to another student. Nine of the twelve modules received ratings of four or above on a five-point scale for this question. The other three, the Robotic Car, Video Report, and Magazine Report modules, have ratings above the mid-point on the five-point scale (3.94, 3.59, and 3.75 respectively) but below the upper quintan. The response counts, 50 and 87 respectively, for the first two of the modules are of good size making the ratings some of the most reliable in the data set. The third is far less reliable as there were only four informants. These modules are also the three that have the greatest number of means below the upper quartile in the student ratings sets.

Discussion and Conclusions

Instructors are using more of the curricular materials than they are providing information about. Survey data from instructors and students confirms that all modules have been used at least twice and in at least two semesters, even the two for which no input has been received from instructors (student informants noted experience with them). Instructors are using multiple units per course or in a semester across several courses as student reports indicate experience with one up to seven modules and in multiple semesters. The course modules have been experienced by at least 719 students, the total count reported with the instructor ratings, but it is known that some of the materials were deployed without information about their use being reported so the actual student user count would be higher. Although there is a need for further evidence from faculty users, the following can be said about the modules based on the submissions. The paper airplane with motors, rocket launch, robot car kit, and video report modules can be understood to have been adequately vetted and have demonstrated value to instructors.

The following statements summarize findings from both faculty and student inputs.

1) The modules were well-received and believed to have value for students although three mentioned above, the Robot Car, Video Report and Magazine Report modules, plus the 2D CAD Drawing module consistently received lower ratings than the others.
2) Materials presented interested the students although the Video and Magazine Report modules had interest ratings below 7.0 on a ten-point scale. It is possible that these modules contain critical information for skill development which has a less pronounced appeal. The instructor rating of 8.9 out of 10 for the Video Report module supports this idea.

3) Students reported at moderately strong to strong levels that all the modules produced the desired forms of learning although the 2D CAD Drawing, the Robot Car, and Video Report modules were consistently rated lower in this area than the other modules.
4) The written and video instructions were found helpful by students although some were rated lower with a few outside the upper quartile.
5) Students strongly agreed that the modules increased their interest in STEM.
6) Student ratings for increases in interest in degree programs and areas of specialization in their career were understandably lower than for increasing interest in STEM. It seems unlikely that one instructional module would strongly influence student degree and career plans although all means were in the third quartile of the rating scale indicating some impact.

Students showed great interest in the hands-on activities which allowed them to interact directly with the material and that foster curiosity, critical thinking, and problem-solving skills. On the other hand, the video report and research projects helped students process and internalize what they've learned. Incorporating these learning modules into course curricula yielded valuable insights. Students were encouraged to think critically as they applied theoretical concepts to real-world scenarios. Moreover, engagement levels increased significantly, as students were enthusiastic about testing their designs and competing to achieve the best results. The hands-on nature of the projects not only enhanced their understanding of core concepts but also fostered collaboration, creativity, and problem-solving skills. The project results revealed some interesting patterns and findings related to promoting aerospace engineering and its related fields in a region without an aerospace engineering undergraduate program.

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