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Recommended Citation

Chapman, A., Weimer, A. A., Torres-Avila, M., Trejo, C., & Racelis, A. (2022). The Effects of Teaching Undergraduate Freshmen Biology Courses in Spanish and English. *SN Social Sciences*, 2(11), 248. <https://doi.org/10.1007/s43545-022-00551-0>

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The Effects of Teaching Undergraduate Freshmen Biology Courses in Spanish and English

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Received: 1 March 2022 / Accepted: 19 October 2022
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Abstract

This study examines the attitudes and experiences of bilingual learners across two instructional types, identifying how the language of instruction affects the context of learning, and how the experience of the learners differs. Participants included 269 predominantly Hispanic undergraduate students in a general biology course attending a Hispanic Serving Institution in a bilingual community along the US-Mexico border. A bilingual faculty member, who recognizes the sociocultural and contextual factors that affect student learning and adopts a teaching philosophy founded in Culturally Responsive Practices (CRP) and valuing students' Funds of Knowledge taught the class. This study utilized a mixed method design including analyses of quantitative student learning outcomes and qualitative data on students' experiences in educational contexts. While all learners were enrolled in sections of the course in which the instructor used CRP, only half of the learners received instruction bilingually in Spanish and English, allowing a comparison of the effects of bilingual instruction. Analyses of student experiences and knowledge gained revealed significantly greater learning in the bilingual courses, compared to English monolingual sections taught by the same faculty member. Results suggest that the use of bilingual instructional approaches can lead to positive outcomes for bilingual undergraduate students. These findings can be used by educators and policy makers alike, with interest in promoting the academic and sociocultural development of bilingual undergraduate students.

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Keywords Cultural and linguistic diversity · Funds of knowledge · Bilingualism

Introduction

Higher education is slowly evolving to reflect changes in college students' socio-cultural, socioeducational, and sociopolitical diversity. There has been an increased focus on bilingual teaching practices related to an increased internationalization in higher education (Archila and de Mejía 2020). These practices could be useful for addressing the underrepresentation of Latinx students in Science, Technology, Engineering, and Mathematics (STEM) undergraduate programs, as many Latinx students are bilingual in Spanish and English. In this paper, we use the terms Hispanic and Latinx interchangeably as they have been referenced in previous research, though it is recognized that there is considerable heterogeneity among these groups and individuals within these groups may identify differently. Latinx was selected as a term to describe our sample as it describes people who relate to Latin American origin, while we recognize that the University of Texas Rio Grande Valley (UTRGV) is identified as a federally designated Hispanic Serving Institution (HSI).

Recent data suggest that this is a growing sample of the K-12 population. About 25% of children in the U.S. are of Hispanic descent and the 71% majority are from immigrant families living in Spanish-speaking homes (García and Jensen 2009). While research on the benefits of bilingual education in K-12 science classrooms has been conducted, less is known about bilingual science learning in higher education. The present study investigates the effectiveness of teaching multiple sections of an undergraduate freshman course, general biology, bilingually in English and Spanish, compared to those taught in English by the same instructor.

Learning in biology: a gatekeeper course

Retention of undergraduate students pursuing a STEM degree is multifarious but has been attributed, in part, to success in science and math courses during their first 2 years of college (Seymour and Hewitt 1997). Introductory science courses such as general biology and general chemistry have been identified as gatekeeper courses as they have a high attrition rate. Often, these courses are taught in large sections with the instructor as the *sage on the stage* who attempts to transfer knowledge passively. Contextual factors such as student engagement and cultural relevance are often overlooked by science faculty members, many who view science as an elite enterprise only for the best of the best. As a result, these introductory courses are often attributed as *gateway* courses, meant to segregate students based on ability, and often have high attrition rates. While performance in these courses qualifies students to advance in STEM studies, these courses have hindered students' enrollment in advanced STEM courses and retention in the STEM pipeline (Scott et al. 2017). This approach has been especially detrimental to women and students of color pursuing careers in STEM (Gallard Martínez et al. 2019).

It is imperative to focus on introductory science courses, often taken by first-year freshmen level students, when identifying barriers to student success in STEM. Gateway courses are especially useful contexts to consider for interventions aimed at promoting the success of underrepresented students in STEM. For example, Black and Latinx youth are as likely to enter STEM majors as their White peers but are also more likely to leave STEM majors (Riegle-Crumb and King 2010). When Black and Latinx students leave STEM majors, the disparity of underrepresented minorities in STEM careers persists (Garrison 2013).

Theoretical framework

Using culturally relevant pedagogy has also been shown to advance students' learning (Ladson-Billings 2000). Ladson-Billings' theory of culturally relevant pedagogy (CRP) emerged from her study of eight exemplary teachers of African American students (Ladson-Billings 1995). CRP has since become a pedagogical foundation based on three tenets: academic success, cultural competence, and socio-political consciousness.

The first tenet of the CRP framework is academic success. Ladson-Billings (1995) defines academic success as where student learning takes place, but not at the expense of the students' cultural identity. Academic success is more than making students *feel good* and should include students developing or having the intrinsic motivation to choose academic success. However, she makes clear that her idea of academic success is not to be conflated with the academic achievement tied to high-stakes standardized testing.

The second tenet is that teachers need to develop cultural competence. While many have incorrectly interpreted it as cultural sensitivity or cultural celebration, cultural competence means that teachers have the skills, mindset, and knowledge for "helping students to recognize and honor their own cultural beliefs and practices while acquiring access to the wider culture" (Ladson-Billings 2006).

The third tenet is sociopolitical consciousness and draws on Paulo Freire's (1970) work. Freire discussed the idea of conscientization or critical consciousness to help students become aware of the social, cultural, economic, political, and historical issues that have led to social injustices, inequities, and dominant ideologies in the classroom. If a teacher wants to facilitate student development of sociopolitical consciousness in the classroom, they need to encourage students to consider social justice issues. Culturally relevant science pedagogy has been found to lead to academic success with middle school students (Laughter and Adams 2012).

Xenia Meyer and Barbara Crawford (2011) believe "viewing science as a cultural way of knowing acknowledges that is laden with cultural understandings, interpretations, and a language of its own" (p. 531). The authors also emphasize the importance of learning the language of science for students whose first language is not English. As an example, they emphasized the importance of understanding the word *inference*. They highlight

Without directing greater attention to students' actual experiences in school science and how science may or may not align with students' diverse racial,

cultural, and linguistic backgrounds and understandings, these student groups will likely remain underrepresented in the sciences (p.530).

Valuing identity and heritage language

Students benefit when their instructors recognize and use their Funds of Knowledge (FoK), i.e., student knowledge brought from the home culture into the classroom (Moll et al. 1992). FoK are multifarious as they are the accumulation of the students' personal, cultural, and social knowledge, skills, and experiences. When curricula are designed with a FoK foundation, it makes it easier for students to connect their personal culture to learning the academic content. We consider heritage language, Spanish, part of students' FoK inventory. An important aspect of FoK is the idea of *confianza* or mutual trust between the teacher and students, which develops based on authentic and reciprocal exchanges. This creates a learning environment that recognizes and utilizes what the student brings to the classroom.

Research has shown that when Spanish English bilingual high school students are encouraged to use their Spanish as an asset, they are better able to acquire the academic vocabulary needed to learn the content in science classes (Chapman and McHatton 2022). These findings align with others who have identified ways to foster scientific literacy and English proficiency among emergent bilinguals. For example, Cory Buxton and Okhee Lee (2010) have suggested that one way to reduce the language-related cognitive load is to build scaffolds that allow students to demonstrate competency along multiple time points. By utilizing Spanish/English bilinguals' Latin foundation, the cognitive load is reduced. These findings offer a promising possibility that bilingual instruction for undergraduate students might also be effective and could be used to address the underrepresentation of Hispanics in STEM fields.

What motivates students in STEM?

Recently, it has been reported that psychosocial factors are especially important for traditionally disadvantaged individuals in STEM fields (Xie et al. 2015). For example, one well-known factor of general academic success is self-efficacy, the belief in one's own capacity to produce a desired outcome (Bandura 1997). Self-efficacy in STEM has been shown to predict the recruitment and retention of STEM students (Lent et al. 2003). Similarly, perceived identity compatibility predicts STEM persistence (Rosenthal et al. 2011). Students with less self-efficacy about STEM abilities are more reluctant to take a STEM education or career path (van Aalderen et al. 2019). In addition, students who hold incremental beliefs, or the idea that cognitive abilities or intellectual development can change as opposed to being rigid and fixed, have a stronger interest, sense of belonging, and identity compatibility for STEM majors (Lytle and Shin 2020). Student's engagement with their professors also affects their choice to pursue and persist as a STEM major (Gasiewski et al. 2012). Thus, it is important to examine how the instructor's language and behavior might affect student factors related to their

persistence such as academic self-efficacy, intrinsic and grade motivation, self-determination, and career motivation.

Purpose

While very little evidence is available on the effectiveness of bilingual instruction for university students, outcomes of bilingual science programs in K -12 are promising. This study explores the effects of teaching General Biology bilingually at one of the largest Hispanic Serving Institutions in the US. This study is part of a more extensive National Science Foundation (NSF) funded project to develop cultural relevance among College of Sciences faculty and students. The university demographics and the funded study provide a unique opportunity to focus on reconceptualizing instruction in a gateway course for Spanish English bilingual learners. The present study investigates the effectiveness of teaching a general biology course bilingually in English and Spanish. Specifically, we examined the following research questions:

1. What is the effect of teaching undergraduate students in a general biology course using a bilingual and culturally relevant approach?
 - a. What is the effect of bilingual instruction on student learning of content?
 - b. What is the effect of bilingual instruction on student attitudes toward science?
2. How did teaching a biology course using a bilingual and culturally relevant approach affect student perceptions?

Design and procedures

This study utilized a mixed method design which included analysis of quantitative student learning and survey outcome data as well as qualitative data which consisted of students' statements about their educational experiences. General biology classes taught entirely in English by the same instructor were assigned as a control, with only the treatment group receiving bilingual instruction. However, all courses were taught using culturally relevant pedagogy. To evaluate the effectiveness of the biology courses, students completed a pre-test during the first week of the semester and post-test in the last week of the semester. Both tests consisted of 40 multiple-choice questions covering all the learning objectives in the course. To determine the effect of the courses on students' attitudes toward language and science, students completed a pre-survey during the first week of the semester and post-survey in the last week of the semester. The assignment of control and treatment classes allowed for evaluating the effectiveness of the language of instruction across the two independent classes. The qualifications and approach of the teacher are provided in her own words, to contextualize the findings best.

Who was the teacher? The case of a culturally relevant bilingual biology professor

I describe my pedagogical approaches to teaching undergraduate biology courses and my culturally relevant approaches to teaching. I am from Puerto Rico, am Spanish English bilingual, and have a Ph.D. in Agronomy from Purdue University. Most of my students are from the Rio Grande Valley, an area along the US-Mexico border with a unique merged culture between Deep South Texas and Mexico. I embrace the uniqueness of this culture and geographical location and use contextualized examples to explain course information.

I bring examples from my Puerto Rican culture, but also integrate with students' cultures. Most of the time, I use food as an example because with food I can explain important science concepts. I use local crops such as *jicama* and *nopales* to explain plant morphological adaptation and the process of photosynthesis. I also use *nopales* as an example of a modified leaf and stem to explain CAM photosynthesis.

Explaining genetic concepts and chances of survival I describe chicken eggs, and how most do not become chickens, some end up as breakfast *tacos*, but because of the internal fertilization process, more chicken fetuses survive, as compared to fish that use external fertilization. This usually earns me a lot of laughs about the *tacos*, but it also resonates with students as they remember the lessons when eating breakfast. *Tacos*, a traditional and common Mexican food often made from corn tortillas, are used as examples alongside *elote* to explain the importance of diversity and/or domestication. Students are familiar with diverse ways of eating corn such as *tortillas* or *elotes*, a domesticated relative of the original plant. Humans selected desirable characteristics like soft, sweet kernels, which have been perpetuated in the crop's gene pool. By authentically integrating local foods into the content, I capture the students' attention in a large lecture hall classroom of over 100 students.

I have also used local precipitation and sunlight availability to explain secondary growth in plants. Annual precipitation in this area is very low, but sunlight is readily available. Regional plants can modify the opening and closing of stomata based on the availability of water and sunlight. Because sunlight is not limiting, plants have less stomata and fewer chloroplasts and because sunlight is more available, they need less chloroplasts to capture the sunlight that helps to produce oxygen and sugar through photosynthesis.

I integrate students' prior knowledge to help students make sense of new information. I also use regional music examples to teach how the nervous system works to differentiate rhythms based on one's prior knowledge and experience. When I first came to the Rio Grande Valley, I could not discern the differences between *cumbia*, *huapango*, and *banda*. Still, now, because of sensory development of the afferent and efferent pathways and association areas in my brain, I dance to *cumbia*. This has become part of our classroom discussions as some students state they dance to *cumbia* at their *quinceanera*, a traditional coming-of-age ceremony celebrated locally among Latinas.

Who were the learners?

Participants included 269 undergraduate predominately Hispanic college students attending UTRGV a large HSI in South Texas. According to the Office of Strategic Analysis and Institutional Reporting at UTRGV (2018/2019) from 2018 to 2019, 87.9–89.4% of the undergraduate student body were classified as Hispanic and non-white. Although no individualized demographic data were obtained about participants, characteristics of typically enrolling students are described below to provide course context and organization. Three semesters of students in General Biology I and II were included as the sample.

General biology is a requirement for major biology students; however, students from other disciplines take the course to fulfill their science credit hours. Most of the students are first-year undergraduate students. The course focuses on the fundamental principles of living organisms, including physical and chemical properties of life, organization, function, evolutionary adaptation, classification, and diversity of living organisms. Each course lasted 15 weeks, consisting of a lecture covering nineteen chapters and a laboratory component. The bilingual instructional approach was in the lecture, with lectures and discussions mainly in Spanish. Since the courses are departmental, the course textbook, online tools, handouts, and exams were in English. Students could select what language they wanted to communicate in class discussions or submit their classwork and assignments. The course instructor was bilingual in Spanish and English and had formal higher education in both languages.

Language and attitudes toward science

We also measured changes in students' attitudes toward language and science motivation using a modified version of the Science Motivation Questionnaire II or SMQ-II (Glynn and Koballa 2006). The SMQ-II examines five components: intrinsic motivation, self-efficacy, self-determination, career motivation, and grade motivation. The instrument was modified to add five components to examine the role of Spanish and attitudes. This was expanded by adding language items to better understand how students perceived Spanish in learning science changed throughout the semester (Table 1).

Results

Effects of bilingual instruction

To address Research Question 1a (the effects of bilingual instruction on student learning outcomes), we compared students' pre- and post-exam scores in the monolingual general biology courses with those in the bilingual sections. Initial analyses were conducted to examine if the two groups differed at

Table 1 Sample items of the science motivation questionnaire II

Component	Sample item	Sample item with language
Intrinsic motivation	I enjoy learning science	I enjoy using Spanish to learn science
Self-efficacy	I am sure I can understand science	I am confident my knowledge of Spanish will help me learn science
Self-determination	I spend a lot of time learning science	I spend a lot of time using Spanish to learn science
Grade motivation	Getting a good science grade is important to me	It is important to use Spanish to get an “A” in science
Career motivation	Learning science will help me get a good job	My knowledge of Spanish will benefit me in a science career

The Science Motivation Questionnaire II (SMQ-II; Glynn and Koballa 2006) has 5 components: intrinsic motivation, self-efficacy, self-determination, career motivation, and grade motivation. The language + SMQ examines the same five components with Spanish

pre-test. Given that the Levene's test for inequality of variances was significant, $t(228.58) = -4.68$, $p < 0.000$, we conducted a Welch's ANOVA test in place of the traditional ANOVA F test. This revealed that there were no statistically significant differences between the means of the groups at pre-test, $F(1, 409) = 3.53$, $p = 0.068$, $\eta_p^2 = 0.009$. This showcases that the two groups did not differ systematically at the study's forefront.

To examine the effects of the independent variable instructional type (monolingual versus bilingual) on the dependent variable: learning outcomes, we again conducted a Welch's ANOVA, because of inequality of variances, which was significant, $F(1227.42) = 21.89$, $p = 0.000$. The means for the bilingual sections ($M = 48.22$, $SD = 22.80$) were significantly greater at posttest than the monolingual section ($M = 42.92$, $SD = 19.03$), after controlling for pretest. There were no interaction effects. Thus, we conclude that teaching biology bilingually improves learning.

To address research question 1b (i.e., effect of bilingual instruction on student attitudes toward science), pre-survey scores on the modified SMQ-II were compared with post-survey scores given at the end of the semester. Initial analyses were conducted to examine if the two groups, monolingual versus bilingual, differed in attitude using gain scores. These were calculated by averaging the students' gains across the ten attitudinal components. We used gain scores, as they have been shown to offer advantages compared to alternative approaches in identifying significant treatment effects (Kim and Steiner 2021) in that we could best control for pre-survey attitudes. Given that the Levene's test for inequality of variances was not significant in this analysis, we conducted a traditional ANOVA F . A 2 (Instructional type) \times 10 (Component) repeated measures ANOVA revealed that there were no statistically significant differences between the means of the groups' gain scores for each of the science or science and Spanish language motivation components, as summarized in Table 2.

Despite no significant differences by instructional type, it was of interest to explore how student attitudes toward science changed given the use of CRP

Table 2 Mean gain scores on the modified science motivation questionnaire II by instruction type (monolingual and bilingual courses)

Component	English mean gain	Bilingual mean gain	Significance (p)	Effect sizes (Eta-squared)
Intrinsic motivation	-0.18	-0.14	0.75	0.001
Grade motivation	-0.16	-0.18	0.91	0.000
Self-determination	-0.14	-0.12	0.83	0.001
Career motivation	-0.09	-0.28	0.15	0.027
Self-efficacy	-0.27	-0.27	0.97	0.000
Intrinsic motivation + Spanish	0.52	0.46	0.74	0.001
Grade motivation + Spanish	0.41	0.42	0.97	0.000
Self-determination + Spanish	0.49	0.46	0.87	0.000
Career motivation + Spanish	0.41	0.11	0.15	0.028
Self-efficacy + Spanish	0.29	0.12	0.41	0.009

approaches in monolingual and bilingual courses, by collapsing across instructional type. One-tailed paired sample *t* test analyses (pairing pre- with post-survey responses; Table 3) in each component revealed two important findings. The first was that student attitudes toward science significantly decreased from pre- to post-survey in four of the five science motivation components with the fifth component (self-determination) trending downward toward significance at $p=0.03$. The greatest decrease was in self-efficacy ($M=-0.27$, $SD=0.50$), $t(79)=4.74$, $p<0.000$, $d=-0.53$, considered a medium effect size (Cohen et al. 2003). All science motivation components demonstrated small-to-medium effect sizes.

The second finding was that students' attitudes toward the role of Spanish language in science significantly increased across four of the five science attitudes + Spanish language components with the fifth component (self-efficacy + Spanish) trending upward toward significance at $p=0.03$ (Table 3). The greatest increases were intrinsic motivation + Spanish language ($M=0.49$, $SD=0.87$), $t(79)=5.012$, $p<0.000$, $d=0.57$ and self-determination + Spanish language ($M=0.47$, $SD=0.92$), $t(79)=4.59$, $p<0.000$, $d=0.52$, both with medium effect sizes (Cohen et al. 2003). All science + Spanish motivation components demonstrated small-to-medium effect sizes.

Note: Given that ten pairwise, one-tailed difference tests were conducted, we adjusted our a priori critical p value of 0.10–0.01. Instead of using 0.10, we used 0.10/10 or 0.01 as there were ten tests to control for the possibility of an inflated chance of falsely rejecting the null hypothesis (Type 1 error).

Student perceptions of bilingual biology instruction

To address Research Question 2 (the effects on students' perceptions), we analyzed data from student essays and the SMQ-II. For the essay, students were asked to respond to the following prompt: "In a few sentences, explain how the

Table 3 Mean pre-, post-, and gain scores on the modified science motivation questionnaire II

Component	Mean Pre	Mean Post	Mean Gain	Significance (p)	Effect size (Cohen's d)
Intrinsic motivation	4.29	4.13	-0.16	0.01*	-0.29
Grade motivation	4.73	4.56	-0.17	0.01*	-0.41
Self-determination	4.29	4.16	-0.13	0.03	-0.26
Career motivation	4.64	4.47	-0.16	0.01*	-0.30
Self-efficacy	4.36	4.10	-0.27	0.00*	-0.53
Intrinsic motivation + Spanish	2.58	3.07	0.49	0.00*	0.57
Grade motivation + Spanish	3.12	3.53	0.42	0.01*	0.31
Self-efficacy + Spanish	2.88	3.35	0.22	0.03	0.25
Career motivation + Spanish	3.54	3.82	0.28	0.01*	0.31
Self-determination + Spanish	2.88	3.35	0.48	0.00*	0.52

*Significant at $p \leq 0.01$

above course in which you are currently enrolled has impacted your studies here at UTRGV?”.

Initially, we used a priori codes established by Glynn’s science motivation questionnaire of self-efficacy, intrinsic motivation, self-determination, career motivation, and grade motivation (Glynn and Koballa 2006). Seventeen student essays were analyzed independently by the three authors, and discrepancies were resolved through discussion. Four predominant themes emerged: self-efficacy, intrinsic motivation, self-determination, and career motivation. We found that 82% of the students reported an increased self-efficacy toward biology and/or Spanish language, while 59% reported greater self-determination. In addition, 53% reported higher intrinsic motivation and 35% reported greater career motivation. For example, one student demonstrated a self-efficacy toward Spanish and learning biology:

“Growing up, Spanish was my first language. This course was the first time I ever took a bilingual course, and it helped me with comprehension, accountability, and discipline.” (Alonzo, a pseudonym)

This quote demonstrates that Alonzo gained awareness about the value of his native language while taking the course. Specifically, Alonzo has come to recognize that his knowledge and use of Spanish can help him learn content in biology. Beyond that, it has developed him as the whole person that will help him navigate the university landscape and be successful in his STEM journey. When educators connect with their students using an FoK framework, they help students develop intrinsic characteristics, such as self-efficacy, that can support their long-term success.

Another student indicated a self-determination toward Spanish and learning biology:

“Being a[n] Exercise Science major, the concept of biology is crucial for my future career [coded as career motivation]. In this course I got a better understanding of domains and kingdoms of organisms, such as plants and all species of animals [coded as self-efficacy and learning]. This course, being taught bilingual, allowed me to grasp a different perspective of science, it taught me the importance of being bilingual in the world of science. Being bilingual helps you understand science with a broader understanding, making it possible to connect two different cultures into the same concept.” (Tomas, a pseudonym)

Many Spanish/English bilingual students often have internalized messages around the stigmatization of their culture, including the Spanish language. However, Tomas recognizes his bilingualism as a strength that might afford him an advantage in pursuing a STEM degree and career. For Tomas, taking the course bilingually has opened his eyes as to how his cultural and linguistic background are assets. Tomas is developing what Ladson-Billings (1995) describes as a sociopolitical consciousness. Specifically, he has gained an awareness of how his bilingualism supports his learning, in contrast to the dominant narrative many Latinx students have internalized.

One student demonstrated several positive attitudinal measures toward Spanish and learning biology:

“At first, I was nervous when I heard this course was going to be a bilingual course. Although I am very fluent in both English and Spanish, I haven’t been in a bilingual course since I was in third grade. This course has changed the way I study for my exams [coded as self-determination]. I really enjoy the lessons being in Spanish [intrinsic motivation]. I really didn’t think I would understand as much as I do, but this class did the complete opposite [self-efficacy and learning]. I was able to understand more terms in biology than I ever had before [self-efficacy and learning]. My understanding of this subject has extended [learning], and I now have a whole new appreciation for biology [intrinsic motivation]. I love going to class and learning the new chapters [intrinsic motivation]. This course has made me think about taking more bilingual courses [career motivation].” (Antonio, a pseudonym)

Like other students, Antonio’s experience in this course has helped him develop a sociopolitical consciousness that challenges the dominant narrative that English is the *right* language and Spanish is the *wrong* language (Chapman and McHatton 2022). This newfound awareness has led to stronger factors linked to pursuing STEM degrees and careers including intrinsic motivation, self-efficacy and learning.

Similar changes were observed with other students. For example, one student stated

“This [course] has made me understand that the university I’m in is doing what it can to involve the minority of students who exclusively speak a first language that many people have yet to learn. This class has also forced me to take more time to study and learn the material to be able to succeed in the class and it has been reflective in my current grades [coded as self-determination and grade motivation]. Each class I take reminds me to not underestimate the amount of work I have to do every day to become successful.” (Jesse, a pseudonym)

While Jesse shows self-determination and grade motivation toward learning biology, he also recognizes the university’s commitment to valuing his culture. Like others, Jesse has developed a sociopolitical consciousness toward the role of Spanish in learning biology at UTRGV.

Similar themes emerged with Jessica:

“Biology has been a difficult course to take but taking it in Spanish has improved my overall grades [coded as grade motivation and self-efficacy]. I am grateful to have experienced this bilingual program, as it has not only helped me improve the way I study for biology, but for other classes as well [self-determination]. For example, I realized that I retain the information better when it is taught in both languages, as the information is repeated, it is easier for me to comprehend at a higher level [learning and self-efficacy].” (Jessica, a pseudonym)

Jessica explicitly states that biology has been difficult, but a bilingual modality improved her learning, her determination to learn, and her abilities to learn. She also recognizes that her bilingualism can help her learn in other courses.

In addition, two students demonstrate a strong intrinsic motivation and self-efficacy toward science:

“This bilingual biology course made me appreciate my roots and my studies more because it makes me feel like, even though I’m considered a minority because I’m a Hispanic, it is still possible for someone like me to be something great as well [coded as self-efficacy]. It made me be more hopeful for what is to come [intrinsic motivation].” (Jesus, a pseudonym)

“I love science and it is something that does interest me [intrinsic motivation]. This class has helped me learn more about Biology but has also helped strengthen my Spanish skills and helped me use the language more in my studies [self-efficacy].” (Jacqueline, a pseudonym)

While Jesus sees himself as able to do science well and connect his culture to learning science, he also recognizes it can help him in his career. Jacqueline also sees herself as capable of doing science well, has a love for science, can learn both biology and Spanish. Both students acknowledge that leveraging their cultural and linguistic Funds of Knowledge will help them on their STEM journey.

We learned from the students’ comments that incorporating bilingual instruction into the biology courses allowed them to embrace their languages and culture as important assets to contribute to STEM fields. Some of the bilingual course students stated that they would like to have the opportunity to take more courses in a bilingual format. Even though some students were fluent in both languages in a US region many Spanish-speaking individuals, this was their first course using a bilingual approach. Consequently, they were not confident at the beginning of the course. However, at the end of the course, many enjoyed the experience and believed they not only learned biology but also indicated a more positive attitude toward learning biology in a bilingual format.

In summary, students who took the bilingual general biology course developed many intrinsic and extrinsic characteristics known to influence academic success in STEM and pursuing STEM careers that students in the monolingual English general biology course did not (Glynn and Koballa 2006). This includes self-efficacy, intrinsic motivation, self-determination, grade motivation, and career motivation. More importantly, these characteristics were positively influenced by an instructor who implements instruction through culturally relevant and FoK frameworks. Next, we discuss the implications of how these frameworks can mitigate the effects of underrepresentation of Latinx students in STEM.

Discussion

Spanish English bilingual instruction in undergraduate biology

We conducted this study to explore a bilingual and culturally relevant approach's effectiveness to teaching undergraduate students in a general biology course. Historically, studies focused on understanding the barriers to Latinx students' success in STEM fields have focused on racial and ethnic group differences, often arising from standardized test score differences (Quinn and Cooc 2015). In contrast to deficit models (Ladson-Billings 2007), we examined how cultural assets integrated into the learning context might benefit students' knowledge acquisition and learning experiences. Further, we interpret our findings within the context of the social, cultural, political, and historical factors influencing Latinx students' STEM journey. In this way, we address a gap in the literature regarding the effectiveness of bilingual instruction in higher education. Based on our findings, we offer two conclusions. First, bilingual instruction in a general biology course improves Spanish-English undergraduate students' learning outcomes. Second, we conclude that students' learning outcomes and attitudes toward science are improved when the instructor utilizes a culturally relevant framework. These findings are consistent with past studies focused on elementary and secondary education populations and expand the literature to include higher education.

For example, research has demonstrated that elementary students' math and science learning outcomes in dual language immersion (DLI) programs are greater than students not participating in DLI (Tran et al. 2015). Similar conclusions arose from research on secondary students learning in science (Madrid and Barrios 2018). Our findings at the undergraduate level are consistent with the research conducted at the elementary and secondary levels in that bilingual instruction or dual language programs lead to greater learning outcomes for students.

Our second finding that culturally responsive teaching leads to greater learning outcomes and improved attitudes toward the role of Spanish in learning biology is attributed to the instructor, Author 3, who uses a culturally responsive approach in her teaching. She is a native Spanish speaker from Puerto Rico with a Ph.D. in Agronomy from Purdue University. She recognizes the value and importance of native Spanish in her students' lives and her own. More importantly, she recognizes and embraces the similarities and differences between her culture and her students' cultures in the Rio Grande Valley. Given that she has employed these strategies, she has integrated two tenets, academic success, and cultural competence, of Ladson-Billings (2006) into her practice. This is what Ladson-Billings considers a strong cultural competence. Even though the control course was taught in English, she used culturally and linguistically affirming pedagogies in all courses that leveraged students' FoK including their knowledge of Spanish such as *elote*, *cumbia*, and *quinceñera* she has engaged students in learning that connects their culture to learning content. Not only is the integration of FoK and culturally relevant pedagogy done authentically, but it also does so in a way that engages her students in a large lecture setting.

Large classes have become the norm for General Biology at large universities and they are characterized as traditional lecturing that does not engage the student in meaningful learning (Huba and Freed 2000). It also allows her students to see they belong in STEM and can contribute because of their unique perspective. By creating a trusting learning environment in which the teacher immerses herself in her students' culture and vice versa, the student can see themselves as belonging to the world of science. This has the potential to broaden and advance the discipline by moving the discourse beyond the traditional Western science paradigm, ultimately shifting the development of new scientific knowledge described as a Eurocentric and patriarchal endeavor (Wolfmeyer et al. 2017).

While students' attitudes toward the role of Spanish in science increased across all five domains, their attitudes toward science alone decreased across all five domains. The loss of interest in and positive attitude toward science in undergraduate gatekeeper courses is consistent with previous reports (Scott et al. 2017). The conclusion is that attitudes toward the role of Spanish are improved when FoK and culturally responsive teaching are utilized as they affirm students' culture, including language. Teaching bilingually preserves heritage language for Latinx students and keeps students connected with academic support systems premised on their home language.

Our results revealing a decline in attitudes toward scientific career pursuit are consistent with past findings of declining interest levels among underrepresented racial and ethnic minority students pursuing a career in medicine from their Freshmen to Sophomore year (Barr et al. 2008). Similarly, others have found that student attitudes toward science decreased in introductory general biology courses but were also short-lived as most student attitudes rebounded over time (Young et al. 2018). These findings were not unexpected because gateway courses such as freshman biology are often perceived as challenging courses that lead students to discontinue their pursuit of STEM careers. However, we posit that when students are taught with a culturally relevant and FoK approach, students' self-efficacy, interest, and motivation toward science improve. Given that choosing a STEM major is dependent on students' intrinsic motivational attributes such as attitude and self-efficacy (Wang 2013), findings from this study suggest that Latinx students' pathways to STEM can be substantially improved through bilingual instruction, not only because it leverages their knowledge of both languages, but because it is culturally and linguistically affirming.

Study limitations and future directions

The present study had several limitations. For example, the learning and science attitudes outcomes were compared at the course level instead of an individual level without considering additional variables such as gender, level of proficiency in English and Spanish, and socioeconomic status. Future research should examine the effect of bilingual instruction by examining these additional demographic variables. It might be that students with greater linguistic proficiency in Spanish, English, or those who are balanced bilinguals experience differential benefits from bilingual

instruction or that students of low income make greater gains than those with more resources. As we learn more about the characteristics of students who make the most gains and those who do not, we can better understand how to meet the needs of Spanish English bilingual students.

The results do not rule out the possibility of covariates' influences or complex relations among the variables. For example, while we contend that students' attitudes toward the role of Spanish in science likely increased because of the bilingual course design, other factors may be at play. The bilingual instruction could have validated the students' Spanish language as an asset and their cultural identity as whole, cascading into a positive career for diverse students. This possibility was suggested as one student noted, "Even though I'm considered a minority because I'm a Hispanic, it is still possible for someone like me to be something great as well." Future research should measure cultural and career identity development to examine how bilingual instruction might build these aspects of student identity.

Another study limitation was that we only examined the impact of instruction at limited time points—three semesters, which is not guaranteed to be representative across all years of students' academic experience. While the present study focused intentionally on freshman level gateway courses, future work should examine the longitudinal effects of bilingual instruction and/or compare the effects among freshman and senior level courses. It is possible that offering bilingual instruction to students in advanced courses has unique advantages such as facilitating their acquisition of academic vocabulary in Spanish just prior to entering the workforce when it can be freshly applied. This study also was limited to only biology courses at one institution. Offering bilingual courses across disciplines at multiple sites would allow comparisons to be made that could provide more specificity about the impact of bilingual instructions. Similarly, exploring the use of bilingual resources (textbooks, supplemental instructional material) would help determine which, if any, aid in student learning.

Summary

In sum, we have demonstrated that culturally relevant and FoK-based curricula positively affect Latinx students' learning and interest in STEM. The key to success was the instructor's utilizing culturally relevant and bilingual instruction that leverages students FoK. This helps students develop a sociopolitical consciousness of how being Latinx and bilingual are valuable assets in their STEM journey. When instructors teach students how to challenge the elitist assumptions about who belongs in STEM, students' gain greater awareness of how their unique cultural and linguistic identity will strengthen their STEM identity and help them make valuable contributions to science careers.

Acknowledgements This study was funded by the National Science Foundation, award # 1832523. We thank Yaritza Marin and Stephanie Garza-Ochoa for their assistance with data collection and management.

Data availability The data that support the findings of this study are not openly available due to approved Institutional Review Board (IRB) policies but are available from the corresponding author upon reasonable request and with UTRGV IRB approval.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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