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ORIGINAL PAPER

Instructional models for the acquisition of English as bridges into school science: effects on the science achievement of U.S. Hispanic English language learners

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Abstract Science educators have suggested that, for minority and low-income students, gaps between home and school science cultures necessitate 'border crossing' for successful learning in science. Our analysis used National Assessment of Educational Progress 2000 and 2005 data to assess the impact of U.S. state-level policy regarding instructional models for language acquisition for the learning of science. Specifically, we assessed whether policy favouring structured English immersion led to better student outcomes than bilingual education among Hispanic English language learners in 4th and 8th grades in the U.S. We found significantly higher science achievement among 4th grade Hispanic ELLs in states with stronger bilingual emphasis in their policy, suggesting that policy support for bilingual education could provide a better bridge to span the cultural gap between home and school science, at least for younger students.

Keywords Bilingual education · Educational policy · Linguistic minorities · Science achievement · Second language acquisition

Introduction

Science achievement among new immigrants, particularly those also struggling to learn the dominant language, is an issue of considerable importance in many economically developed countries in Europe, North America and elsewhere that receive large numbers of immigrants. Although the children of immigrant families will form an increasing

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proportion of the workforce in the future (American Association for the Advancement of Science 1993; Business Roundtable 2005), few of these calls for innovation have specifically addressed the learning needs of language minorities. Language minority status and race interact powerfully in the U.S., with Hispanic youth particularly 'at risk' of low achievement and disengagement (Fry 2007). As the largest and fastest-growing minority group in the U.S. and with 79 % of English language learners (ELLs) being Hispanic (Lazarín 2006), it is clear that addressing demands for a more scientifically literate workforce and citizenry must include strategies for meeting the needs of Hispanic ELLs. This analysis evaluates the differential effect of two major instructional models of language development [bilingual education and structured English immersion (SEI)] on science achievement in eight U.S. states that have high proportions of Hispanic students.

Cummins (2000) asserts that academic fluency in one's native language is a prerequisite for acquiring academic fluency in a second language. This theory might help to explain why some researchers have found immersion strategies (i.e. programs that focus exclusively on students' second language) to be effective (e.g. Rossell and Baker 1996) whereas others have found bilingual education to be more effective (e.g. Slavin and Cheung 2005). Notably, researchers have found that the level of academic native language proficiency hinges on socioeconomic status (e.g. Hoff 2003)—a variable that is believed to differentially influence the efficacy of instructional methods. To date, however, the empirical basis for Cummins' theory is somewhat nebulous (August and Shanahan 2006) and it has not been tested for its tenability or generalisability (i.e. nationally, across groups of ELLs with varying levels of socioeconomic status, and in different subject areas). MacSwan and Rolstad's (2005) case studies, for example, suggest possible limitations of Cummins' theory.

Within this context, two broad instructional models for the acquisition of English are still contested: SEI and bilingual education. Bilingual education is based on the Interdependence Hypothesis (Cummins 1979). This theoretical approach asserts that, for individuals who have not had formal schooling in their native language, academic instruction in the native language fosters academic proficiency (in the native language). The effective transfer of knowledge or proficiency to the second language is enabled given sufficient exposure to the second language. Although bilingual education programs tend to share the basic premise of providing academic instruction in the student's native language as they also acquire English, there is also much variation across programs (Freeman 1998), and the laws addressing the linguistic provisions for instruction of ELLs vary substantially across those states, a point to which we will return later. Proponents of SEI, the language development instructional approach that replaced bilingual education in the states of Arizona, California and Massachusetts, claim that immersion settings promote English acquisition and achievement more quickly than bilingual education (e.g. Rossell 2002). California eliminated bilingual education in 1998 by popular vote with the passage of Proposition 227. Soon after, Proposition 203 (2000) eliminated bilingual education in Arizona. Massachusetts, the first state in the nation to enact bilingual education in 1971 (Transitional Bilingual Education Bill), eliminated bilingual education with the passage of ballot measure Question 2 in 2006.

There remains considerable disagreement about the relative effectiveness of these two basic models to improve dominant language skills in the first instance and secondly to strengthen academic achievement in ancillary subject areas such as science, mathematics and social studies. Clearly, policy decisions about school-based second language development approaches are also intimately linked to broader policies on immigration, a hotly debated issue in the United States and elsewhere. Thus, the need for a systematic, empirical investigation of the impact of various instructional models for the acquisition of English is acute. A report by the National Literacy Panel also concluded that the impact of socio-cultural context, of which state policy is one element, is an understudied aspect of language acquisition (August and Shanahan 2006). In a prior study, when we examined state legislation about instruction for language acquisition across states with the highest concentration of Hispanic students, we found that a stronger bilingual emphasis had a statistically significantly positive effect on fourth grade National Assessment of Educational Progress (NAEP) reading achievement scores among both Hispanic ELLs and Hispanic non-ELLs (Lopez and McEneaney 2012). Here, we shift our attention to assess the impact of this state-level policy on science achievement, a particular area which has been subject to a paucity of scholarly research (Lee 2005), and present quantitative analysis using NAEP data from 2005, comparing patterns to those in 2000 prior to when much of the major reform initiatives took root.

Two instructional models for English language acquisition

In the U.S., there are essentially two state-level models based on dissimilar philosophical frameworks and potentially dissimilar instructional opportunities for the acquisition of English: (1) SEI and (2) bilingual education. SEI is sometimes referred to as 'English-only' instruction. Although federal policy does not specify the kind of support that ELLs receive, in cases where states or schools implement SEI, federal policy requires schools to include some kind of structured support, but this support is variable in extent. There are several bilingual education models in the U.S., but all include instruction in the student's native language and varying amounts of English instruction. In many ways, the SEI approach is a 'back to the future' sort of innovation, as it harkens back to much earlier periods of immigration, during which ELLs were expected to pick up English via a sudden, complete immersion experience. States including Arizona and Massachusetts have followed California's 1998 implementation of SEI programs in an apparently accelerating U.S. trend. These reforms attributed poor performance and high dropout rates among ELLs to bilingual education. Considerable research effort has evaluated the effect of the two different types of instruction for language acquisition on reading achievement. Trends are ambiguous, but more recent and rigorous studies of reading achievement effects give the edge to bilingual education over SEI (e.g. Greene 1998; Rossell and Baker 1996; Slavin and Cheung 2005). No similar body of previous research has involved evaluating the effect of language acquisition instructional models on science achievement.

One issue, then, is whether the newer SEI approach in fact produces better student outcomes than the more established bilingual education model. However, it would be an oversimplification to label state-level policy as falling neatly into one camp or the other, given the historically common roots and overlap, and the considerable variation in the degree to which bilingualism and even biculturalism is encouraged as opposed to a strict immersion approach with very little time for transition allowed. We therefore developed a measure of *bilingual emphasis,* rating states on a scale of 0–5 based on the strength of the state's policy in promoting bilingualism. We discuss details of the construction of this measure in the section on data and methods.

Race, language minority status and science achievement

Minority students' management of the conflict between their own culture and the dominant school culture has been characterised as cultural 'border crossing' (Aikenhead and Jegede

1999) because acquiring Anglo-European school science culture often demands that minority students marginalise their own culture (Jegede and Aikenhead 1999). Lee (2003, p. 466) explains that, for ELL students, their experience in home and community environments, as well as their linguistic and cultural experiences are "sometimes discontinuous with science disciplines as traditionally defined". For example, while the norms of Western science and contemporary school science emphasise active questioning, home experiences and cultural backgrounds of some ELL students reinforce respect for authority in a way that discourages a questioning mode of learning. If students do not adapt to the dominant science culture, their participation in school science and subsequent achievement can be restricted.

Science entails general literacy (of the kind that immersion strategies might promote), but it also has distinct language conventions (Laplante 1997; Settlage et al. 2005), such as precise terminology that often has a different meaning from the same words in colloquial usage. Research in ELL education (Lee 2005; Rosebery and Warren 2008) stresses the overlap of second-language learning with the treatment of scientific language as a language, including a constructivist philosophy, an inquiry orientation, and building from concrete experience to abstract knowledge. Settlage et al. (2005) note, however, that implementing a fully inquiry-oriented science classroom environment, which involves doing and questioning first and learning appropriate language and concepts later, could conflict with suggested general protocols for working with ELL students (e.g. Echevarria et al. 2000) that emphasise a structured introduction of new language prior to other classroom activities.

Thus, although there have been no instructional models proposed for teaching science specifically to ELL students (Settlage et al. 2005, p. 51), the question of how to provide appropriate scaffolding for science learning at all grade levels remains. What might this effective science instruction for ELL students look like? Such instruction, according to Lee (2003, p. 483), helps students to become both "bilingual and bicultural, to cross borders between the language and culture of Western science and their home language and culture".

We argue that, for Hispanic ELLs, the bilingual education model is most likely to provide the needed support to ease the cultural and linguistic border crossing described in the literature. Bilingual education has been characterised as creating an 'additive' rather than 'subtractive' school learning environment that views home language and culture as educational assets rather than deficiencies (Gándara and Rumberger 2009; Stritikus and Garcia 2003; Valenzuela 1999). Such an environment might provide a type of cultural 'bridge' that allows easier passage into Westernized school science, resulting in higher average levels of achievement.

Data and methods

Our core data source for this analysis was the NAEP for U.S. fourth and eighth graders, as administered in 2000 and 2005. Although the NAEP program assesses reading and mathematics achievement every 2 years, science and other subjects are included less frequently, such as in 2000 and 2005. We focused on seven states with the highest proportion of Hispanic or Latino residents: Arizona, California, Colorado, Florida, New Mexico, Nevada and Texas (U.S. Census Bureau 2010). To add geographical and policy variation, we also included respondents from the Midwestern state of Wisconsin in the analysis. Figure 1 provides a map of the states included in the analysis. The NAEP program has been in existence since 1969, and is commonly referred to in the U.S. as the Nation's Report Card. Beyond the legitimacy bestowed by its longevity, a major advantage in using NAEP in this evaluation of state policy is that the complex samples of schools and then students within those schools are drawn to be representative of individual states. Other large-scale studies, such as Trends in Mathematics and Science Study (TIMSS), drew samples that are representative of national systems. However, in strongly decentralised educational systems like the U.S., where major policy decisions and funding for education are implemented (and vary considerably) at the state/provincial level, an evaluation of policy is best accomplished using samples drawn to represent those more local jurisdictions. It is not a longitudinal data system that follows a sample of students over time, but rather cross-sectionally administered, a fact that we return to later.

Another advantage of NAEP is that it also includes a large representative sample of ELLs for the states included in this analysis. Moreover, NAEP's measure of science achievement is broad and multifaceted, as it is in other subject areas, with items representing the National Assessment Governing Board's science framework. The measurement approach relies on item response theory (Lord 1980) through the use of matrix sampling; each student answered 25–30 items in the three content areas of earth, life and physical sciences. Item formats included multiple-choice and constructed-response questions and the assessment included hands-on performance tasks at both grade 4 and grade 8. Unlike in previous administrations, language accommodation, such as use of a bilingual dictionary or bilingual test booklet, was permitted in the science content portion of the assessment. However, in 2005, only about one-fifth of eighth grade ELLs received accommodation and about one-third of fourth grade ELLs. After administration of the test, NAEP generates five 'plausible values' that represent an estimate of the student's achievement in the three content areas, as well as an overall composite science achievement measure (Johnson 1989).

Our choice to analyse data from 2000 and 2005 was critical to an evaluation of state-level language acquisition instruction policy, because of major shifts in these policies in several states occurring around 2000. In particular, as discussed previously, states with significant ELL populations such as California and Arizona renounced bilingual education and adopted a policy of SEI in 1998 and 2000, respectively. These state-level policy shifts would not be expected to have immediate impact on student learning because some time is required to adjust curriculum and instruction to align with policy. Thus, the grade 4 and 8 cohorts of ELLs participating in NAEP in 2000 would not have experienced the shift away from bilingual education and toward SEI; the vast majority of ELL students across all states would have been receiving instruction under a bilingual education model, albeit with variation in terms of quality of implementation. In contrast, ELL students participating in the 2005 NAEP from California and Arizona would have received a significant amount of instruction based on the SEI model. This would be particularly true in these two states for fourth graders who, by 2005, would have received instruction shaped by the SEI policy mandate for all their years of formal schooling. For ELL eighth graders in 2005, the differential effect of state-level bilingual education versus SEI policy would be somewhat muted, since some of the eighth graders in SEI states would have received some instruction in the early grades using a bilingual education approach. As a consequence, the 'purest' test of the impact of bilingual emphasis on science achievement would be with fourth grade ELLs in 2005. We hypothesised that science achievement among eighth graders in 2005 would show less of an effect, and both grade cohorts in 2000 would show no consistent pattern of effects, because the major shift in some states toward SEI had not been fully implemented.

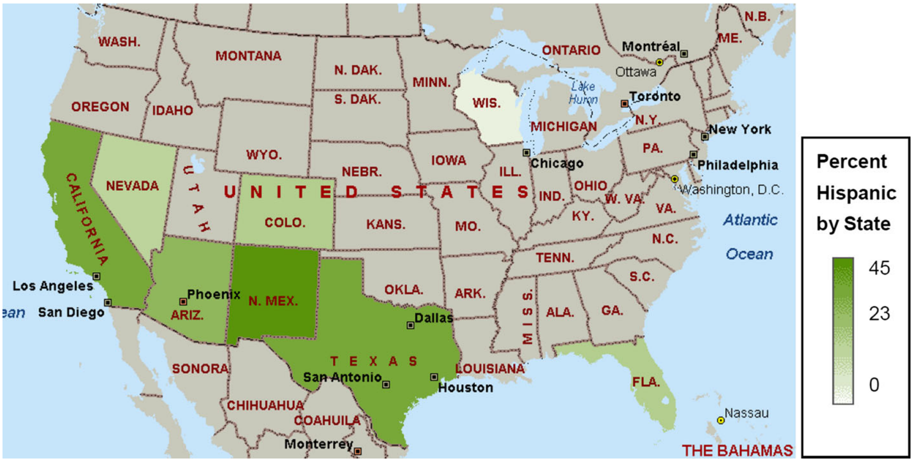

Fig. 1 Percentage of Hispanic students in different states

We used the National Center for Education Statistics' online Data Explorer (http://nces.ed.gov/nationsreportcard/naepdata/) to produce basic analysis from the Grades 4 and 8 NAEP from 2000 and 2005. The online Data Analysis System produces state-level means and standard errors for earth, life, and physical science achievement, as well as composite science achievement, adjusting for complex sampling and the use of plausible values. Statistical tests comparing group means are adjusted by the online system for multiple pairwise comparisons in accordance with False Discovery Rate procedures. To compare the effect of the major SEI policy initiatives in California and Arizona, we also analysed analogous data on fourth and eighth grade science achievement in 2000. In that year's administration of NAEP, however, not all eight states met reporting standards for the group of Hispanic ELLs, which was our focus, and so means could not be computed for all states.

There are some shortcomings in using NAEP's online Data Explorer. This bivariate analysis tool generates achievement means for state jurisdictions among subgroups defined by no more than three characteristics or variables. Furthermore, it allows neither control for multiple additional factors (such as state-level variation in the implementation of the language acquisition instructional program) nor adjustments for key individual and school-level effects that could vary systematically across the Hispanic ELL populations in the eight states considered. For the analysis here, we calculated composite science achievement score means for each state for the subgroup of Hispanic ELLs who were not designated as learning disabled. Although this essentially bivariate analysis is not the most robust test of the effect of state-level policy on language acquisition instruction, our comparison of patterns across the two critical years of 2000 and 2005 ameliorates some of the problems. Specifically, if we can assume that there have been no *other* major changes between 2000 and 2005 in policy or implementation that would affect science achievement scores for Hispanic ELLs, or if those changes are randomly distributed across the states in the analysis and not correlated to changes in language acquisition instruction policy, then controlling for these effects within a statistical model is less crucial. Similarly, including these effects in our analysis is somewhat less critical if we can assume that there have been no major changes in characteristics of the populations of Hispanic ELLs during this time period (i.e. immigration status, socioeconomic status, residential segregation), or if these changes occurred randomly across the eight states in our analysis. Therefore, our bivariate analysis rests on the assumption that the major relevant variable that differs between states in the analysis is the language acquisition instruction policy, particularly the degree to which bilingual education is emphasised or, as in the case of states that adopted SEI, rejected.

A key feature of our analysis, as mentioned previously, was our construction of a rating scale of the bilingual emphasis in state-level policy based on criteria as follows. It is critical to note again that these criteria are the basis of a measure regarding the content of policy, and not the *implementation* of the policy, which is likely to vary to greater and lesser extent from the letter of the policy (Coburn 2004; Meyer and Rowan 1977). Nevertheless, as state education policy in this area is subject to vigorous political debate (Holmes 1998; Medina 2002), its effects are worthy of analysis in their own right.

States that were assigned the highest rankings were those mandating instruction using students' native language; Texas and New Mexico were both assigned a ranking of five. In New Mexico, the Bilingual Multicultural Education Act, 22, Article 23, (New Mexico Statutes Annotated 1978) asserts that "the state's bilingual multicultural education program goals are for all students, including ELL" (p. 6.32.2, New Mexico Administrative Code). Texas law (Acts of the 67th Texas Legislature 1981) requires each school district with an enrollment of 20 or more limited English proficient students in the same grade level district-wide to offer a bilingual education program.

Wisconsin law (Ch. PI 13 2002) requires schools within a school district to design a program, prepare a formal plan of services, and staff respective classrooms with licensed bilingual teachers when there are at least 10 ELL students in grades K-3 or 20 in grades 4 and higher within a single school building. Wisconsin was assigned a rank of four because districts are not obligated to provide services when student numbers across different schools within the same district meet the state minimum threshold for mandated assistance as is the case in Texas.

Florida law (Section 1003.56, F. S.) and Colorado law (Section 1111, b, 1) outline linguistic provisions for ELLs; however, language programs can include English as a second language (ESL), immersion or bilingual education. Given that Florida and Colorado neither mandate nor outlaw bilingual education, they were assigned a rank of three. Although Nevada law (NRS 388.405) also includes linguistic provisions that can include ESL, immersion or bilingual education, Nevada was categorised as two because "Nevada has very few bilingual programs. The few that exist are located in the Clark County School District" (Nevada State Board of Education 2002, p. 54, para. i). California law (California Education Code §§ 300–340 1998) replaced bilingual education with SEI, but the law allows bilingual education in cases for which parents of ELLs have signed a waiver. In such cases, schools must provide bilingual education when there are at least 20 ELLs with waivers within a grade level; however, students with waivers in schools where the minimum of 20 students is not met must be allowed to attend other schools that provide bilingual education. Given the allowances made by the law (see Rossell 2002), California was assigned a rank of one.

Bilingual education was also replaced by SEI in Arizona (Arizona Revised Statutes §15–751 2000). To receive a waiver in Arizona, however, students must demonstrate proficiency in English, be at least 10 years old, or be identified as having special needs with confirmation that instruction in English is not the best option for the child. The differences in waiver requirements between California and Arizona resulted in Arizona being assigned a rank of zero.

To review the logic of our analysis, in all of these states included, the language instruction model was in place as state policy for at least 5 years in 2005. Eighth graders in Arizona and California, for example, would have received what was essentially SEI for only about half of their time in school, while fourth graders would have experienced essentially one model or the other for their entire school careers, assuming that they did not move into the state. In 2000, grade 4 and 8 students in Arizona and California would have had almost no exposure to SEI approaches. Thus, the analysis of fourth grade science achievement in 2005 represents the best test of our central hypothesis that States with stronger bilingual emphasis have higher mean science achievement scores for Hispanic ELL students. We did not anticipate strong relationships between state bilingual emphasis for eighth graders in 2005 and especially for fourth and eighth graders in 2000, because SEI approaches had not been implemented for any significant amount of time. As argued above, we believe that bilingual approaches are more likely than SEI to create an additive school environment that provides a bridge not only between the first language spoken at home and the dominant language of English spoken at school, but also between the home culture and Westernised school science.

Results

Figure 2 shows a scatterplot of a state's bilingual education emphasis rating versus the states' mean composite science score among non-disabled grade 4 Hispanic ELL students in 2005. For the states of Arizona and California, this cohort of students received their entire formal education under the SEI approach (i.e. under the weakest policy of bilingual emphasis). Figure 2 underscores the notion that Hispanic ELLs in general have low achievement in science, because mean scores for fourth grade Hispanic ELLs in *all* states considered fall at or below the NAEP-designated 'basic' standard of 130. The pattern relating bilingual emphasis and science achievement in Fig. 2 is clear: States with weaker bilingual emphasis (Arizona, California and Nevada) had lower mean composite science achievement than states with stronger bilingual emphasis. Using adjusted comparisons of multiple pairs, there were no statistically significant differences between means for Arizona (115), California (114) and Nevada (113) (p values ranging from 0.65 to 0.79, family size = 0.28).[1] Colorado, Florida, Wisconsin and Texas had means ranging from 124 to 130. Among this group, there were no statistically significant differences (p values ranging from 0.16 to 0.79, family size = 0.28), but all of them had significantly higher means, adjusted for multiple comparisons using the False Discovery Rate procedure, than each of the weaker bilingual emphasis states of Arizona, California and Nevada (p values ranging from 0.013 to less than 0.0001, family size = 0.28). States with stronger policy on bilingual education such as Texas and Wisconsin had the highest mean achievement, although science achievement in New Mexico was somewhat lower than we would have anticipated given that state's high rating of bilingual policy. Mean science achievement among New Mexico's Hispanic ELL students was significantly lower than the mean in Texas (120 vs. 129, $p = 0.0006$, family size = 28), but significantly higher than the mean science achievement of California's Hispanic ELLs (120 vs. 114, $p = 0.016$, family size = 28).

[1] For security purposes, NAEP Data Explorer does not provide the number of cases analysed. P values for the pairwise comparison of state subgroup means were adjusted for multiple comparisons, with family size corresponding to the number of unique pairwise comparisons involved.

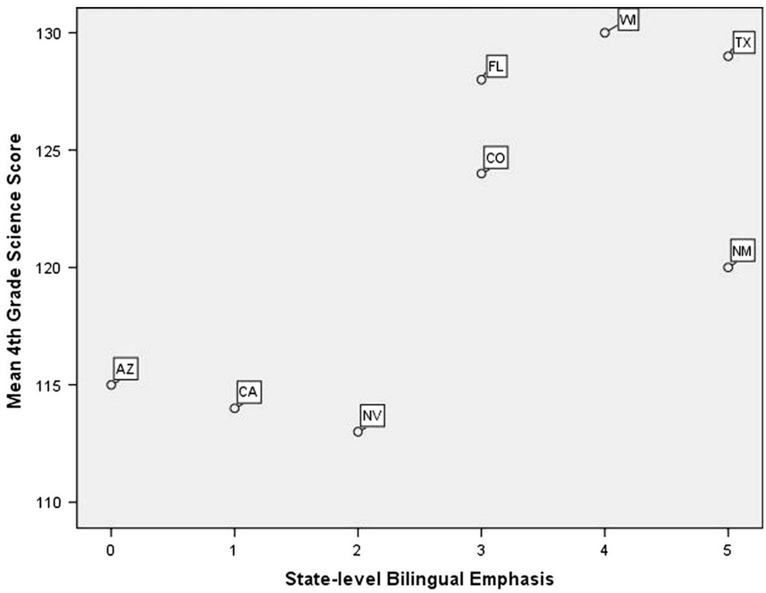

Fig. 2 Mean NAEP science score for 4th grade Hispanic ELLs by bilingual emphasis in State Policy, 2005

Thus Fig. 2 shows a pattern that supports the central hypothesis that higher science achievement among Hispanic ELLs occurs in states with stronger bilingual emphasis (as opposed to a SEI approach).[2] In particular, however, the effect of bilingual emphasis in state policy on science achievement is not linear. Instead, it appears that there is a break point between bilingual emphasis ratings of two and three such that, at least among the states that we considered, states that rated three in terms of their bilingual education policy tended to have substantially higher achievement than states with lower bilingual emphasis ratings.

Figures 3 and 4 show results for cohorts of students who, in the cases of Arizona and California, received most of their formal schooling *prior to* the implementation of SEI approaches, and therefore were subject to a mixture of bilingual and SEI. Figure 3 shows the results for eighth grade Hispanic ELLs in 2005. Wisconsin did not have a sufficient number of cases to meet reporting standards and therefore could not be included in the analysis. As expected, bilingual emphasis does not have as strong an effect as it did with the fourth grade cohort. The state with the lowest mean science achievement was Texas (science achievement mean = 100), which also rated among the strongest in terms of bilingual emphasis. Conversely, Arizona, with the weakest bilingual emphasis rating, had one of the higher means at 109. Florida, with mid-level bilingual emphasis, was also among the low scoring states in terms of eighth grade science achievement. In fact, the only statistically significant difference between state means is that Colorado (science achievement mean = 114) and New Mexico (mean = 110) had higher achievement scores than Texas ($p = 0.0025$ and $p = 0.0042$ respectively, family size = 21), with all three states having somewhat to very strong emphasis on bilingualism in state policy. In general,

[2] This pattern holds when we analyse science achievement subscores in Earth Science, Life Science and Physical Science.

then, Fig. 3 does not show a clear pattern of stronger bilingual emphasis being associated with higher science achievement among Hispanic ELLs. However, we did not anticipate a strong association, because this cohort of students in Arizona and California received instruction under a bilingual education policy for most of their formal schooling.

We should note, however, that Fig. 3 again reflects especially low science achievement for Hispanic ELLs across all states in our analysis, because the mean of even the highest scoring state of Colorado (114) was substantially below 143, the level of 'basic' proficiency for eighth graders on this assessment.

We analysed the patterns among fourth graders in 2000 in Fig. 4 as an additional test of the converse condition to Fig. 2. As with the eighth graders in 2005, fourth graders in 2000 would have had very little exposure to instruction under SEI policy in California (at most about 1 year, with the referendum approved in 1998) and no exposure in Arizona because the relevant proposition was passed there in 2000. As with the analysis of eighth graders, there was no clear association between bilingual emphasis and science achievement, and in fact statistical tests showed no statistically significant differences between any of the means shown in Fig. 4 (p values range from 0.08 (for New Mexico-California comparison) to 0.98 (Texas-Arizona), family size = 10). (Note, however, that the three states of Wisconsin, Colorado and Florida did not meet reporting standards and so state means could not be calculated.) Again, we were not anticipating a pattern of association between bilingual emphasis and science achievement for this cohort because students in Arizona and California did not receive much, if any, formal instruction in the newly implemented SEI approaches.

Because means for only three states were available from the NAEP Data Explorer for eighth grade Hispanic ELLs in 2000, we do not show those in a scatterplot. New Mexico's Hispanic ELLs scored significantly higher (science achievement mean of 122) than the analogous groups in California (mean = 0.96; $p = 0.0009$, family size = 3) and Texas (mean 103; $p = 0.0253$, family size = 3); there was no statistically significant difference between science achievement means for Hispanic ELL eighth graders in California and Texas in 2000. This result is as hypothesised, because this sample of students would not have been exposed, in terms of actual instruction, to the full spectrum of instructional models (based on the strictest SEI state policy, with no bilingual emphasis to full bilingual/bicultural policies rated highly in terms of bilingual emphasis).

To summarize, then, as we looked across fourth and eighth grade cohorts in 2000 and 2005, we anticipated that only Hispanic ELL fourth graders in 2005 would show a pattern of positive association between the bilingual emphasis of a state's education policy and mean achievement in science. This was so because, by 2005, fourth grade students in the states at the lower end of the bilingual emphasis scale (Arizona and California), had received all of their formal schooling under policy mandates for SEI, an instructional model that is distinctly opposed to bilingual approaches. Subsequent analyses of other cohorts demonstrated that it is not the case that Arizona, California and Nevada (states with weaker bilingual emphasis) are simply weak in terms of science achievement because of inferior curriculum, inadequate funding or other factors. Rather, these states sometimes scored rather high when Hispanic ELLs were not subject to SEI policy mandates. Conversely, our analysis showed that the pattern in Fig. 2 cannot be explained by claiming that strong bilingual emphasis states like Texas and New Mexico happen to have high science achievement among Hispanic ELLs because of better curriculum, teachers with better content knowledge, or other characteristics. Instead, we saw that cohorts in these states often scored about the same as cohorts from Arizona and California before those states' policy embrace of SEI.

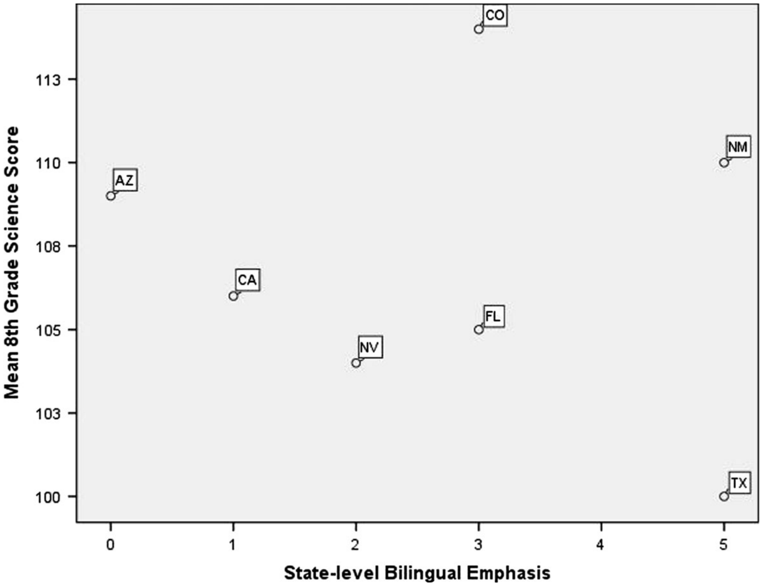

Fig. 3 Mean NAEP science score for 8th grade Hispanic ELLs by bilingual emphasis in State Policy, 2005

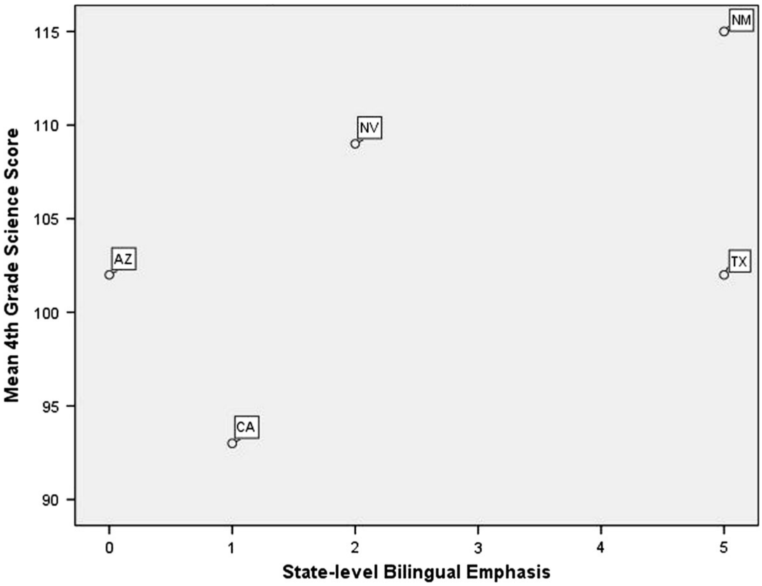

Fig. 4 Mean NAEP 4th grade science scores for Hispanic ELLs by bilingual emphasis in State Policy, 2000

Discussion and implications

Policies that de-emphasise bilingual pedagogy, such as SEI, have been promoted in a growing number of U.S. states as a reform strategy for improving educational achievement for ELLs, in contrast to existing bilingual education models. Our preliminary analyses suggest that this claim is not supported by the results from the 2000 and 2005 NAEP data on science achievement. In 2005, fourth graders in Arizona and California, where SEI policy existed during their entire formal schooling, score significantly lower in NAEP science on average than Hispanic ELLs in the states that adopted a stronger bilingual education policy. This correlation cannot be attributed to other state-level characteristics that were stable over the previous 5 years because fourth grade Hispanic ELLs in Arizona and California scored about the same in 2000 as their counterparts in other states in our analysis. Likewise, this correlation cannot be attributed to other state-level characteristics present in 2005 that would have stable effects across grade levels because we found no association between bilingual emphasis and science achievement of eighth grade Hispanic ELLs in 2005.

Yet, the analysis here shows that the effect of bilingual emphasis in state policy is only partial as well as non-linear. For fourth graders in 2005, for example, New Mexico and Texas had significantly different mean science achievement, even though both states rated five on the level of bilingual emphasis in state policy, indicating clearly that bilingual emphasis does not explain most of the variation in the means. Moreover, results from that cohort in Fig. 2 also show that there was a relatively equal level of science achievement at the lower end of bilingual emphasis, including not only the SEI states of Arizona and California, but also the somewhat more bilingual education-friendly state of Nevada. There is then a jump in mean achievement from the moderately low bilingual emphasis of Nevada (2) to the moderately higher bilingual emphasis in Colorado and Florida (3), with mean science achievement again leveling off across higher bilingual education states. Thus, there could be a ‘tipping point’ after which more intensive bilingualism in schools is not helpful in terms of science achievement (although it could be a positive and contributing factor to some of the many other functions of formal schooling, such as building an active citizenry.) Alternatively, there could be additional factors to consider when rating the strength of state-level bilingual education policy.

Addressing the partial nature of the effect of bilingual policy emphasis as well as potential non-linearity would necessitate a much more complex statistical analysis. Nonetheless, pending more sophisticated analysis with multilevel data with both substantive and control variables at the individual student, school and state levels, it appears that bilingual education might provide a better, but by no means perfect, bridge into school science that helps Hispanic ELLs cross the linguistic and cultural gap that can exist between home environment and school science, particularly for fourth graders. As additional NAEP science achievement data become available, it will also be possible to trace these relative effects on eighth grade students as well, because that cohort of students in Arizona and California would have been taught with under mandated SEI approaches throughout their formal schooling, thereby offering the most effective comparison with the impact of long-standing policies supporting bilingual programs. An even more potent test, of course, would be to use representative data collected longitudinally on ELL students and their schools and states to trace the impact of state policy at the macro-level down to the meso-level effect on implementation at the school or district level as well as its micro-level effect on individual students, along with control variables at each level. Although individual states including Florida and Texas are beginning to establish longitudinal data collection on public school students (Calder Center 2011), there has been no public discussion of turning NAEP into a longitudinal research scheme. While there are major longitudinal educational data collection and research efforts in the U.S., such as the Early Childhood Longitudinal Study and the High School Longitudinal Study of 2009, unlike

NAEP, samples drawn from these studies are representative of the U.S. as a whole but not representative of individual states. For decentralised education systems such as the U.S., Canada and Germany, drawing samples that are representative of the relevant political unit (i.e. at the state or provincial level) is essential for gauging the effects of education policy.

If additional research confirms these initial findings that a stronger bilingual education emphasis in state policy contributes to a more positive learning environment in science for Hispanic ELLs, more research would be needed regarding the details of implementation of the policy, including impacts on local funding, teacher training and development, and fidelity during implementation to policy guidelines. Further research could establish, for example, what kind of scaffolding support tends to be available for ELLs in bilingual education classrooms that tends not to occur in SEI classrooms. Such research must be sensitive to the demands of both sides of the cultural and linguistic divide between the home and community experiences of many ELL students and that of Western science and school science as traditionally defined. Another challenge for future quantitative or qualitative research is to avoid treating the experiences and needs of ELL children and youth as monolithic, disregarding issues of poverty and immigration status (Goodwin 2002).

An important question when moving forward, however, is to what extent policy emphasising bilingual education can be effective in social contexts where there are many different language minority communities such as in Berlin, New York and Amsterdam, along with countless smaller communities in immigrant-receiving countries, rather than a single, relatively large linguistic minority group. Among the many economically developed countries that are major receivers of immigrants whose home language is other than the dominant language, more comparative research is needed about the variations in instructional models for the acquisition of English and their relative effectiveness, not only in improving literacy skills, but also across all academic subject areas, including science, that are thought to be vital for sustained contributions to society.

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