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Not everyone is the same: How Demographic, Contextual, and Instructional Factors Contribute to Mathematics Identity in Various Student Populations

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Abstract

Research suggests a positive mathematics identity is associated with increased achievement and engagement in mathematics. However, previous large scale research on mathematics identity has examined students as a homogeneous group, ignoring differences that may exist due gender, race, or ability level. Additionally, research examining conceptual instruction has focused on the effect it has on achievement, but not on the way it improves identity. This study addresses these two gaps by examining the contribution conceptual instruction makes to the mathematics identity of students and how that contribution differs when considering race, gender, and achievement. This secondary analysis of survey data from the High School Longitudinal Study of 2009 uses multiple regression to investigate the relationship between conceptual instruction and mathematics identity in a sample of over 23,000 ninth graders. I divided the sample by achievement level to look for different relationships between samples of low and high achieving students across the United States. Findings show that conceptual instruction positively contributes to student mathematics identity and reveals race to be a significant moderator in this relationship.

Introduction

Over the past few decades a considerable amount of research has focused on the affective components of education (Middleton et al., 2017). Education is no longer seen as a merely cognitive experience, but a social and emotional one as well, and these additional components have a powerful influence on student engagement, persistence, and achievement (Bishop, 2012). One important construct that has become relevant in mathematics education research is that of students' mathematics identities. Martin (2006) describes a mathematics identity as,

the dispositions and beliefs that individuals develop... about their ability to participate and perform effectively in mathematical contexts and to use mathematics to change the conditions of their lives..[It] encompasses a person's self-understanding of himself or herself in the context of doing mathematics... It also encompasses how others "construct" us in relation to mathematics. (p.206)

A mathematics identity influences the way students respond to the questions, "Who am I? Where do I fit in? Where do I belong?" (Oyserman, 2001, p.499). As students evaluate their responses to these questions it influences

their future performance, success, and persistence in mathematics (Cribbs et al., 2015). Given the influence it has on students' effort and decision making in mathematics (and related subjects), there is a need for research that clarifies how students construct their mathematics identities and identifies steps educators and families can take toward strengthening the identities in students.

One branch of current identity research investigates the connection between mathematics instruction and the development of students' mathematics identities. Researchers outline a strong theoretical connection between learning experiences in mathematics and student identities (Bishop 2012). Students' mathematics identities can be indirectly influenced by teachers who are sensitive, provide quality feedback, and utilize quality instructional learning formats (Miller & Wang, 2019). Additionally, students who engage in problem solving may be more likely to develop identities which include mathematics as part of their envisioned futures when compared with students who learn in lecture-based settings (Boaler & Greeno, 2000).

The National Council of Teachers of Mathematics (NCTM, 2014) declared that current mathematics education places too much emphasis on learning procedures without connecting them to meaning, understanding or application. They further claim the emphasis on high stakes assessment creates a focus on rote learning while neglecting the deeper problem solving and reasoning tasks. The research cited above suggests that in addition to decreased understanding, the deficiencies the NCTM noted may contribute to diminished student identities in mathematics as well. When instruction fails to develop meaning and conceptual understanding, students are less likely to see themselves as being good at mathematics or envision how it relates to their lives. The current research investigates the influence conceptual instruction may have on students' mathematics identities and how that influence may vary according to race, sex, and achievement level.

Conceptual Instruction

In order to develop strong identities in mathematics, students need instruction that builds connections across concepts so they will understand relationships and be able to think flexibly with mathematics. The NCTM has called for instruction that promotes conceptual understanding and reasoning along with procedural fluency (NCTM, 2014). Conceptual instruction can be achieved in a variety of ways. Problem based learning, inquiry learning, discourse, and modeling are just some of the approaches explored in effort to increase the conceptual knowledge students develop through their mathematics instruction. In this paper I assume that any instructional approach can be used to build conceptual knowledge so the issue is not about the method of instruction, but rather the deliberate efforts a teacher makes to focus on building conceptual understanding.

In a critical response to Principles to Actions (NCTM, 2014), Martin (2015) stated that the goal of high-quality mathematics education for all was rhetoric that had been repeated for years without practically being addressed. He specifically claimed that African American, Latin@, Indigenous, and poor students are not having their need for a quality education addressed. There is evidence to support this claim. Research shows that students from racial minority groups or low-income families are more likely to be placed in lower tracked mathematics classes where they make little or no academic progress (Ansalone, 2004; Gorski, 2008). Unfortunately, in many lower

tracked, or below-level, mathematics courses, mathematics instruction is inferior to instruction in higher level classes and is not taught in a way that develops deep conceptual understanding (Ansalone, 2004). Instead, instruction in these classes focuses on rote memorization and algebraic manipulations (Kilpatrick et al., 2001; Larnell, 2016).

Instead of exposing students in these classes to conceptual instruction, which might help them create meaning in mathematics, they are frequently limited to curriculum that is so simplified and procedurally based they only ever see mathematics as a vague, disconnected, abstract set of rules and procedures with no connection to their interests or futures. The fact that students are inequitably assigned to tracked mathematics classes and therefore prohibited access to quality education is an important issue, but not the objective of this paper. As Martin (2015) suggests, the historical record does not engender hope in a future overhaul of educational policy that would alter the inequity in education. However, I submit that continual minor improvements should eventually contribute to significant changes that will improve equitable education. One such change may come through changing beliefs and instructional practices pertaining to below grade level mathematics classes. Focusing on conceptual instruction in classes that traditionally rely on procedures and memorization will increase the quality of mathematics instruction for students who have historically been left behind and may help them develop stronger mathematics identities.

In this paper I take a nuanced approach to examining how the focus a teacher places on conceptual instruction relates to the identity development of their students. Miller and Wang (2019) found that teaching practices influenced student identities differently for Black and white students. This makes sense because mathematics identities are tightly linked to students' beliefs about race, gender, and social class (Hannula et al., 2016). Instead of treating all students as a homogeneous group I hypothesize that the influence of conceptual instruction may vary according to race, gender, or prior mathematics achievement. By identifying these differences educators can take a more informed and deliberate approach to truly improving mathematics education for all students.

Method

The purpose of this study was to use large scale data to examine the relationship between conceptual instruction and student mathematics identity. Specifically, this study answers the following research questions:

- 1) How does the emphasis a teacher places on conceptual instruction in ninth grade relate to students' mathematics identity as measured in the HSLs:09 dataset?
- 2) Does conceptual instruction contribute to mathematics identity differently for students when considering past achievement, race, and gender?

The information in Table 1 summarizes my research questions and how they will be investigated.

Research Design

This study is a quantitative secondary analysis of the HSLs:09 data set (Ingels et al., 2013). A secondary data

analysis allows researchers to utilize large, high quality data sets to provide representative samples and bring greater breadth to their study. The HSLs:09 used a nationally representative sample of over 23,000 ninth grade students from over 944 schools across the United States. The study used a two-stage stratified sampling process,

Table 1. Summary of Research Questions and Method of Analysis

Research Questions	Data Source	Data Analysis
1) How does the emphasis a teacher places on conceptual instruction in ninth grade relate to students' mathematics identity as measured in the HSLs:09 dataset?	HSLs:09 data Student baseline year and 1 st follow up instruments Math teacher instrument	Multiple Regression
2) Does conceptual instruction contribute to mathematics identity differently for students when considering past achievement, race, and gender?		

Note. HSLs:09 = High School Longitudinal Survey, 2009

First identifying and selecting eligible schools to participate and then randomly selecting ninth-grade students from within the schools. Schools were categorized according to the following three criteria: a) school type (i.e., public, private-Catholic, private – other), b) region of the U.S. (i.e., Northeast, Midwest, South, West), and c) locale (i.e., city, suburban, town, rural). These criteria were used to create 48 different sampling strata which then led to the selection of a nationally representative sample of schools. Once the school sample was selected, between 20 and 50 students were systematically selected to ensure a sample that represented the school population in terms of gender and race/ethnicity.

Study Sample

The participants in this study included two different subsets of the HSLs:09 sample, determined by algebraic reasoning assessment scores. All HSLs participants took an algebraic reasoning assessment as part of the study which provided a measure of student mathematical understanding. To look for differing effects in various subpopulations of students, I created two groups of students based on their ninth-grade algebraic reasoning (AR) scores. Students who scored in the top 40% of students are referred to as High AR students, and those who scored in the lower 40% are referred to as Low AR students.

A summary of the demographic information relevant to the study sample is found in Table 2. The two groups of students came from very different socio-economic backgrounds. The SES_U scales from the HSLs:09 data set considers family income, parent educations and occupations, and school urbanicity. In the current study the students in the Low AR group had significantly lower SES_U scores ($\bar{X} = -.31, SD = .66$) than students in the high AR group ($\bar{X} = 36.08, SD = 7.8$).

Multiple researchers suggest that differences exist in how students develop their mathematical self-beliefs. Gender and racial differences have been suggested for how students interpret feedback or influences from teachers, family, and peers (Usher, 2009). Examining students in the low AR and high AR groups separately can provide additional clarity for how teacher instructional priorities may influence students' mathematics identity development differentially by achievement level, as well as by gender or race.

Table 2. Demographic Information for the Study Sample

Characteristic	<i>N</i> (Low AR)	% (Low AR)	<i>N</i> (High AR)	% (High AR)
Male	3910	51.7	4903	51.3
Female	3660	48.4	4648	48.7
White	3702	48.9	5742	60.1
Hispanic	1601	21.2	1118	11.7
Black	1217	16.1	576	6.0
Asian	258	3.41	1187	12.4
Am. Indian/Pacific Islander	144	1.9	85	<1%
>1 Race	648	8.6	843	8.8
Urban HS	1934	25.5	2971	31.1
Suburban HS	2575	34.0	3546	37.1
Town HS	1041	13.8	955	10.0
Rural	2020	26.7	2039	21.3
Total Count	7570		9551	

Survey Instrument

The HSLs:09 is an extensive longitudinal study sponsored by the National Center of Educational Statistics (NCES) designed to investigate the transition of students from high school, through any post-secondary education, into adulthood and long-term careers. The initial surveys took place in the fall of 2009 with follow-up surveys occurring Spring 2012, November 2013, and February 2016. In the initial wave of the study students took the previously mentioned algebraic reasoning assessment along with an extensive survey which asked about their experiences, attitudes, and perceptions related to school, with a specific focus on science and mathematics learning. To provide additional context, parents, mathematics teachers and school administrators completed additional questionnaires.

Algebraic Reasoning Assessment

As described previously, I used scores from the algebraic reasoning assessment to identify my sample for this project. The algebraic reasoning assessment was administered as part of the baseline year survey and then again when students were in their junior year of high school. It assessed students' understandings across six domains of algebraic content and four algebraic processes (See Table 3). Students took the computer-based assessment in two stages. All students took the same initial segment of the test, then, based on their results, were routed into one of

three second stage tests with varied levels of difficulty.

Table 3. Summary of Content on the Algebraic Reasoning Assessment

Content Domains	Processes
Language of algebra	Demonstrating algebraic skills
Proportional relationships and change	Representing algebraic ideas
Linear equations, inequalities, and functions	Performing algebraic reasoning
Nonlinear equations, inequalities, and functions	Solving algebraic problems
Systems of equations	
Sequences and recursive relationships	

Variables Used in the Study

The variables used in this analysis came predominantly from information gathered on the student baseline year questionnaire given early Fall 2009. Additional information came from the first follow up survey (Spring 2012) and the baseline year mathematics teacher instrument. Following is a list and description of all variables used in the analysis.

Mathematics Identity

The dependent variable in this study was mathematics identity. The NCES created this scale (MTHID) in both the baseline year and first follow up data. The MTHID scale was created from two items (i.e., “I see myself as a math person,” and “Others see me as a math person”). I used these scales to measure identity in both the baseline year (ID_1) and at the first follow up (ID_2). Each variable is standardized with $\bar{X} = 0$ and $SD = 1$ and scaled so that higher values are associated with stronger of identity beliefs. Cronbach’s alpha is a measure of internal consistency and can be used as a measure of scale reliability (Cronbach, 1951). Both scales showed good reliability with $\alpha_{ID_1} = .84$ and $\alpha_{ID_2} = .87$ (Ingels et al., 2013).

Conceptual Instruction

To investigate how identity is influenced by a teacher’s emphasis on conceptual instruction I created the variable *conceptual instruction* from the teacher questionnaire. Mathematics teachers responded to multiple Likert-type items asking them to rate the level of instructional emphasis they placed on things like problem solving skills or speedy and accurate computations. I identified six items I believed would help students develop conceptual understanding and then used principal components factor analysis (PCA) with a Promax rotation to see if those five items created a unique factor.

The six items created a unique factor with factor loadings ranging from .44 to .85 (See Table 4). I combined these six items to create the conceptual instruction variable such that higher values indicated instruction more likely to develop conceptual knowledge. The scale shows acceptable internal consistency ($\alpha = .79$) and was standardized

to have $\bar{X} = 0$ and $SD = 1$.

Table 4. Items Considered for Conceptual Instruction

HSLs Designation	Item Wording	Factor Loading	Included in Variable
MIREASON	How much emphasis are you placing on teaching students to reason mathematically?	.85	Yes
MIIDEAS	How much emphasis are you placing on teaching students how mathematics ideas connect with one another?	.78	Yes
MIPROBLEM	How much emphasis are you placing on developing students' problem-solving skills?	.76	Yes
MIEXPLAIN	How much emphasis are you placing on teaching students to explain ideas in mathematics effectively?	.69	Yes
MILOGIC	How much emphasis are you placing on teaching students the logical structure of mathematics?	.64	Yes
M1CONCEPTS	How much emphasis are you placing in teaching students' mathematical concepts?	.44	Yes
M1COMPSKILLS	How much emphasis are you placing on developing computational skills? (Reverse coded)	.10	No
M1COMPUTE	How much emphasis are you placing on teaching students to perform computations with speed and accuracy? (Reverse coded)	.01	No
M1ALGORITHM	How much emphasis are you placing in teaching students' mathematical algorithms or procedures? (Reverse coded)	-.05	No

Additional Variables

As covariates, I included student race and sex so I could look for how these demographic variables might interact with conceptual instruction to produce different effects for Low AR and High AR students. I also included student socio-economic status (SES_U) as a control variable in the models. The HSLs scale SUS_U is a composite measure of student socio-economic status that considers family income, but also parent education levels and occupations, as well as school urbanicity (Ingels et al., 2013).

Data Analysis

For the first part of the analysis, I ran identical OLS regression models on the High AR and Low AR subsamples. Multiple linear regression allows a researcher to investigate the contribution of multiple predictor variables on a single dependent variable (Montgomery et al., 2021). I used the same set of predictor variables from the HSLs data to predict both ID_1 and ID_2, applying robust standard errors to account for violations of normality and homoskedasticity (Rabe-Hesketh & Skrondal, 2008), and compared results from the two subsamples. Next, I ran

additional models to look for moderation effects related to student sex or race.

A moderation effect occurs when one predictor variable changes the way another predictor variable influences the dependent variable (Denis, 2015). For example, mathematics identity in female students may benefit more from conceptual instruction than in male students. However, this effect may not be observable in students who score highly in algebraic reasoning. The use of interactions in regression models, along with the split sample allowed me to look for these complex relationships.

The first set of models included conceptual instruction as the primary predictor, with gender, race, and SES_U as control variables. The second set of models added interaction effects for conceptual instruction and gender, and the final set included an interaction for race and conceptual instruction. I used tests of simple slopes (Aiken et al., 1991) to visualize how the two predictor variables interacted to influence the development of student mathematics identity.

Results

The purpose of this study was to examine how a teacher's emphasis on conceptual instruction influenced the mathematics identities of their students, and how that influence varied due to race, sex, and achievement level. The results for this study will be presented in three sections. First, I will describe the results of the Low AR and High AR models that include main effects for conceptual instruction, race, sex, and SES_U. Second, I will report results that examine the interaction between conceptual instruction and student sex for both achievement groups. Finally, I will present the findings that describe how conceptual instruction interacted with race.

Models with No Interaction Effects

The first set of regression models analyzed each sample for the main effects of conceptual instruction, race, sex, and SES_U on students' mathematics identity in the baseline year and then again in the first follow up. Results show that conceptual instruction in ninth grade made a weak but significant contribution to the mathematics identities of students in both the Low AR and High AR groups (See Table 5). Students whose teachers placed more emphasis on instruction that develops conceptual knowledge in mathematics had higher predicted mathematics identities than students whose teachers did not have this same emphasis. For High AR students, conceptual instruction in ninth grade still predicted stronger identities over two years later.

Results also show that female students had significantly weaker mathematics identities when compared to male students, but this influence was stronger for High AR students than Low AR students. When considering race, Asian and Black students in the Low AR group had stronger identities at both timepoints when compared to their white peers. This same pattern was only seen in the High AR group for Asian students. Being Black significantly predicted ID_1, but not ID_2. Interestingly, the effect of being Hispanic or from the other non-white racial category was not generally a significant predictor of mathematics identity, but it was significant when predicting ID_2 in Low AR students.

Interaction Models (Low AR)

I ran separate models to see how the demographic variables of sex and race moderated the effect of conceptual instruction on mathematics identity at the two timepoints. I found no significant effects for the interaction of sex with conceptual instruction for Low AR students on both ID_1 ($\beta = -.009, p = .755$) and ID_2 ($\beta = -.037, p = .236$). However, when looking at the interaction between race and conceptual instruction I found a statistically significant interaction between being Hispanic and conceptual instruction ($\beta = .075, p < .05$) at the first timepoint. When predicting identity at the second timepoint, there were significant interactions with both the Hispanic ($\beta = .099, p < .05$) and other non-white ($\beta = .138, p < .05$) racial groups. For Low AR students in these racial groups, having a teacher in ninth grade who focused on conceptual instruction predicted an identity two years later that was approximately one tenth of a standard deviation higher than that of their white peers. These effects can be seen in the graphs in Figure 1. The slightly negative slope for the line representing white students indicates that conceptual instruction did not have a significant effect. However, for Hispanic students, and students from more than one racial group, the slopes are significantly positive, suggesting that conceptual instruction had a stronger influence on their mathematics identities.

Table 5. Main Effects for both Low AR and High AR Samples (No Interactions)

	Low AR Students		High AR Students	
	ID_1 Std. β (S.E.)	ID_2 Std. β (S.E.)	ID_1 Std. β (S.E.)	ID_2 Std. β (S.E.)
Conceptual Inst.	.036 (.02) *	.024 (.02)	.040 (.01) ***	.039 (.01) **
Female	-.080 (.03) **	-.097 (.03) **	-.133 (.02) ***	-.217 (.03) ***
Asian	.341 (.07) ***	.188 (.08) *	.213 (.04) ***	.320 (.04) ***
Black	.258 (.05) ***	.254 (.05) **	.110 (.05) *	.047 (.06)
Hispanic	.070 (.04)	.132 (.04) **	-.051 (.04)	.034 (.05)
Other non-white	.070 (.05)	.172 (.06) **	.016 (.04)	.029 (.05)
SES_U	.025 (.02)	-.005 (.02)	.019 (.02)	.048 (.02) **
N =	4186	3395	5366	4864

Note. Robust standard errors in parentheses.

* $p < .05$, ** $p < .01$, *** $p < .001$

Interaction Models (High AR)

There were no significant interaction effects between sex and conceptual instruction among High AR students ($\beta_{ID_1} = -.028, p = .254$; $\beta_{ID_2} = -.041, p = .140$). Similarly, there were no significant interaction effects between race and conceptual instruction in the High AR group. These findings suggest that among high achieving students, the influence of conceptual instruction on student identity is independent of race or gender.

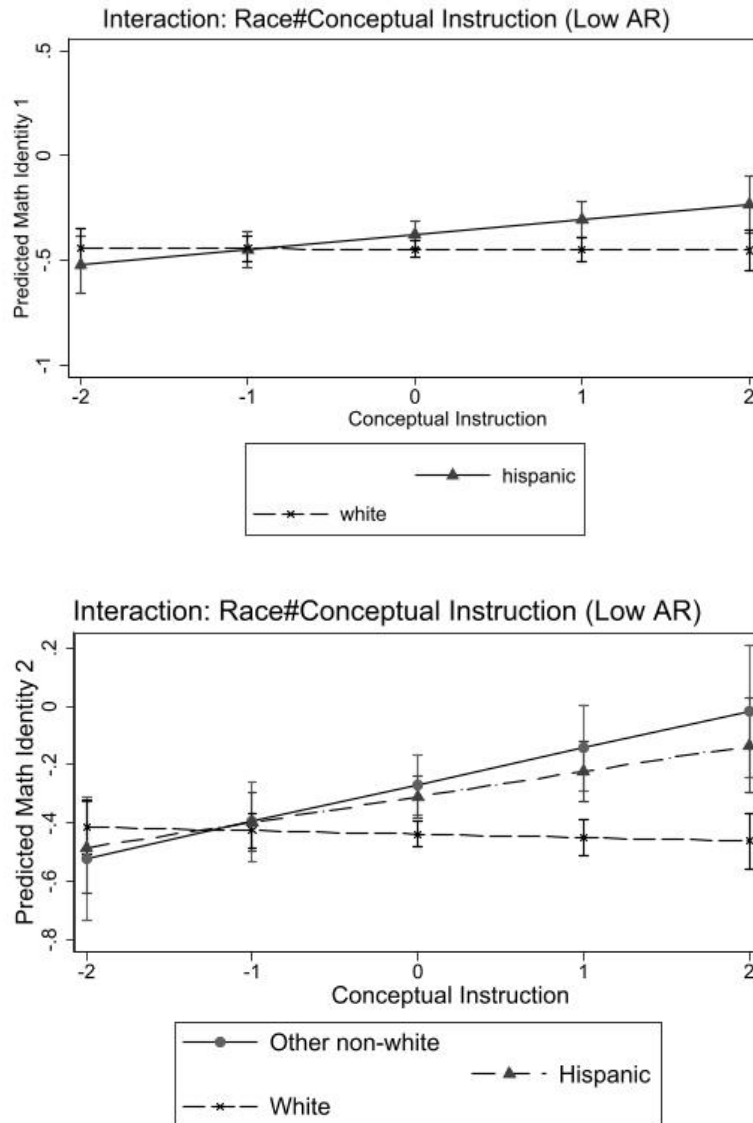


Figure 1. Simple Slopes Plots to Illustrate Interaction with Race in Low AR Students

Discussion

The results of this study suggest two important findings that illustrate the influence of conceptual instruction on students' mathematics identities. Considering the first research question, findings suggest that when a teacher focuses on instruction that develops conceptual knowledge it makes a significant positive contribution to their students' mathematics identities. This relationship was seen for both Low AR and High AR students in ninth grade with an extended effect for the High AR students two years later. The focus on conceptual instruction can positively influence student identities in two ways. First, as students develop their ability to connect concepts and think creatively in mathematics, their confidence for understanding and exploring mathematics grows. Richard Skemp (2012) compared conceptual understanding of mathematics to developing a mental map of a new city. Without a map, an individual may be able to find their way around using a memorized list of directions but if the destination changes, or a road is closed, the individual can quickly become lost and unable to navigate to their

destination. However, with a mental map they are able to find alternate routes that allow them to arrive at the desired destination. Access to a map, and the ability to use it, allows an individual to be more confident when navigating a new city.

Similarly, in mathematics, as students develop conceptual knowledge they can understand mathematics in multiple contexts, connect different mathematical ideas, and develop solutions to previously unseen problems. This increases confidence and helps students feel that they actually know mathematics instead of just being able to do mathematics. This confidence can then be reinforced through improved achievement. Yu and Singh (2018) found that teaching that built conceptual knowledge improved achievement while teaching that focused on procedural proficiency had a negative effect. This improved achievement would further strengthen student identity through the creation of more positive mastery experiences with mathematics (Eccles & Wang, 2016).

When considering the second research question, I found the influence of conceptual instruction was significantly different for Hispanic students in the Low AR group than for their white peers, and that the effect was still significant two years later. Some aspects of identity are stable and not subject to change, but these findings suggest that conceptual instruction can have a lasting influence on the mathematics identities of Hispanic students. Hispanic students face many stereotypes that create barriers to their education. One of these stereotypes is that they are intellectually lazy and do not value education (Marx, 2008). The findings of this study provide evidence to suggest that the deficit lies with the quality of instruction offered to students instead of a deficit in the student themselves. Low achieving and minority students are less likely to receive high quality instruction (Haberman, 2010; Ladson Billings, 2006) but actually show the greatest improvement in more rigorous courses (Edgerton & Desimone, 2018).

This research suggests that providing instruction that focuses on building students' conceptual knowledge will have a compounded effect for Hispanic students. Conceptual instruction is a more rigorous approach that provides for deeper understanding of mathematics my results suggest that it will have a positive effect on the identity of Hispanic students as well. The continued significance of these findings when considering student identity more than two years later suggests the positive influence of instruction in ninth grade may have lasting effects. Experiences in adolescence are very influential in the way students develop beliefs about their abilities (Zeldin et al., 2008), but having a teacher in ninth grade who focuses on conceptual instruction may strengthen the identities of struggling Hispanic students and increase the likelihood of future engagement in mathematics (Marsh et al., 2019).

The findings in this research support the ongoing efforts to bring about instructional and curricular changes that promote conceptual instruction, and urges these efforts be applied equally to lower-level classes where instruction is traditionally focused more on rote learning. Instead of resorting to simplified instruction which relies more on memorization than reasoning, students in these classes will benefit more from rigorous instruction that emphasizes connections and reasoning. Not only will it increase their achievement in mathematics, it will allow them to see the connection mathematics has with the world around them and empower them in using mathematics to change that world.

Conclusion

In this study I analyzed data from the first two waves of the High School Longitudinal Study, 2009. The results of the multiple regression analyses indicate a positive relationship between instruction that builds conceptual understanding in mathematics and students' mathematics identities for both high and low achieving students. Additionally, a significant interaction between race and conceptual instruction showed that low achieving students from racial minority groups (Black students not included) benefitted much more from conceptual instruction than their white peers. Findings support the need for continued efforts to provide instruction that develops mathematical reasoning and problem-solving abilities while connecting mathematical concepts. Results also suggest that instruction in remedial mathematics classes needs to focus more on building conceptual understanding instead of explicit instruction of memorized procedures.

Recommendations

The findings from this paper suggest two main avenues for future research. First, research that studies conceptual instruction, achievement, and identity simultaneously is needed to help to clarify the exact relationship between these three variables. Second, research should further investigate how conceptual instruction may help Hispanic students. Could this type of instruction be instrumental in overcoming language related barriers? Why was there a significant interaction for Hispanic students but not Black students? Further understanding this relationship will shed light on ways instruction should be tailored to more deliberately help different student populations. As we find ways to improve students' mathematics identities, we will make strides towards improving achievement and increasing entry into mathematics related careers.

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