Chapter

Impact of Integrated Science and Mathematics Instruction on Middle School Science and Mathematics Achievement

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Abstract

Despite the impetus from professional organizations for science and math integration, evidence in support of such efforts in raising both science and mathematics achievement is scarce, particularly for underrepresented students. The available literature is mixed especially regarding impact on mathematics outcomes. This exploratory study documents the impact of the Middle School Math and Science $(MS)^2$ Integration project based on the results of the internal evaluation of an intensive teacher training model for integrated science and mathematics in middle school. Multivariate analysis of variance shows $(MS)^2$ positively impacted middle school students' science and mathematics knowledge in this sample of diverse students. Overall, the $(MS)^2$ group outperformed the comparison group. There was also evidence that students who received $(MS)^2$ integrated instruction in science classrooms slightly outperformed those who received $(MS)^2$ integrated instruction in math classrooms. Multiple regression results indicated that $(MS)^2$ group membership and opportunity to learn through integrated instruction were significant predictors of students' science and mathematics scores. Although students in $(MS)^2$ classrooms were more likely to have higher achievement scores, the frequency of integrated instruction opportunities also significantly predicted student achievement, particularly in mathematics classrooms. Ethnicity and gender were not significant predictors of student scores. Implications are discussed.

Keywords: integrated science and mathematics instruction, mathematics achievement, middle school, science achievement

1. Introduction

Science and mathematics integration has become increasingly popular in recent years. In the USA, the National Council of Teachers of Mathematics [1] and the National Science Teachers Association (NSTA) [2], continuously highlight the benefits of integrating science and mathematics to improve the quality of education. Education researchers have advocated for the implementation of educational initiatives that emphasize a science and mathematics integrated curriculum, such as the Mathematics Common Core State Standards (CCSS-M) and the Next Generation Science Standards (NGSS) [3]. A well-recognized benefit of integrated instruction is its alignment with student-centered approaches to learning that promote critical thinking (e.g., [4–6] interest [7], motivation [8] and cognitive engagement [9–11]. Indeed, integrated STEM (science, technology, engineering, and mathematics) can shift and shape STEM beliefs and engagement [12]. Despite the promise of these efforts, additional evidence of its impact on student science and math achievement is needed [13, 14].

Thus, the main purpose of this study was to examine the impact of integrated science and mathematics instruction on middle school student achievement and to examine if the impact varies by classroom disciplinary context (i.e., whether integrated instruction occurred in mathematics classrooms or science classrooms) or by student gender. A secondary purpose is to examine the extent to which integrated science and mathematics instruction is a predictor of student science and mathematics achievement beyond student ethnicity, gender, or classroom disciplinary context. These analyses will also provide information about the degree to which the impact of integrated instruction is shared equally among student of different ethnicities and genders.

1.1 What is integrated instruction?

Although there are several definitions of science and mathematics integration, three definitions serve as the foundation for the definition applied in this study. Ref. [15] proposed the Berlin-White Integrated Science and Mathematics (BWISM) model that emphasizes the need to integrate big ideas that are common in both science and mathematics to enhance integration of the curriculum. A second definition, proposed by [16] underscores integrated instruction happens when there is alignment between content of the CCSS-M and NGSS. For instance, two disciplinary practices that align with the CCSS-M and NGSS are the use of arguments. The NGSS promotes activities in which students engage in arguments from evidence, while the CCSS-M encourages students to make viable arguments and critique the reasoning of others when learning new mathematical concepts [13]. Therefore, teachers can design activities in which students make interdisciplinary connections to further understand specific topics pertaining to both science and mathematics. These two integration perspectives draw attention to the synergistic relationship between science and mathematics content and disciplinary practices. These synergistic relationships refer to concepts that mutually correspond to both science and mathematics, which may also overlap in disciplinary norms, cognitive demand, or complex problem-solving [13]. For instance, teachers can integrate science and math instruction by teaching students inductive and deductive reasoning strategies to find patterns in both science and mathematics activities [15]. In this context, teachers exploit mathematical concepts such as differential equations (functions) to teach about exponential growth and decay within ecosystems in relation to specific populations.

Consequently, instruction that emphasizes synergistic relationships between science and mathematics provides students with interdisciplinary connections that helps them understand and make deeper connections with content concepts [17–19]. The third definition proposed by [20, 21] highlights the importance of using the integration continuum model to assess progress towards fully integrated practice. This model reflects overlapping elements between mathematics and science in instruction. That is, movement along the continuum represents different levels of integration whereas the ends of the continuum signal non-integrated practice [21]. Informed by these approaches to integration, we define integration as instruction that "coordinates the teaching of science and mathematics through engagement with disciplinary practices and/or coordinating concepts" [13].

1.2 Impact of math science integration

Advocates for integrated instruction argue that (a) deep understanding depends upon connections between ideas and (b) integrated instruction better resembles problems people will face in the real-world [22]. Previous studies provide the theoretical justification as well as initial empirical evidence that integrated instruction leads to increases in math and science achievement [23, 24], student interest [25, 26], and creativity [27]. More recent quasi-experimental methods and randomized controlled trials provide further empirical evidence that the use of integration increases student interest [28], math and science achievement [29], and problem-solving skills [30]. For example, [30] separated 4th grade students into an integrated math-science group and a control group (N = 117). Both groups of students studied the same topics for 8 weeks and took a problem-solving skills pre-test and a post-test. Results indicated that the integrated instruction group had a larger increase in problem solving skills than the control group. Similarly, [29] collected science assessments and attitude surveys from students in 8th grade math-science integrated classrooms and compared them to non-integrated classrooms (N = 1695). They found students in integrated classrooms had higher confidence in graphing, understanding of math-science integrated concepts and female students outperformed male students in science. We build on these studies by examining the impact of integrated instruction on science and mathematics achievement and explore the relationship between opportunity to engage in integrated instruction and achievement. We also examine if these opportunities had a differential impact based on student ethnicity or gender.

1.3 Context for the study

This study was part of a larger research study investigating the effectiveness of an intensive middle school integrated science and mathematics teacher development project: The Middle School Math and Science Integration program $(MS)^2$. This larger project was a three-year state-wide teacher development program providing teachers with a master's degree in multidisciplinary science and mathematics instruction in a hybrid environment. Program coursework and activities were designed to develop teachers' content and pedagogical knowledge to implement integrated instruction. Teachers took synchronous online courses over the fall and spring semesters and engaged in intensive face-to-face instruction over extended summer sessions. Initial evidence of positive impact on teacher learning and practice has been published elsewhere [13]. The focus of this paper is to report on the impact of integrated instruction on middle school students' science and mathematics achievement.

The main goal of the larger teacher-training project was to increase teachers' pedagogical content knowledge (PCK) [31] Three education courses aimed to: (a) expose teachers multiple integration approaches; (b) provide multiple models of fully integrated lessons; and (c) provide meaningful opportunities to situate these lessons in culturally and linguistically diverse classroom contexts. Two mathematics and seven science content courses served to engage teachers in complex science and math content and problem solving intended to support teachers' development of content knowledge needed to construct and implement effective integration lessons. Three of the content science courses were taught in an integrated manner. In these courses, a science professor (i.e., biology or physics professor) co-taught with a mathematics professor to provide teachers with experience in integrated instruction at the professional level. Thus, were simultaneously enrolled in both a science and mathematics course that were designed to complement the content of the other discipline.

To support learning of science and mathematics disciplinary practices, teachers were also provided with opportunities to engage in mathematics and scientific communities through local and national research lab participation. Required research lab experiences further supported the development of these *habits of mind* (e.g., healthy skepticism, curiosity, appreciation for new ideas, etc.) and grounded their pedagogical content knowledge (PCK). If teachers are to create authentic communities of practice in their science and math classrooms, they need direct experiences in discipline-based communities of practice. These experiences have been linked to improved science teaching quality and improved student performance [32]. In their second year of program participation, teachers were invited to participate in research either locally or in national research labs. Finally, teachers collaborated with other teachers and STEM faculty to develop artifacts they used in their classrooms. Development of these materials also supported development of PCK contextualized to their classroom environments. A sample of teachers from this larger project was recruited to participate in the current study. We report on the impact of integrated science and mathematics instruction on student learning. The specific research questions addressed here include:

1. What is the impact of math and science integrated instruction on student achievement? Does math or science achievement vary by disciplinary context?

2. What classroom (disciplinary context and level of integration opportunities) and student factors (ethnicity, gender) significantly predict science and mathematics achievement?

2. Methodology

A 2 [instruction group: [$(MS)^2$ or comparison] by 2 (discipline context: math or science classroom) by 2 (gender: male or female) factorial research design was implemented to answer the research questions. **Table 1** presents the research design and sample sizes for each cell. For the first research question, a multivariate analysis of variance (MANOVA) with instruction group, discipline, and gender as fixed factors and

	$(MS)^2$		$(MS)^2$	Control		Control
	Male	*Female*	**Total**	*Male*	*Female*	**Total**
Math Class	66	79	145	81	56	137
Science Class	52	68	120	76	66	142
Total	118	147	265	157	122	279

Table 1.
Design and cell sample sizes.

mathematics and science achievement scores as dependent variables. For the second research question, two multiple regression analyses were performed with five predictor variables (instruction group, discipline context, integration opportunities, ethnicity, and gender) and mathematics or science achievement scores were the outcome variable.

2.1 Participants

2.1.1 Students

A total of 544 students [265 $(MS)^2$ and 279 comparison] representing 19 diverse classrooms [9 $(MS)^2$ and 10 comparison] from 19 schools in ethnically diverse schools throughout a state in the southwest of the United States participated in the study. Of these students, 50.5% (275) are male and 49.4% (269) are female. Student ethnicity/race was reported as follows: 36.2% (197) Latinx; 27.5% (150) African American; 25.7% (140) White; and 10.5% (57) other. Students were also roughly evenly distributed between math and science classes with 51.8% enrolled in a mathematics class and 48.2% enrolled in a science class. The great majority of students (97.6%) received free and reduced lunch. The comparison group was matched based on socio-economic status.

2.1.2 Teachers

Nineteen [9 $(MS)^2$, 10 comparison] middle school mathematics [9: 4 $(MS)^2$, 5 comparison] and science [10: 5 $(MS)^2$, 5 comparison] teachers participated in the study. One of the $(MS)^2$ teachers moved to another state in the middle of the year and thus was dropped from the study. Comparison group teachers were identified based on matching on three key teacher characteristics: years teaching in the discipline (math or science), gender (male or female), and completion of a master's degree related to the discipline they taught or an education-related degree (e.g., MA in Curriculum and Instruction). At the time demographic information was collected, about 32% of these teachers [6: 3 $(MS)^2$ and 3 comparison teachers] regularly taught two or more middle school grades, all taught 6th for at least one class period. Years of teaching experience ranged from 2 to 15, with an average of 7.23 years for the $(MS)^2$ teacher and 6.67 for the comparison teachers. All participants [$(MS)^2$ and comparison] hold certification in the content they taught. Teachers taught in schools where at least one third of the school student population is economically disadvantaged as indicated by state designation criteria (i.e., percent receiving free or reduced lunch). In addition, all the teachers at the start of the program taught in stand-alone mathematics or science classrooms. $(MS)^2$ teachers enrolled in and completed the program (MS in Science Education) because of their interest in integration. $(MS)^2$ teachers were asked to implement integrated instruction in their most ethnically diverse class. Teachers were identified based on having at least one class that had at least 50% students of color enrolled.

2.2 Instrumentation

2.2.1 Iowa test of basic skills (ITBS)

To determine the impact of integrated science and mathematics instruction, the Iowa Test of Basic Skills (ITBS)-are multiple-choice, standardized achievement tests for students in kindergarten through eighth grade- was administered to all students. The science and mathematics batteries were administered to students in April.

Students were given 60 minutes to complete the mathematics test and 60 minutes to complete the science test.

2.2.1.1 ITBS math

The math survey battery (63 items total) is comprised of three sections: (1) concepts and estimation section; (2) problem solving and data interpretation; (3) computation. The concepts and estimation section is comprised of 27 items that measure concepts such as numeration, properties of number systems, and number sequences; fundamental algebraic concepts; and basic measurement and geometric concepts- probability and statistics. The 20, estimation knowledge and skills items measure (a) standard rounding—rounding to the closest power of 10 or, in the case of mixed numbers, to the closest whole numbers; (b) order of magnitude involving powers of 10; and (c) number sense, including compatible numbers and situations that require compensation. The problem solving and data interpretation includes 6 items that measure "problem-solving process" or "strategy." Such items measure steps of (1) getting to know the problem, (2) choosing what to do, (3) doing it, and (4) looking back. The data interpretation skills assessed in this test are reading amounts, comparing quantities, and interpreting relationships and trends in graphs and tables. The computation section includes 10 items that assess a single operation—addition, subtraction, multiplication, or division on whole numbers, fractions, and decimals.

2.2.1.2 ITBS science

The science test consisted of 60 items from two ITBS forms to target more of the 6th grade curriculum. Items targeted content and process pertaining to four domains: scientific inquiry, life science, earth and space science and physical science. Scientific inquiry targets understanding methods of scientific inquiry and process skills used in scientific investigations. Life science assesses knowledge of characteristics of life processes in plants and animals; body processes, disease, and nutrition; continuity of life; and environmental interactions and adaptations. Earth and space science assesses the Earth's surfaces, forces of nature, conservation and renewable resources, atmosphere and weather, and the universe. Physical science targets basic understanding of mechanics, forces, and motion; forms of energy; electricity and magnetism; properties and changes of matter.

2.2.1.3 ITBS reliability and validity

Several dozen validity studies indicate the ITBS instruments have strong technical quality (e.g., [33, 34]) with K-R20 coefficients ranging from 0.87 to 0.933 for the mathematics and 0.90 for science batteries. Past studies also show high correlations with state assessments, 0.76–0.81 (e.g., [35]) and measures (e.g., [36]) as is predictive of grade point average (e.g., [37]).

2.2.2 Integrated science and mathematics opportunity to learn student (OTL) survey

Students were asked to report on the frequency of integrated instructional opportunities. The integrated instruction OTL survey was comprised of eight items asking how often content concepts represented integrated topics, how often the teacher explained how concepts were integrated, how often the teacher provided feedback

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prompting making connections between content areas and how often the lessons involved science inquiry or project-based learning. Students reported their response on a five-point scale ranging from "1" representing never or hardly ever, to "5" representing "every day." Internal consistency for this survey was .88, indicating strong reliability. Internal consistency on these items was strong (.92, Cronbach alpha).

2.3 Procedures

2.3.1 Teacher training

$(MS)^2$ teachers were trained on math and science integration as part of a hybrid master's program [13]. Teachers participated in a two-year state-wide program that provided teachers with a master's degree in multidisciplinary science and mathematics instruction in a hybrid environment. Program coursework and activities were designed to develop teachers' PCK to implement integrated instruction. Teachers took synchronous online courses during the fall and spring semesters and engaged in intensive face-to-face instruction during two summer sessions. A total of 12 courses included three education courses noted in the Context for the Study section above. Two mathematics courses targeted middle school mathematics and were integrated with biology content. Seven science content courses engaged teachers in complex science problem solving. These content courses supported teachers' growing development of content knowledge needed to construct and implement effective integration lessons. Six of the nine content courses were taught in an integrated manner with mathematics and science purposes of teaching integrated topics.

2.3.2 Lesson development

In each of the content courses, teachers developed integrated lesson plans in learning circles. Each learning circle consisted of one mathematics middle school teacher, one middle school science teacher and one faculty member. These triads developed integrated lesson plans in each of the content courses and the faculty member provided feedback on the integrity of the content concepts targeted by the lessons and the appropriateness for math and science integration. We have reported elsewhere that initially these lessons did not represent fully integrated content, but as they progressed in the program, the level of integration reflected synergistic concepts and improved student feedback [13]. Teachers used the lessons they developed during the master's coursework throughout the yearlong implementation of this study.

Comparison group teachers received 6 hours of regular district training in science inquiry and problem-based learning and attended the mandatory district training throughout the year of the study. Teachers administered the science and mathematics integration opportunity survey as well as the mathematics and science assessments in May of the year the study took place.

3. Results

3.1 Impact on student learning

The MANOVA results indicated there were statistically significant differences in achievement based on instructional group, $F(2, 535) = 1004.48$, $p < 0.001$; Wilk's

Λ = 0.210, partial η^2 = 0.790. Prior to examining the between-subject effects, the homogeneity of variance assumption was tested for both achievement measures. The Levene's *F* tests were statistically significant ($p < 0.05$), suggesting that the variances associated with math and science achievement were not homogenous. However, an examination of the standard deviations revealed that none of the largest standard deviations were more than four times the size of the corresponding smallest standard deviation (**Table 2**), indicating that the between-subject effects would be robust in this case [38].

Between subject effects showed the instructional group had a significant effect on both math and science achievement, $F(1, 536) = 1057.19$, $p < 0.001$; partial $\eta^2 = 0.663$ and $F(1, 536) = 1516.57$, $p < 0.001$, partial $\eta^2 = 0.739$, for math and science achievement, respectively. Math and science mean comparisons show the $(MS)^2$ group outperformed the comparison group regardless of gender and disciplinary context (**Figure 1**). Effect sizes (partial η^2) are large indicating the instruction group effect accounts for a large proportion of the variance in student scores. Disciplinary context did not significantly affect students' mathematics ITBS scores (p = 0.229). The disciplinary context main effect for the science ITBS scores, however, was nearly significant (p = 0.051). Given the observed power was below optimal levels (0.424), this result may be attributable to sample size [39]. Mean score differences in science achievement between students in math and science classes (**Figure 1**) was 0.12 which is not meaningfully different. Gender differences were also not significant (p's > 0.05). Thus, student math and science performance was comparable whether they were in math or science classrooms or whether they were male or female students.

Math Achievement								
Variable	**Math Class**				**Science Class**			
	$(MS)^2$ Group		**Control Group**		**$(MS)^2$ Group**		**Control Group**	
	x	***SD***	***x***	***SD***	***x***	***SD***	***x***	***SD***
Male	46.95	9.35	26.37	3.13	45.63	8.93	26.80	3.03
Female	46.46	11.33	26.13	2.90[1]	49.81	9.94	26.73	3.13
Total	46.68	10.44	26.27	2.03	48.00	9.708	26.77	3.07
Science Achievement								
Variable	**Math Class**				**Science Class**			
	$(MS)^2$ Group		**Control Group**		**$(MS)^2$ Group**		**Control Group**	
	x	***SD***	***x***	***SD***	***x***	***SD***	***x***	***SD***
Male	59.00	5.69	47.01	2.65[2]	61.37	1.59	46.17	4.30
Female	59.87	4.48	47.54	4.17	61.60	1.90	47.00	5.06
Total	59.48	5.07	47.23	3.35	61.50	1.77	46.56	4.67

[1]*The assumption that the largest standard deviation is not more than four times than the size of the corresponding smallest standard deviation is met [38]. In this case, 2.90 is the smallest SD and 11.33 is the largest SD. Since (2.90 × 4) = 11.6 and 11.6 > 11.33 the assumption is met.*

[2]*The assumption that the largest standard deviation is not more than four times than the size of the corresponding smallest standard deviation is also met. In this case, 2.65 is the smallest SD and 5.69 is the largest SD. Since (2.65 × 4) = 10.6 and 10.6 > 5.69 the assumption is met.*

Table 2.
Means and standard deviations for math and science achievement.

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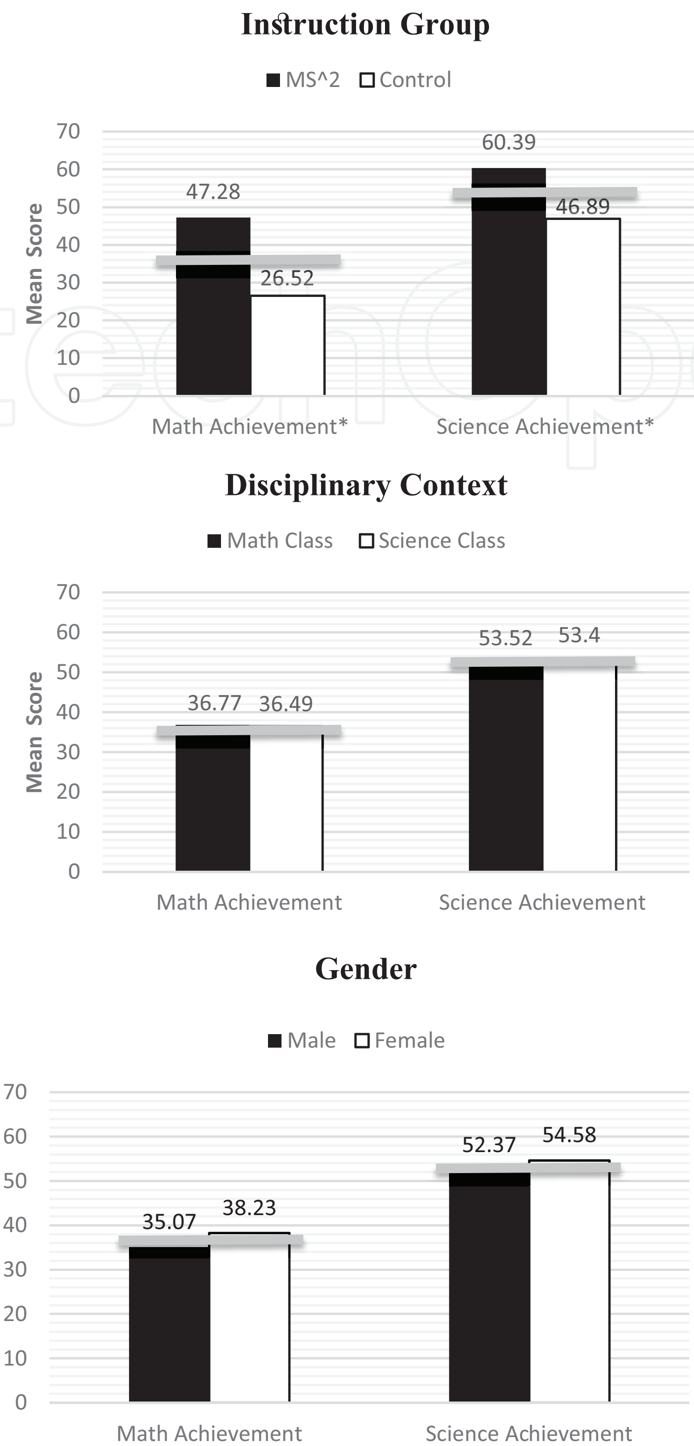

Figure 1.
*Instruction group, disciplinary context, and gender comparisons for mathematics and science achievement. Note: *statistically significant at the 0.001 level; gray line represents the grand mean.*

For math achievement, the instruction group by disciplinary context interaction was not significant, $F(1, 536) = 0.154$, $p = 0.695$, partial $\eta^2 < 0.001$. However, for science achievement, the instructional group by disciplinary context interaction effect had a significant effect on science achievement, $F(1, 536) = 15.502$, $p < 0.001$, partial $\eta^2 = 0.028$. Cell mean comparisons show the $(MS)^2$ group performance advantage depended slightly on disciplinary context (**Figure 2**). That is, $(MS)^2$ students in science classes performed slightly higher on the science ITBS ($x = 61.50$) than $(MS)^2$

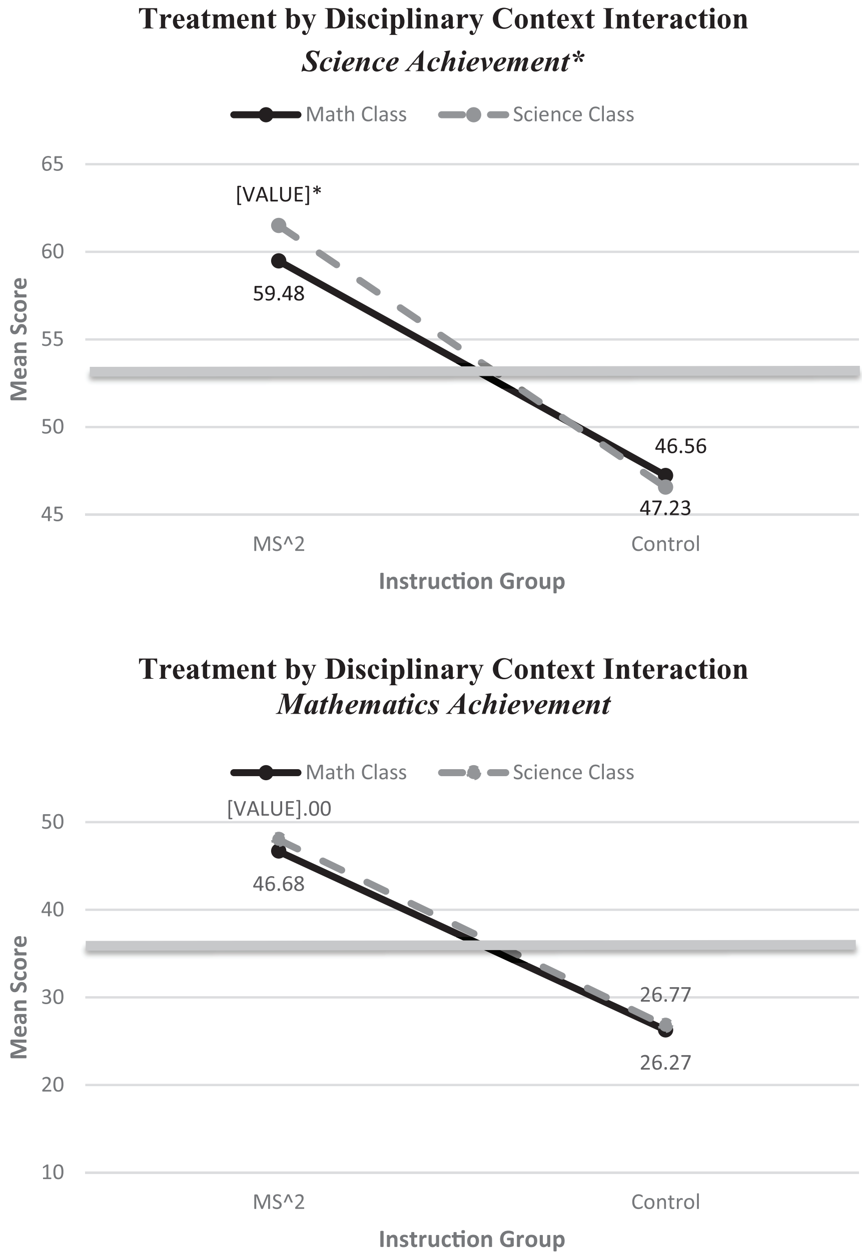

Figure 2.
*Interaction effects for science and mathematics achievement. Note: * statistically significant at the 0.001 level; gray line represents the grand mean.*

students in math classes (x = 59.48). However, the effect size was small indicating the magnitude of this difference is relatively small. Comparison group students' achievement did not differ based on whether they were in math or science classes (**Figure 2**). No other interaction effects were statistically significant (p's > 0.05). Boys' and girls' performance was comparable regardless of whether they were enrolled in a math or science class, and performance was also comparable across instruction groups. The three-way interaction was also not statistically significant (p > 0.05).

3.2 Predictors of math and science achievement

Two separate multiple regressions were conducted to identify significant predictors of math and science achievement. The Breush-Pegan and Koenker test was significant for both the science and mathematics scores, indicating the heteroskedasticity in the data. To correct for the non-constant variance in the regression results (heteroscedasticity), a heteroskedasticity- consistent estimator (HC3 method) was used to calculate robust standard errors in both regression analyses. The predictor variables for both analyses included three classroom factors (instruction group, disciplinary context, integration opportunities) and two student factors (ethnicity, gender). Two of the three classroom variables (instruction group and integration opportunity) were found to be significant predictors of students' science scores [$F(9, 534) = 205.378$, $p < 0.001$)] with an R^2 of 0.772 indicating the model accounted for 77.2% of the variance in science scores. Students' predicted science achievement scores was equal to 44.028–9.758 (instruction group) + 1.856 (integration opportunity) where instruction group was coded as 0 = $(MS)^2$ and 1 = control group, and integration opportunity was measured on a five-point Likert scale (1 = very few or no integration opportunities, 5 = daily integration opportunity). Results show that science scores were 9.758 points higher for students in the $(MS)^2$ group and their scores increased by 1.856 points for every one-point increase in reported integration opportunity. Neither student ethnicity nor student gender were significant predictors of the science achievement. Disciplinary context was also not a significant predictor of science achievement. Further, none of the interaction terms were significant predictors of science achievement.

Like the science achievement results, two classroom variables (instruction group, integration opportunity) significantly predicted mathematics achievement scores [$F(9, 534) = 195.794$, $p < 0.001$)] with an R^2 of 0.764 indicating the model accounted for 76.4% of the variance in student math scores. Students' predicted math achievement score was equal to 18.178 + 9.271 (instruction group) + 5.293 (integration opportunity). Instruction group and integration opportunity were coded the same as in the science achievement analyses. Math scores were 9.271 points higher for the students in the $(MS)^2$ group and increased by 5.372 points for every one-point increase in reported integration opportunities. Like science scores trends, neither student ethnicity nor student gender were significant predictors of the math achievement. Disciplinary context nor any of the interaction effects were significant predictors of math achievement.

4. Limitations

There are design limitations that should be considered when interpreting the results of this study. Since all of the $(MS)^2$ teachers showed interest in integration when enrolling in this program, there may be a selection bias for the intervention group influencing the results. Another limitation is the lack of additional information related to student background, such as prior math and science achievement. This limited our ability to test for potential initial differences between instruction groups, meaning that the generalizability for this study is limited. Initial differences between the groups cannot be fully attributed to effectiveness of the $(MS)^2$ group since the groups may not have been equivalent. Further, given the homogeneity issues noted in the MANOVA results section, the results may be biased. However, since the sample sizes of the instruction group and comparison group are comparable (265 and 279) the analysis of variance can be considered robust for violation of homogeneity of the variances [40]. Another potential study limitation is that results may not be generalizable to students outside of the region within the United States the study was conducted. Therefore, additional studies should focus on replicating this current project using a national representative sample. Despite these limitations, the large effect sizes suggest the approach is promising.

5. Discussion

This study sought to examine the extent to which integrated science and mathematics instruction impacted student science and math achievement and to explore the extent to which opportunities to engage in integrated science and mathematics instruction significantly predicted student achievement above and beyond student gender, ethnicity, and disciplinary context. The results show $(MS)^2$ positively impacted middle school students' science and mathematics knowledge in this sample of students. Students who received $(MS)^2$ outperformed students in the comparison group on science and mathematics achievement tests.

5.1 Interaction effects

The significant disciplinary context by instruction group effect for science suggests that students who received $(MS)^2$ integrated instruction in science classrooms slightly outperformed those who received $(MS)^2$ integrated instruction in math classrooms. This interaction effect was not found for mathematics achievement. This pattern suggests that the impact of integrated instruction differs for mathematics achievement depending on whether the instruction was delivered in a science or mathematics classroom. Stronger science achievement was observed in $(MS)^2$ science classrooms than $(MS)^2$ mathematics classrooms; but the mathematics achievement impact was comparable in both contexts. This finding may be a result of differences in pedagogical practices, learning objectives, or skill requirements that are different in science and mathematics classrooms. Given science classrooms would target more science content than mathematics classrooms, it is not surprising that students in science classrooms slightly outperform students who received integrated instruction in mathematics classrooms. Thus, this finding likely reflects the differences in content standards for which science and mathematics teachers are responsible. On the other hand, a disciplinary context by instruction group interaction effect for mathematics achievement was not observed. Therefore, one could argue that an interaction effect should have been observed given the emphasis in mathematics in math courses. Yet, mean scores on the mathematics ITBS were comparable whether students received $(MS)^2$ instruction in a math or science classroom.

This pattern could be attributable to the science emphasis in the $(MS)^2$ professional development experience. Teachers in the $(MS)^2$ group took more science than mathematics courses. This imbalance in content emphasis may have contributed to the lack of instructional group by disciplinary context interaction effect for mathematics achievement. Therefore, future studies should examine the impact of different proportions of science and mathematics content exposure teachers receive on their students' achievement outcomes. These differences could also be attributable to student level factors such as task orientation [41] or school level factors such as socioeconomic composition [42]. Future studies should scale up efforts to examine the role of these factors in mediating the impact of integrated instruction.

5.2 Magnitude of impact on mathematics achievement

What was not expected was the findings related to mathematics achievement. The effect size for the $(MS)^2$ impact on mathematics achievement ($\eta^2 = 0.663$) was larger than reported impacts in past research [43]. Although there is limited research on the differential impact of integrated instruction on mathematics achievement, past research has suggested that integrated instruction may be problematic for mathematics content learning [44, 45]. For example, in a meta-analysis conducted by [43], 9 of 13 studies had effect sizes for mathematics achievement of 0.2 or less. In contrast, 6 of 13 studies had effect sizes for science achievement of .50 or greater and nine studies having effect sizes above 0.20. Further, other scholars have argued that an integrated approach may not be consistent with mathematics epistemic knowledge which, in turn, restricts mathematics learning [46]. The higher impact observed for mathematics achievement may have been due to the prolonged training teachers received in the project or the multiple opportunities teachers were provided to engage with faculty in science and mathematics research laboratories. These experiences may have contributed to differences in teaching practices that contributed to greater gains in student mathematics achievement. Though, as noted above, the proportion of mathematics to science content engagement in the training may not be ideal for developing teachers' mathematics PCK.

5.3 Predictors of science and mathematics achievement

The regression results provide a potential explanation for the higher effect sizes observed in mathematics achievement. Recall that $(MS)^2$ instruction increased student mathematics and science achievement scores by 9 to 10 points. The relative consistency in the provision of integrated opportunities also significantly improved student math and science scores. We also observed the magnitude of the impact on the math scores was higher than the science scores. Integrated opportunities increased mathematics scores by over 5 points for each level of increase of integration opportunity, compared to a 1.9-point increase in science scores. Students in our sample, particularly the $(MS)^2$ group, may have had more consistent opportunities to engage in science and mathematics integrated instruction than students from other studies. Minimally, the regression results suggest that another source of variability of impact on mathematics achievement is related to the frequency of opportunities students are provided to engage in integrated lessons. It is possible the larger effect sizes are attributable to the quality of instruction students in $(MS)^2$ group received as resulting from the extensive training $(MS)^2$ teachers received. Although we would expect the intensive training teachers received would impact their commitment to provide consistent opportunities for integrated instruction, student reports of integrated instruction opportunity was a significant predictor of mathematics achievement which suggests variability in the frequency of these opportunities in the $(MS)^2$ sample. This finding underscores the impact of consistent opportunities to engage in integrated instruction is also important in raising student scores, particularly for mathematics. Future studies could examine this impact more directly by varying the consistency in the frequency of integrated opportunities.

5.4 Differences across gender and race/ethnicity

We also found that gender and race/ethnicity did not significantly predict student outcomes despite consistent research showing both gender [47] and race/ethnicity gaps [48] in math-science achievement in the US. Ethnicity and gender did not significantly predict science and mathematics achievement in the integrated instruction groups regardless of whether they were in an integrated math or integrated science class. This finding suggests that integrated science and mathematics instruction can lead to more equitable outcomes in mathematics and science achievement and therefore should be considered as a promising approach to reducing achievement gaps. These findings are encouraging given that others have found the impact is not uniform across groups of students. For instance, in a large scale, quasi-experimental study, [48] found achievement disparities persisted, advantaging Anglo-American students, despite the integrated SE instruction. [48] also found a significant relationship between quality of SE integration and student outcomes. They concluded that low integration quality largely contributed to the lack of impact on student outcomes. The authors also acknowledged that the lack of instructional scaffolds for diverse learners likely contributed to group disparities.

6. Implications

The results of this study suggest integrated science and mathematics instruction is a possible strategy for improving student math and science achievement. Given the increasing evidence supporting the argument that integrated instruction promotes critical thinking, motivation, and persistence in STEM, it is critical to support teachers and schools in developing this approach to STEM instruction. Integrated instruction appears to provide the experiences that shape student interest; over time, these opportunities can lead to sustained interests in STEM which is important in developing positive STEM identity and self-efficacy [7].

However, integrated instruction requires significant investment in the development and dissemination of quality professional development for teachers. Teachers in the $(MS)^2$ group received 2 years of professional development and they engaged with science and mathematics professors in designing curricular materials, practicing the presentation of synergistic concepts and principles, and conducting authentic disciplinary practices in university and national laboratories. This degree of investment is likely not possible in schools in the USA. Therefore, it is important for school districts to partner with university programs to provide experiences that meaningfully engage them in disciplinary practices with STEM professionals.

Further, teachers seeking to use integrated science and mathematics instruction need administrative support. In practice, this means administrators should allot time for teachers to collaborate with each other on the development of integrated lessons that work for science and mathematics classrooms. This structured time provides opportunities for science and mathematics teachers to gain from each other's expertise and experience. In addition, during appraisals and observations of teachers, administrators should also recognize teacher investment in integrated instruction and provide feedback in terms of the consistency of integration opportunities provided to students as well as the quality of math-science integration. Therefore, there is a need to expand current evaluation and observation tools to include an integrated instruction domain. For instance, the Texas Education agency (TEA) implemented the Texas Teacher Evaluation and Support System (T-TESS), which captures the quality of teacher instruction and its effectiveness in students' outcomes. This measure includes three main components: goal-setting and professional development, the evaluation cycle (informal and formal observations), and a student growth measure. Therefore, evidence of student opportunities to be engaged in integrated instruction can be collected by surveying the students' perceptions of integrated instruction including how often these opportunities were provided to them and the degree to which it helped their understanding of math and science content as a way to gauge students' perceptions of the impact of these opportunities. Past large-scale studies investigating student perceptions of teaching quality as predictors of science achievement are mixed [49, 50] however, these studies use general surveys of student perceptions. This study surveyed student perceptions of the frequency of integrated instruction, not general quality perceptions.

7. Conclusion

Overall, the results of our study suggest that integrated science and mathematics instruction can yield strong results in mathematics and science learning for all students. The large effect sizes indicate integrated science and mathematics instruction is promising in raising achievement for students from diverse ethnic and socioeconomic backgrounds, provided schools invest in supporting teachers in developing their ability to provide all students with meaningful and consistent integrated science and mathematics opportunities.

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References

[1] National Council of Teachers of Mathematics (NCTM). *Principles and Standards for School Mathematics*. Reston, VA: NCTM; 2000

[2] Miranda RJ, Hermann RS. An integrated instructional approach to facilitate inquiry in the classroom. Science Scope. 2012;**35**(8):66-72

[3] NGSS Lead States. *Next Generation Science Standards: For States, by States*. Washington, DC: The National Academies Press; 2013

[4] English L. STEM education K-12: Perspectives on integration. International Journal of STEM Education. 2016;**3**(3):1-8. DOI: 101186/s40594-016-0036-1

[5] English L. Advancing elementary and middle school STEM education. International Journal of Science and Mathematics Education. 2017;**Suppl 1**: S5-S24

[6] Vasquez J. STEM: Beyond the acronym. Educational Leadership. 2015;**72**(4):10-15

[7] Aguirre-Muñoz Z, Pantoya M, Pando M, Loria EG. Engineering integration in science elementary classrooms: Effects of disciplinary language scaffolds on English learner content learning and engineering identity. Journal of Engineering Education. 2021;**110**(*3*):517-544. DOI: 10.1002/jee.20409

[8] Struyf A, De Loof H, Boeve-de Pauw J, Van Petergem P. Students' engagement in different STEM learning environments: Integrated STEM education as promising practice? International Journal of Science Education. 2019;**41**(10):1387-1407. DOI: 10.1080/09500693.2019.1607983

[9] Aguirre-Muñoz Z, Pantoya M. Engineering Literacy and Engagement in Kindergarten Classrooms. Journal of Engineering Education. 2016;**105**(4):630-654

[10] Skilling K, Bobis J, Martin AJ, Anderson J, Way J. What secondary teachers think and do about student engagement in mathematics. Mathematics Education Research Journal. 2016;**28**(4):545-566. DOI: 10.1007/s13394-016-0179-x

[11] Tang KS, Williams PJ. STEM literacy or literacies? Examining the empirical basis of these constructs. The Review of Education. 2018;**7**(3):675-697. DOI: 10.1002/rev3.362

[12] Skilling K. Student STEM beliefs and engagement in the UK: How they shift and are shaped through integrated projects. In: Anderson J, Li Y, editors. Integrated Approaches to STEM Education: An International Perspective. Switzerland: Springer; 2020. pp. *251-270*

[13] Aguirre-Muñoz Z, Yeter I, Loria E, Koca F. Building teachers' capacity to integrate math and science content: Implications for professional development and learning. Journal of Science Teacher Education. 2021;**32**(1):62-84. DOI: 10.1080/1046560X.2020.1789814

[14] Penuel WR, Reiser BJ, Novak M, McGill T, Frumin K, VanHorne K, et al. Using co-design to test and refine a model for three-dimensional science curriculum that connects to students' interests and experiences. Paper presented at the Annual Meeting of the American Educational Research Association. New York, NY; 2018

[15] Berlin DF, White AL. The Berlin-White integrated science and mathematics model. School Science and Mathematics. 1994;**94**(1):2-4. DOI: 10.1111/j.1949-8594.1994.tb12280.x

[16] Breiner JM, Harkness SS, Johnson CC, Koehler CM. What is STEM? A discussion about conceptions of STEM in education and partnerships. School Science and Mathematics. 2012;**112**(1):3-11. DOI: 10.1111/j.1949-8594.2011.00109.x

[17] Bossé MJ, Lee TD, Swinson M, Faulconer J. The NCTM process standards and the five Es of science: Connecting math and science. School Science and Mathematics. 2010;**110**(5):262-276. DOI: 10.1111/j.1949-8594.2010.00033.x

[18] Furner JM, Kumar DD. The mathematics and science integration argument: A stand for teacher education. Eurasia Journal of Mathematics, Science, & Technology Education. 2007;**3**(3):185-189. DOI: 10.12973/ejmste/75397

[19] Lederman NG, Lederman JS. Is it STEM or "S & M" that we truly love? Journal of Science Teacher Education. 2013;**24**(8):1237-1240. DOI: 10.1007/s10972-013-9370-z

[20] Huntley MA. Design and implementation of a framework for defining integrated mathematics and science education. School Science and Mathematics. 1998;**98**(6):320-327. DOI: 10.1111/j.1949-8594.1998.tb17427.x

[21] Huntley MA. Theoretical and empirical investigations of integrated mathematics and science education in the middle grades with implications for teacher education. Journal of Teacher Education. 1999;**50**(1):57-67. DOI: 10.1177/002248719905000107

[22] Czerniak CM, Weber WB, Sandmann A, Ahern J. A literature review of science and mathematics integration. School Science and Mathematics. 1999;**99**(8):210-220. DOI: 10.1111/j.1949-8594.1999.tb17504.x

[23] Hurley MM. Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. School Science and Mathematics. 2001;**101**(5):259-270. DOI: 10.1111/j.1949-8594.2001.tb18028.x

[24] McComas WF, Wang HA. Blended science: The rewards and challenges of integrating the science disciplines for instruction. School Science and Mathematics. 1998;**98**(6):340-348. DOI: 10.1111/j.1949-8594.1998.tb17430.x

[25] Bragow D, Gragow KA, Smith E. Back to the future: Toward curriculum integration. Middle School Journal. 1995;**27**(2):39-46. DOI: 10.1080/00940771.1995.11496152

[26] Greene LC. Science-centered curriculum in elementary school. Educational Leadership. 1991;**49**(2):42-46

[27] Kim MK, Roh S, Cho MK. Creativity of gifted students in an integrated math-science instruction. Thinking Skills and Creativity. 2016;**19**:38-48

[28] Guthrie JT, Wigfield A, VonSecker C. Effects of integrated instruction on motivation and strategy use in reading. Journal of Educational Psychology. 2000;**92**(2):331-341. DOI: 10.1037/0022-0663.92.2.331

[29] McHugh L, Kelly AM, Burghardt MD. Professional development for a middle school mathematics-infused science curriculum. Journal of Science Teacher Education. 2018;**29**(8):804-828. DOI: 10.1080/1046560X.2018.1514825

[30] Orime SA, Ambusaidi A. The impact of using the integration approach between science and math on acquiring the skills for solving scientific problems for fourth grade students. Journal of Turkish Science Education. 2011;**8**(2):9-22

[31] Shulman LS. Those who understand: Knowledge growth in teaching. Educational Researcher. 1986;**15**(2):4-14. DOI: 10.3102/0013189X015002004

[32] Silverstein SC, Dubner J, Miller J, Glied S, Loike JD. Teachers' participation in research programs improves their students' achievement in science. Science. 2009;**326**(5951):440-442. DOI: 10.1126/science.1177344

[33] Dunbar S, Welch C. *ITBS* Research and Development Guide. Orlando, FL: Houghton Mifflin in Harcourt Publishing Company; 2015

[34] Lee G, Dunbar SB, Frisbie DA. The relative appropriateness of eight measurement models for analyzing scores from tests composed of testlets. Educational and Psychological Measurement. 2001;**61**(6):958-975. DOI: 10.1177/00131640121971590

[35] Loyd BH, Forsyth RA, Hoover HD. Relationship of elementary and secondary school achievement test scores to later academic success. Educational and Psychological Measurement. 1980;**40**(4):1117-1124

[36] Ansley TN, Forsyth RA. Relationship of elementary and secondary school achievement test scores to college performance. Educational and Psychological Measurement. 1983;**43**(4):1103-1112. DOI: 10.1177/001316448304300419

[37] Qualls AL, Ansley TN. The predictive relationship of achievement test scores to academic success. Educational and Psychological Measurement. 1995;**55**:485-498

[38] Howell DC. Statistical Methods for Psychology. Belmont, CA: Thompson Wadsworth; 2007

[39] Cohen J. Statistical Power Analysis for the Behavioral Sciences. New York: Academic Press; 1969

[40] Ramashandran KM, Tsokos CP. Mathematical Statistics with Applications in R. 2nd ed. San Francisco: Academic Press; 2015. DOI: 10.1111/j.1949-8594.2007.tb17769.x

[41] Yerdelen S, Sungur S. Multilevel investigation of students' self-regulation processes in learning science: Classroom learning environment and teacher effectiveness. International Journal of Science and Mathematics Education. 2019;**17**(1):89-110

[42] McConney A, Perry LB. Science and mathematics achievement in Australia: The role of school socioeconomic composition in educational equity and effectiveness. International Journal of Science and Mathematics Education. 2010;**8**(3):429-452

[43] Becker K, Park K. Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. Journal of STEM Education: Innovations and Research. 2011;**12**(5):23-37

[44] Baldinger EE, Staats S, Covington Clarkson LM, Contreras Gullickson E, Norman F, Akoto B. A review of concptions of secondary mathematics in integrated STEM education: Returning voice to the silent M. In: Anderson J, Li Y, editors.

Integrated Approaches to STEM Education: An International Perspective. Switzerland: Springer; 2020. pp. 67-90

[45] Tytler R. STEM education for the twenty-first century. In: Anderson J, Li Y, editors. Integrated Approaches to STEM Education: An International Perspective. Switzerland: Springer; 2020. pp. 45-66

[46] Honey M, Pearson G, Schweingruber H. *STEM* Integration in K-12 Education: Status, Prospects, and an Agenda for Research. Washington, DC: National Academies Press; 2014

[47] Stout JG, Dasgupta N, Hunsinger M, McManus MA. STEMing the tide: Using ingroup experts to inoculate women's self concept in science, technology, engineering, and mathematics (STEM). Journal of Personality and Social Psychology. 2011;**100**(2):255-270. DOI: 10.1037/a0021385

[48] Guzey SS, Harwell M, Moreno M, Peralta Y, Moore TJ. The impact of design-based STEM integration curricula on student achievement in engineering, science, and mathematics. Journal of Science Education and Technology. 2017;**26**(2):207-222. DOI: 10.1007/s10956-016-9673-x

[49] Zhang F, Bae L, Broda M. Science self-concept, relatedness, and teaching quality: A multilevel approach to examining factors that predict science achievement. International Journal of Science and Mathematics Education. 2021;**20**:503-529. DOI: 10.1007/s10763-021-10165-2

[50] Zhang D, Campbell T. An examination of the impact of teacher quality and "opportunity gap" on student science achievement in China. International Journal of Science and Mathematics Education. 2015;**13**(3):489-513