5th grade mathematics and science: an analysis of inquiry-based instruction vs. teacher-directed instruction

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ABSTRACT

This applied research was designed to analyze the effectiveness of inquiry-based instruction as compared to teacher-directed instruction in 5th-grade mathematics and science courses at the subject school. The subject school modified mathematics and science curriculum for 3 years and became an Alabama Math, Science, and Technology (AMSTI) school. AMSTI provided extensive professional development and ongoing support for the use of inquiry-based mathematics and science instruction. The impact on student achievement of inquiry-based instruction on various subgroups of 5th-grade students was statistically analyzed. Statistically significant improvement of multiple student subgroups was evident when inquiry-based instruction was employed.

Keywords: math, science, teacher-directed instruction, inquiry-based instruction

INTRODUCTION

Students in American schools today will enter a global society with extreme competiveness among talented youth for the best careers (Cornish, 2004). Although ongoing research studies seek to find the best way to give American youth the most appropriate education in this era of great world change (Kirby, Berends, & Naftel, 2003), various fears have not yet allowed innovative teaching methodology to become widespread (Emery, 2007). The Alabama Mathematics, Science, and Technology Initiative (AMSTI, 2009) seeks to provide schools with intensive professional development, inquiry-based learning units, and the necessary supplies to execute these learning experiences.

This study investigated the effectiveness of inquiry-based instruction in improving the mathematics and science achievement of fifth graders in a rural elementary school in south Alabama as measured by standardized achievement scores. Standardized achievement test scores in mathematics and science over a 6-year time period were analyzed in order to compare the group percentile rank of fifth graders in mathematics and science when teacher-directed instruction was utilized with the group percentile rank of fifth graders in mathematics and science following the implementation of inquiry-based instruction.

The activities of inquiry include observations, questioning, gathering data, and creating explanations (National Research Council, 1996). Dewey (1938) said inquiry-based instruction occurs when the "educator is responsible for a knowledge of individuals and for a knowledge of subject-matter that will enable activities to be selected . . . in which all participate and are the chief carrier of control" (p. 56). The work of Dewey and a colleague of the theorist, Vygotsky (1962), were pivotal to understanding the framework of inquiry-based instruction. As such, writings of the two are frequently utilized in this study.

In a more recent review of the pedagogical shifts in American education during the last hundred years, Sherman (2009) held that the progressive movement in education is vital to the success of American students into the 21st century. The researchers outlined two facets of inquiry-based instruction evident in American classrooms in recent history: open education and differentiation. Open education allows the daily classroom instruction to be dictated by the desires of the students, while differentiation allows student preferences to guide how particular content is encountered. Sherman warned that one technique, open education, was attempted and abandoned. Further, the researchers posited differentiation, the most current technique associated with inquiry-based instruction, may not remain an active component of modern classrooms unless wider support for the use of inquiry-based instruction is solicited.

This progressive model of education is in contrast to traditional, teacher-directed instruction with specific, organized bodies of knowledge presented by teachers to students. When teacher-directed instruction is employed, Dewey (1938) said, "books, especially textbooks, are the chief representatives of the lore and wisdom of the past, while teachers are the organs through which pupils are brought into effective connection with the material" (p. 18). A study by Olsen and Sexton (2009) found that a significant factor contributing to the continuation of the ideal of teachers leading students to wisdom is societal validity. Namely, the structures that provide fiscal support for public schools and then monitor the progress of the institutions expect and in many cases demand the familiar construct of teacher-directed instruction without consideration for the potential effectiveness of other pedagogical strategies.

BACKGROUND AND JUSTIFICATION

The history of the formal American educational system reveals a close reliance on teachers as dispensers of knowledge to students, and this is a difficult pattern for educational agencies to end (Hickey, Moore, & Pellegrino, 2001). By demonstrating the effectiveness of inquiry-based mathematics and science instruction at the local school level, this study may increase student achievement outcomes by adding support for research-driven, inquiry-based instruction in mathematics and science. The study notes meaningful trends in standardized testing data as well as positive teacher perceptions of inquiry-based instruction over time, allowing school administrators to more confidently support teachers in their efforts toward inquiry-based instruction.

The work of Vygotsky (1962) on constructivist learning along with the work of Dewey (1938) is an important component of the theoretical framework for this study. The assumption of the role of facilitator of student learning experiences on the part of teachers is fundamental to both AMSTI and the constructivist learning theory. By supporting learning in relevant contexts (Dewey, 1938; Vygotsky, 1962), AMSTI (2009) offers teachers the opportunity to encourage student construction of meaningful knowledge through the providing of professional development, classroom supplies, and ongoing technical support.

Building on the constructivist learning theory and inquiry-based learning while adding to the professional literature on the subject, a longitudinal study conducted by Le, Lockwood, Stecher, Hamilton, and Martinez (2009) found that progressive educational reforms in mathematics and science consistently led to gains in achievement measures designed to assess students' problem-solving and processing abilities.

An elementary school serving 1,210 students in rural south Alabama, from kindergarten through fifth grade, began utilizing mathematics and science units devoted to inquiry-based learning after years of relying on teacher-directed instruction in these subject areas. This study explored the effectiveness of the implementation of AMSTI over three subsequent school years and identified existing trends in student data before the AMSTI was implemented. It is important to demonstrate the effectiveness of inquiry-based instruction in mathematics and science as measured by student achievement on standardized assessments if teacher, administrator, and parent support for the initiative is to continue.

For the purposes of this study, the research statistically analyzed the aggregate mathematics and science standardized testing data of the fifth-grade students to observe trends in the data during the 3 years before AMSTI implementation and the 3 years following AMSTI implementation. Fifth grade will be targeted for the purposes of this study due to the emphasis on the group's positive performance on standardized testing instruments before the students are placed at the middle school for the following instructional year.

Fifth-grade students in the study school performed less well compared to same-age peers across the national norming group in nearly every area during the 2003-2004 school year. As evidenced in Table 1, the only subgroup of students performing above the 50th national percentile were Caucasians in mathematics and science (Alabama Department of Education, 2009). Of particular concern were the percentile rank score in mathematics of African Americans and the science percentile rank scores of students living in poverty. Each of these student groups performed only slightly above the 30th percentile rank compared to the national norming group. Teacher-directed instruction was implemented during this school year. This calls into question the effectiveness of teacher-directed instruction with African Americans students and students living in poverty in the areas of mathematics and science.

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An analysis of fifth-grade students in the study school indicated performance below same-age peers across the national norming group was still apparent during the 2004-2005 school year. As evidenced in Table 2, African American students and students living in poverty were continuing to perform significantly below the 50th percentile in both mathematics and science (Alabama Department of Education, 2009). The percentile rank scores in science of these two student subgroups were especially concerning. Again, these student groups scored only slightly higher than the 30th percentile compared to the national norming group.

Teacher-directed instruction was implemented during this school year. Particularly, concerning science instruction, concerns arose concerning the effectiveness of teacher-directed instruction with the African American students and students living in poverty.

Performance below same-age peers across the national norming group continued to be evident during the 2005-2006 school year. As evidenced in Table 3, African American students and students living in poverty were continuing to perform below the 50th percentile (Alabama Department of Education, 2009). In fact, these student groups once again performed only slightly better than the 30th percentile compared to the national norming group. Also of note, when considering the percentile rank scores of all fifth-grade students in mathematics and science, percentile rank scores in both mathematics and science were only slightly above the 50th percentile compared to the national norming group. Teacher-directed instruction was implemented during this school year. Following this school year, the fifth-grade teachers underwent extensive professional development required of all schools interested in participating with AMSTI. As a result, mathematics and science instruction for the following academic years was more inquiry-based in nature.

Performance below same-age peers across the national norming group appeared to dwindle for the study group during the 2006-2007 school year. As evidenced in Table 4, the only area of continuing concern involves two subgroups of students in science. African American students and students living in poverty continued to perform near the 30th percentile rank compared to the national norming group. In fact, percentile rank scores in science continued at relatively low levels for females, African Americans, and students living in poverty. These student groups are not mutually exclusive. For example, a female African American student living in poverty who struggles in science would have her standardized achievement score factored into the group percentile rank for all students, African American students, female students, and students living in poverty. It is important, then, to target student instruction to meet the needs of struggling students at risk for poor performance on standardized testing instruments. Inquiry-based instruction was implemented for the first time during this school year.

Performance, when compared to same-age peers across the national norming group during the 2007-2008 school year scores for fifth-grade students in the subject school, showed promising gains. As evidenced in Table 5, the only area of ongoing concern continues to involve two subgroups of students in science: African American students and students living in poverty. Of interest, there is a single group performing near the 30th percentile compared to the national norming group. Although efforts must continue to increase the science achievement of students living in poverty, it is encouraging that scores are increasing. Inquiry-based instruction was again implemented during this school year. The question remains whether or not inquiry-based instruction will satisfactorily increase the achievement of student groups consistently performing below the 50th percentile at the subject school compared to the national norming group.

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LITERATURE REVIEW

Teacher-Directed Instruction. According to Heal, Hanley, and Layer (2009), "Direct instruction is characterized by relatively simple and precise materials tailored to specific learning objectives, planned (and sometimes scripted) prompting procedures, provision of high-quality reinforcers for responding, and multiple trials conducted during brief teaching periods" (p. 124). Examples of direct instructional strategies include teacher-led lectures, student completion of worksheets, and skill repetition computer programs (Thompson, 2006). For many years, this instruction has composed the majority of student learning experiences in America in an attempt to maximize student achievement. The theoretical framework for teacher-directed instruction is, quite simply, that teachers have utilized this pedagogical technique throughout our history to build student learning (Alsup, 2005). Most recently, the NCLB Act (2001) set student achievement goals closely aligned with the memorized content mastery expected outcomes of direct instruction.

Heal et al. (2009) found direct instruction was most effective and often preferred by the preschool students in a recent study. This is in opposition to common practice with children in early elementary and preschool settings, which often consist of structured play. The researchers found that contrary to pervasive theories on early childhood education, preschool children could benefit from and even enjoy prescribed, teacher-directed learning activities.

Expanding on the link between teacher-directed instruction and the NCLB Act (2001), response to intervention (RTI) has been suggested in recent legislation as a means to address gaps in student learning effectively (Codding, Hilt-Panahon, Panahon, & Benson, 2009). School districts are to systematically analyze student-testing data and prescribe intervention strategies that vary in intensity to address the severity of student needs. RTI, then, is applicable to students performing at the grade-level standard as well as those with deficiencies in core subject areas. The learning activities selected for students are to be evidence based and offered in tiered succession.

The three tiers of RTI are distinct portions of the school day, and students participate in at least one if not all three tiers of instruction. Students performing at or above the standard of mastery set by the district receive Tier 1 instruction: whole group, largely teacher-directed lessons. Students with some deficiencies are given Tier 2 instruction, which is usually small group, teacher-directed drill-and-repetition instruction. Finally, students with the greatest needs for progress in a given subject area receive Tiers 1, 2, and 3 of RTI. Tier 3 is most often a separate, layered, teacher-directed learning opportunity specifically targeted to the strengths and weaknesses of the small student group.

For mathematics instruction, RTI addresses primarily computational concerns and strategies for tiered interventions vary from whole class to individualized delivery including the use of scripted teacher-direct lessons, repetitive use of flash cards, and other drilling of target skills. For their analysis of the varied strategies currently employed as RTI in mathematics, Codding et al. (2009) found "explicit instructional components such as drill, repetition, segmentation, strategy cues and active instruction represented the most variance associated with high effect sizes" (p. 281). These teacher-directed instructional strategies were found to be the most effective when addressing general education mathematics students in a whole-class setting. Increasingly prescribed, teacher-directed methodologies were employed as students were placed in more complex tiers designed to close significant gaps in achievement. The authors reported widespread success of teacher-directed instruction in providing the computational framework they perceive as necessary for building the conceptual framework of mathematics.

Inquiry-Based Instruction. In contrast to the focus of direct instruction on the teacher as a content expert, according to Hazari, North, and Moreland (2009), "constructivism is inquiry-based, discovery learning in which learners construct personal interpretation of knowledge based on their previous experience and application of knowledge in a relevant context" (p. 189). Thompson (2006) said constructivist-learning activities involve the use of "manipulatives or hands-on materials" (p. 53) "incorporating inquiry, discovery, and problem-solving approaches . . . [and] applying math and science concepts to real-world context" (p. 54). Further, inquiry-based learning connects classroom activities to specific careers, involves the analysis of original data, and encourages student communication and collaboration (Thompson, 2006). In a study of 10,000 students and 400 teachers, Thompson supported the idea that inquiry-based instruction is effective in improving student achievement and teacher satisfaction when appropriate professional development opportunities are in place.

Inquiry-based instruction has been utilized in a variety of settings in a myriad of ways for the 70 years since Dewey (1938) penned the progressive movement of education and yet there is still a great propensity to the use of teacher-directed instruction (Codding et al., 2009). In the case of mathematics instruction previously considered, although proponents of teacher-directed instruction believe basic computational facts and operations must be memorized first (Codding et al., 2009), inquiry-based learning advocates propose the formation of authentic, real-world concepts of mathematics before basic skill sets are memorized (Thompson, 2006).

Theoretical Underpinnings of Inquiry-Based Learning

Progressive Movement in Education. Dewey (1938) outlined the following:

> It is a cardinal precept of the newer school of education that the beginning of instruction shall be made with the experience learners already have; that this experience and the capacities that have been developed during its course provide the starting point for all future learning. (p. 74)

Dewey moved on to contextualize traditional, teacher-directed instruction. He stated that the methodology of teachers offering to students a prescribed set of facts stems from an age when it was assumed that the future would be quite similar to the past. In fact, 70 years ago as the progressive movement began in education, change was already considered inevitable. For the purposes of this review of the literature, the ideals, theories, and suggestions of Dewey and Vygotsky (1962) will be thoroughly explored because the writings are so critical to a thorough understanding of the inquiry-based instructional framework.

The primary question set forth by Dewey (1938) and, subsequently, by proponents of today's inquiry-based instruction is, "What does freedom mean and what are the conditions under which it is capable of realization?" (p. 22). Papanikolaou and Grigoriadou (2009) conducted a pilot study of an instructional technology medium capable of offering students guidance as they freely selected individual learning paths towards completion of an authentic product. Papanikolaou and Grigoriadou delineated a distinction between this new hypermedia and older existing media that focus on the definition of specific outcome objectives, design of materials and procedures that are targeted on these objectives, and assessment procedures that determine if learners have attained the desired objectives whilst the constructivist approach focuses on in-context learning organized around authentic tasks. (p. 194) Through the use of expert reviews of the medium as well as a 19-student trial, these researchers found that the active participation solicited through the inquiry-based model's use of guiding questions and student choice was both highly motivating and effective.

Historically, Dewey (1938) described the teacher's role in an inquiry-based instructional setting as a quintessential planner. The teacher must constantly seek connections between students' prior experiences with mathematics or any subject area and new experiences that may be offered to the student who is then free to build further connections, skills, and factual information. Contrasting teachers in inquiry-based classrooms to teachers in teacher-directed classrooms, Dewey noted that the range of planning is far longer for teachers in inquiry-based learning situations because they must more authentically offer experiences that continue to scaffold on students' prior experience.

Marshall (2010) began with the premise, "our habits of mind, innate curiosity, and ways of thinking and acting are shaped and developed through immersion in experience and repeated practice" (p. 48). The researchers posited how students are asked to learn is equally important to the content they are learning. The most effective teachers, then, will individualize learning experiences as Marshall suggested and prepare students to meet the changing global society outlined by Cornish (2004).

Particularly in today's climate of accountability in education, it is important to note that Dewey (1938) did not intend all experiences to be seen as a means of education nor did he propose that all educative experiences are inherently equal. Dewey saw a teacher's role in inquiry-based instruction as an important guide for student experiences. Teachers in this model are responsible for helping students avoid experience that will dull their capability to respond intelligently and meaningfully to new, ever more complex situations while directing them toward experiences and inquiries that will awaken natural curiosity and concept development. Dewey charged teachers with knowing "how to utilize the surroundings, physical and social, that exist so as to extract from them all that they have to contribute to building up experiences that are worthwhile" (p. 40).

The initial ideas of teachers as planners and those who awaken and guide natural curiosity are still an integral part of inquiry-based instruction. Kazempour (2009) found inquiry-based professional development opportunities for teachers were an important contributing factor to the implementation of inquiry-based instruction in today's classrooms. The case study focused on a high school science teacher's changes in perceptions of the ability to and necessity of implementing inquiry-based instruction that resulted from inquiry-based professional development delivered through a summer workshop series. Through these inquiry-based professional development opportunities, the case study subject was more confident in his ability to plan for inquiry-based instruction and guide them through their personal learning.

In an interesting dialogue concerning retention of subject-matter knowledge, Dewey (1938) offered that learning of facts in isolation through teacher-directed drills and practice in its worst form can leave students less able to perform well on standardized tests of student achievement than if no education was acquired at all. The theorist found children have innate capacities to reason that are harmed through isolated drill routines. Further, Dewey stated that skills and content learned in this way will not easily be transferred from the practice situation to any other application. According to this line of logic, it follows that teachers are often mystified by students' lack of performance on the mandated tests of today. This also may demonstrate yet another support for the use of inquiry-based learning to improve student achievement scores because the very nature of inquiry-based learning is the transference of experiences along a continuum.

Dewey (1938) said if "the two principles of continuity and interaction as criteria of the value of experience are so intimately connected that it is not easy to tell just what special educational problem to take up first" (p. 51), then it is perhaps better to understand education in a social context where the two constructs exist simultaneously. Dewey likened the premises underlying inquiry-based instruction to a democratic society and went on to ask if readers can question a preference for democracy (i.e., inquiry-based learning) over a dictatorial regime (i.e., teacher-directed instruction). Dewey did own, though, that inquiry-based instruction has a far less direct tie to courses of study and sequencing of instructional goals than teacher-directed instruction. This, of course, is an ongoing cause for concern among school administrators focused on achieving adequate yearly progress. This apparent lack of accountability to the required content and skill mastery expected may be avoided if teachers thoughtfully design conceptually based instructional units for inquiry such as those available through AMSTI.

The importance of social collaboration to the success of learning and content knowledge retention was also supported by Schiller (2009). The study found that students engaged in collaborative, inquiry-based learning are highly motivated to attend to the learning task and retain information at the application stage of understanding. This study dealt with higher-level mathematics students in a university setting but implications included the applicability to cooperative, inquiry-based learning to K-12 mathematics courses as well.

Response to Instruction. Vygotsky (1962) posited,

> direct teaching of concepts is impossible and fruitless. A teacher who tries to do this usually accomplishes nothing but empty verbalism, a parrot like repetition of words by the child, simulating a knowledge of the corresponding concepts but actually covering up a vacuum. (p. 83)

While agreeing with the basic premises of Dewey and Piaget, Vygotsky made an important distinction. The theorist allowed that the thought processes of children originate from their personal experiences and that these processes are quantitatively different from those of adults. Vygotsky, though, drew attention to the different methods children use to form spontaneous and nonspontaneous concepts not as mutually exclusive approaches but as almost entirely codependent.

Supporting the superior effectiveness of student-centered learning experiences, Hernandez-Ramos and De La Paz (2009) conducted a study comparing teacher-directed learning and inquiry-based learning among nearly 800 students in one middle school and roughly the same number of students in a neighboring middle school with comparable student demographics and teacher credentials. The students who received inquiry-based instruction performed better compared to those in the control group in the areas of content knowledge recall and intrinsic motivation and also experienced gains in the ability to think critically in the content area.

Students may then be said to form the concepts necessary for understanding and retaining science instruction by a unique interplay between their life experiences and structured school experiences designed to enable students to build upon their existing conceptual understandings in meaningful ways to reach full realization of scientific concepts. According to Vygotsky's (1962) premise, to utilize teacher-directed science instruction simply is akin to teaching students to feign an understanding of science without ever developing an understanding of science at all. Inquiry-based instruction allows teachers a venue to provide learning activities designed to engage students in authentic learning in the areas of mathematics and science.

Three beliefs of early childhood intellect were discussed by Vygotsky (1962). The first belief Vygotsky explored was Piaget's idea that children are able to experience activities, react to and learn from these activities at an egocentric level long before rational thought is possible. This underscored Vygotsky's notion that teaching concepts to students verbally before allowing inquiry is fruitless. Next, Vygotsky utilized Stern's supposition that children have an unexplained epiphany of thought processes that leads to a seemingly unimportant experience serving as catalyst for a profound inquiry-based learning experience. Finally, Vygotsky espoused the merits and faults of the ideas of both Piaget and Stern before setting forth the conceptual framework for inquiry-based learning. Vygotsky added, "Our investigation shows that the development of the psychological foundations for instruction in basic subjects does not precede instruction but unfolds in a continuous interaction with the contributions of instruction" (p. 101).

RESEARCH QUESTIONS

Research Question 1. How does the group percentile rank for students receiving inquiry-based mathematics instruction differ from the group percentile rank for students receiving teacher-directed mathematics instruction in terms of Stanford Achievement Test, 10th Edition (SAT-10), mathematics subtest scores for fifth graders at the subject elementary school? The researchers assessed the merit of AMSTI compared to teacher-directed learning in mathematics (Stufflebeam, 2002) by exploring statistical trends and differences in the group percentile ranks in mathematics on the SAT-10 for fifth graders at the study school for 3 years before AMSTI implementation and 3 years after AMSTI implementation. It was the supposition that the trend of standardized achievement scores in mathematics will support earlier independent findings of the success of AMSTI in improving student test scores (Ricks, 2008).

Finney (2010) conducted a group randomized control trial of 40 Alabama schools to compare the effectiveness of AMSTI inquiry-based instructional practices with teacher-directed practices longitudinally. The study further supports the effectiveness of AMSTI inquiry-based instructional units in increasing students' standardized test scores in mathematics and science over time. This will further indicate the continued applicability of the educational theories of Dewey (1938) and Vygotsky (1962) to modern mathematics instruction.

Research Question 2. How does the group percentile rank for students receiving inquiry-based science instruction differ from the group percentile rank for students receiving teacher-directed science instruction in terms of SAT-10 science subtest scores for fifth graders at subject elementary school? The merit of AMSTI was assessed compared to teacher-directed learning in science (Stufflebeam, 2002) by exploring statistical trends and differences in the group percentile ranks in science on the SAT-10 for fifth graders at the study school for 3 years before AMSTI implementation and 3 years after AMSTI implementation. It was the supposition that the trend of standardized achievement scores in science will support earlier independent findings of the success of AMSTI in improving student test scores (Finney, 2010; Ricks, 2008). This will further indicate the continued applicability of the educational theories of Dewey (1938) and Vygotsky (1962) to modern science instruction.

RESULTS

Research Question 1. How does the group percentile rank for students receiving inquiry-based mathematics instruction differ from the group percentile rank for students receiving

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teacher-directed mathematics instruction in terms of SAT-10, mathematics subtest scores for fifth graders at the subject elementary school?

The researchers employed a factorial analysis of the group percentile rank. The statistical analysis was applied to mathematics data from the SAT-10 for fifth graders attending the target school for the 2002-2003, 2003-2004, and 2004-2005 school terms during which teacher directed instruction was employed as compared to the 2005-2006, 2006-2007, and 2007-2008 school terms during which inquiry based instruction was employed. Some statistically significant changes in student achievement were revealed. The total student population performance with teacher directed instruction and inquiry based instruction was analyzed as was the performance of the student subgroups of male and female, black and white, and poverty and non-poverty when considering the years of teacher directed instruction as compared to inquiry based instruction.

Although the total student population group percentile rank standardized scores were greater when inquiry based instruction was employed, the difference is not statistically significant ($t = -1.50$, $p = .136$). This is depicted in Figure 1.

The potential difference in mathematics achievement of females and males was also explored for the six years considered. Very similar results were found when analyzing the effectiveness of teacher directed instruction as compared to inquiry based instruction for the student subgroups of females and males ($t = 2.08$, $p = 0.071$) The use of inquiry based instruction was found to have a significant, positive effect on student achievement for both females and males. Figure 2 further demonstrates the positive impact of inquiry based instruction on student mathematics achievement for males and females. Figure 3 depicts the impact of inquiry based instruction on the performance of fifth grade females. Female students earned higher achievement test results during the three years of inquiry-based mathematics instruction.

The difference in student performance of males as impacted by the implementation of inquiry-based instruction is seen in Figure 4. Not only did male students perform better on a standardized mathematics achievement test following inquiry based instruction, but the variance in performance of male students decreased when inquiry based instruction was employed.

The combination of differences between the performance of black and white students and those between teacher directed and inquiry based instruction explain much of the variation in the data ($R^2(adj) = 76.8\%$). For this combination of data, the student subgroups of black and white are a significant variable ($t = -5.89$, $p = 0.000$) while the instructional delivery method, teacher directed or inquiry based, is also a significant factor ($t = 2.06$, $p = 0.074$). Figure 5 depicts the interactions of these data sets.

As Figure 6 demonstrates, there is a significantly positive difference in mathematics achievement as measured by the SAT-10 for black students when inquiry based instruction is provided. This continues to hold true although the overall performance of black students is at a lower percentile rank than white students at the target school. The study further found that there is both a desirable increase in student mathematics performance when inquiry based instruction is employed and also a desirable decrease in variation of performance among white students with the use of inquiry based instruction. The direction and power of this interaction is illustrated in Figure 7.

For students living in poverty, inquiry based learning was found to have a positive, statistically significant impact on student achievement ($t = -2.70$, $p = 0.037$). Figure 8 shows both the strength and direction of this statistical relationship. The variance of scores for students designated as living in poverty was found to be equal when teacher-directed instructional years and inquiry-based instructional years were considered. This was observed with both an F-test and Levene's test as seen in Figure 9.

Further analyses of the SAT-10 mathematics achievement data illustrate student subgroups with no statistically significant differences attributable to the use of inquiry based instruction as compared to the use of teacher directed instruction. No significant difference was found for white students with respect to the different teaching methods but, as described above, there was a significant difference for black students. In addition, no significant difference was found for non-poverty students when inquiry based learning was employed.

Research Question 2. How does the group percentile rank for students receiving inquiry-based science instruction differ from the group percentile rank for students receiving teacher-directed science instruction in terms of SAT-10 science subtest scores for fifth graders at subject elementary school?

Again, the researchers employed a factorial analysis of the group percentile rank. The statistical analysis was applied to science achievement data from the SAT-10 for fifth graders attending the target school for the 2002-2003, 2003-2004, and 2004-2005 school terms during which teacher directed instruction was employed as compared to the 2005-2006, and 2006-2007 school terms during which inquiry based instruction was employed. Some statistically significant changes in student achievement were revealed. The total student population performance with teacher directed instruction and inquiry based instruction was analyzed as was the performance of the student subgroups of male and female, black and white, and poverty and non-poverty when considering the years of teacher directed instruction as compared to inquiry based instruction.

For the total student population in fifth grade science achievement, no statistically significant difference was noted. As Figure 10 illustrates, the use of inquiry based science instruction has a statistically significant, positive impact on the achievement of black students ($t = -1.27$, $p = 0.147$). As seen in Figure 11, the variances for the scores of black students during teacher-directed instructional years are comparable to that of black students during inquiry-based instructional years. This underscores the statistical significance of the data demonstrating the positive impact of inquiry-based instruction for this student subgroup.

A statistically significant, positive difference was also noted for male students when inquiry based science instruction was employed ($t = -1.11$, $p = 0.173$). The power of the impact is depicted in Figure 12. Levene's test demonstrates the equal variances for male students when teacher-directed and inquiry-based instruction was employed. This data is shown in Figure 13. Students living in poverty were also positively impacted by inquiry based science instruction ($t = -2.60$, $p = 0.40$). Figure 14 demonstrates the strength and direction of this relationship.

The test for equal variances among the SAT-10 data for students living in poverty is again satisfactorily passed to a level of 90% confidence. This is shown in Figure 15. It was also noted a non-statistically significant impact of inquiry based science instruction for several student subgroups. Inquiry based instruction did not impact the science achievement of white students, female students, or non-poverty students to the level necessary to reach statistical significance.

CONCLUSIONS

For mathematics achievement, the common significant effect found in each factorial experiment was teaching method. For the target school, inquiry based mathematics instruction as

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provided by AMSTI is effective in increasing student mathematics achievement as measured by the SAT-10 for certain student subgroups, particularly black students. This study further supports the findings of Finney (2010) and Ricks (2008) by demonstrating significant, positive impacts on student achievement of AMSTI, inquiry based instruction.

For science achievement, the common significant effect found in each factorial experiment was teaching method. For the target school, inquiry based science instruction as provided by AMSTI is effective in increasing student science achievement as measured by the SAT-10 for certain student subgroups, particularly black students, female students, and students living in poverty. By increasing the science achievement of traditionally underperforming student subgroups in the area of science, inquiry based instruction cements an important place in the total school plan to obtain AYP under NCLB (2001).

Through a thorough analysis of standardized achievement data during instructional periods with teacher directed mathematics and science instruction as well as instructional periods with inquiry based mathematics and science instruction, it may be concluded that AMSTI is effective in increasing student achievement in mathematics, particularly among black students. Further, students living in poverty may be expected to greatly increase their science achievement through the use of inquiry based science instruction. These are important conclusions to reach for the target school, since NCLB requires adequate yearly progress of these student subgroups. Additionally, black students and those living in poverty have historically been at risk student populations (Alsup, 2005).

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TABLES

Table 1
Stanford Achievement Test, 10th Edition, Percentile Ranks for Fifth-Grade Students in the 2003-2004 School Year

Group	Subtest	Percentile rank score
All students	Mathematics	41
All students	Science	47
Females	Mathematics	42
Females	Science	47
Males	Mathematics	41
Males	Science	47
African Americans	Mathematics	34
African Americans	Science	37
Caucasians	Mathematics	55
Caucasians	Science	63
Students living in poverty	Mathematics	29
Students living in poverty	Science	35

Note. From *Accountability Reporting*, by Alabama Department of Education, 2009. Retrieved from http://www.alsde.edu. Copyright 2009 by Alabama Department of Education. Reprinted with permission.

Table 2
Stanford Achievement Test, 10th Edition, Percentile Ranks for Fifth-Grade Students in the 2004-2005 School Year

Group	Subtest	Percentile rank score
All students	Mathematics	59
All students	Science	49
Females	Mathematics	62
Females	Science	50
Males	Mathematics	56
Males	Science	48
African Americans	Mathematics	43
African Americans	Science	31
Caucasians	Mathematics	78
Caucasians	Science	74
Students living in poverty	Mathematics	43
Students living in poverty	Science	33

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Table 3
Stanford Achievement Test, 10th Edition, Percentile Ranks for Fifth-Grade Students in the 2005-2006 School Year

Group	Subtest	Percentile rank score
All students	Mathematics	61
All students	Science	53
Females	Mathematics	61
Females	Science	51
Males	Mathematics	61
Males	Science	55
African Americans	Mathematics	43
African Americans	Science	37
Caucasians	Mathematics	82
Caucasians	Science	73
Students living in poverty	Mathematics	43
Students living in poverty	Science	37

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Table 4
Stanford Achievement Test, 10th Edition, Percentile Ranks for Fifth-Grade Students in the 2006-2007 School Year

Group	Subtest	Percentile rank score
All students	Mathematics	60
All students	Science	48
Females	Mathematics	61
Females	Science	46
Males	Mathematics	59
Males	Science	50
African Americans	Mathematics	49
African Americans	Science	36
Caucasians	Mathematics	77
Caucasians	Science	69
Students living in poverty	Mathematics	52
Students living in poverty	Science	39

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Table 5
Stanford Achievement Test, 10th Edition, Percentile Ranks for Fifth-Grade Students in the 2007-2008 School

Group	Subtest	Percentile rank score
All students	Mathematics	63
All students	Science	58
Females	Mathematics	64
Females	Science	53
Males	Mathematics	62
Males	Science	63
African Americans	Mathematics	51
African Americans	Science	44
Caucasians	Mathematics	78
Caucasians	Science	76
Students living in poverty	Mathematics	52
Students living in poverty	Science	39

Note. From *Accountability Reporting*, by Alabama Department of Education, 2009. Retrieved from http://www.alsde.edu. Copyright 2009 by Alabama Department of Education. Reprinted with permission.

FIGURES

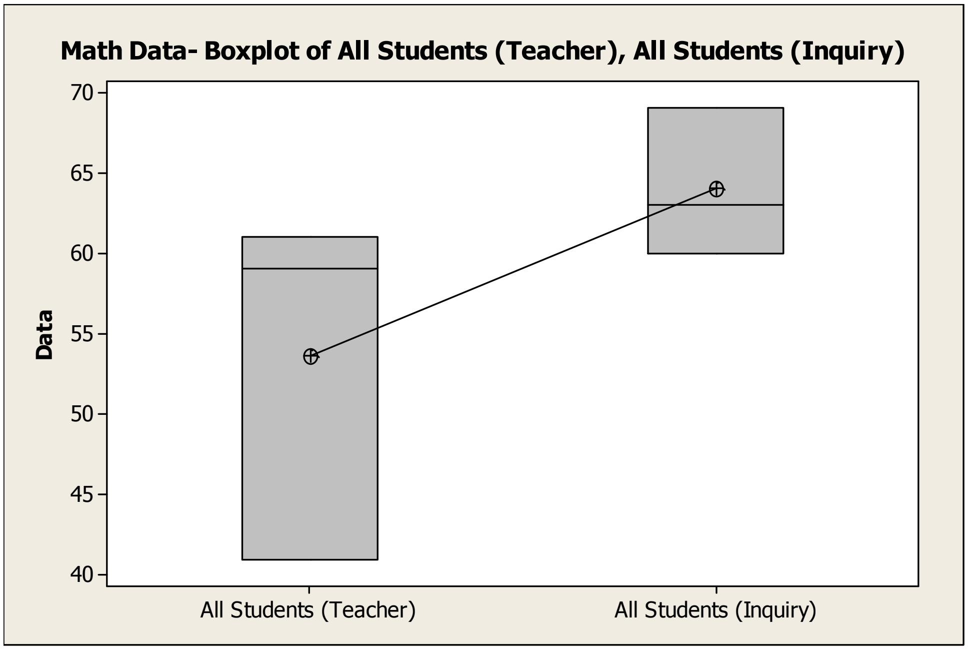

Figure 1: Plot of Method Effect on All Students

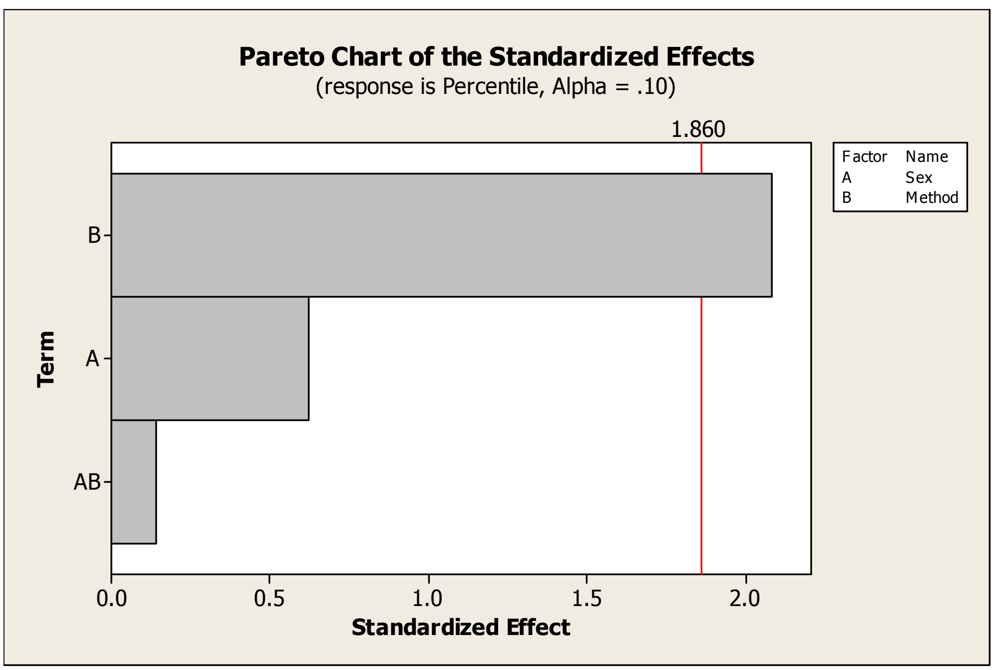

Figure 2: Pareto Chart of Sex Effect (A) and the Method Effect (B).

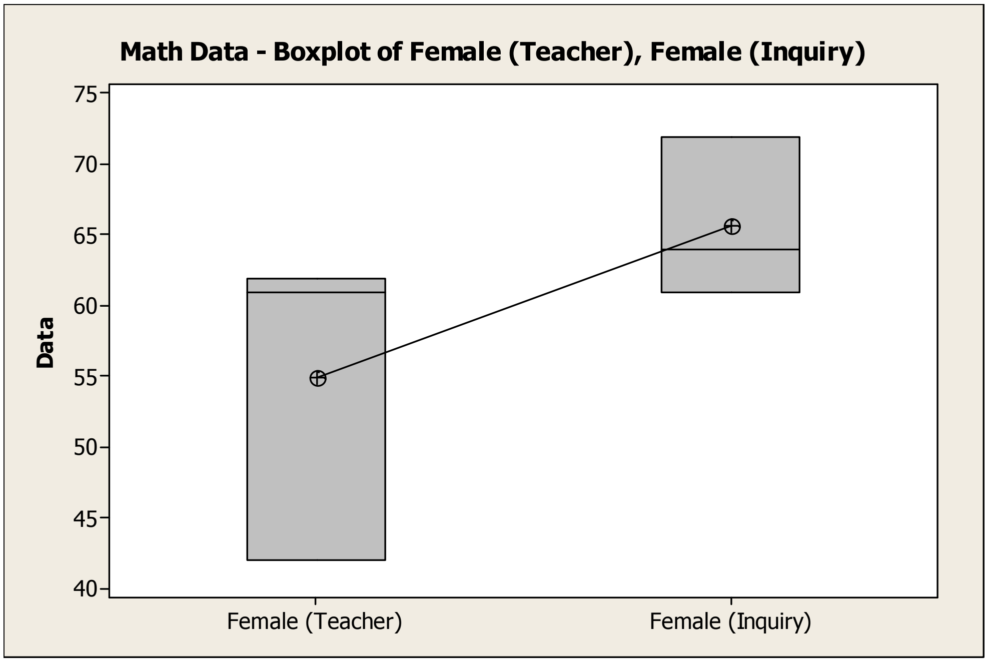

Figure 3: Plot of Method Effect on Female Students

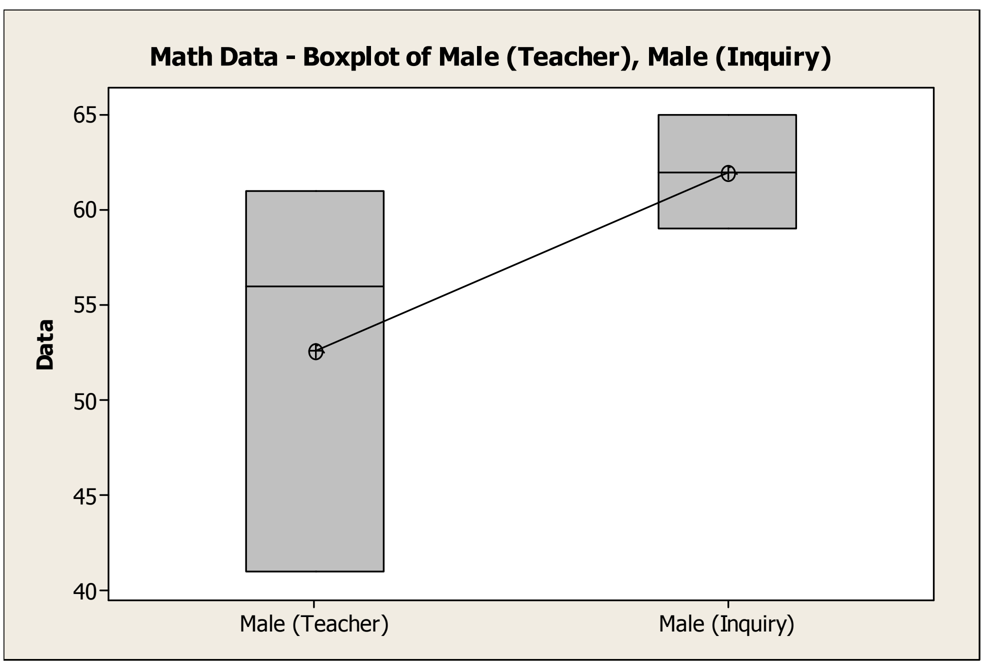

Figure 4: Plot of Method Effect on Male Students

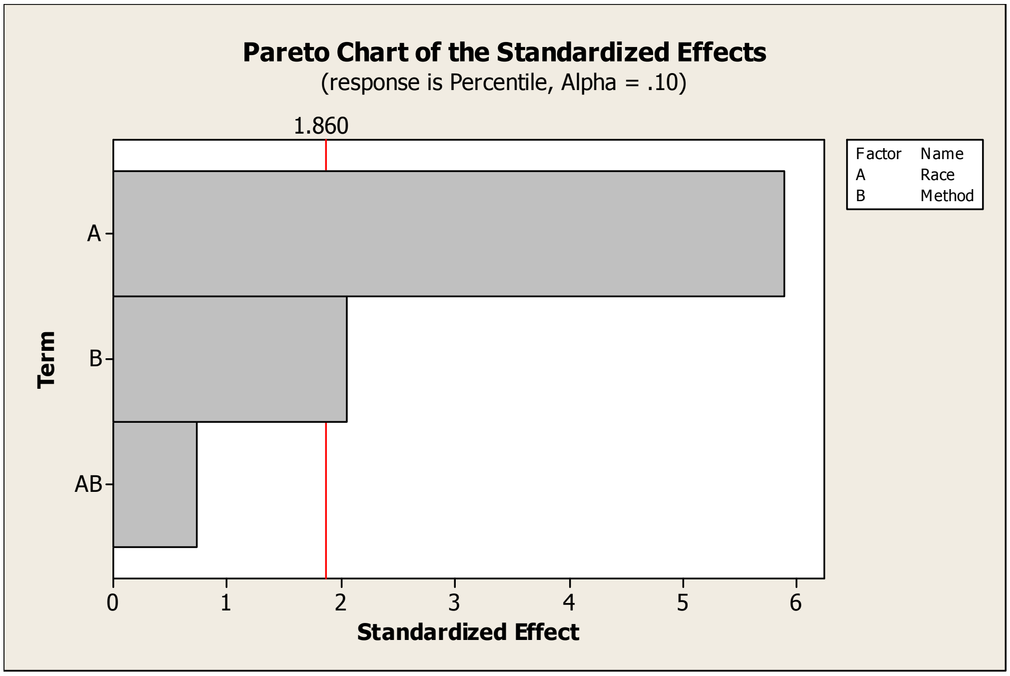

Figure 5: Pareto Chart of Race Effect (A) and the Method Effect (B).

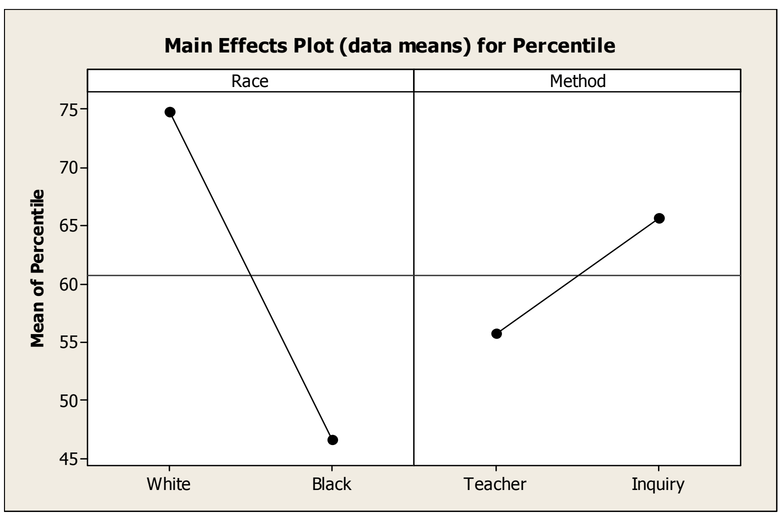

Figure 6: Plot of Race Effect (A) and the Method Effect (B).

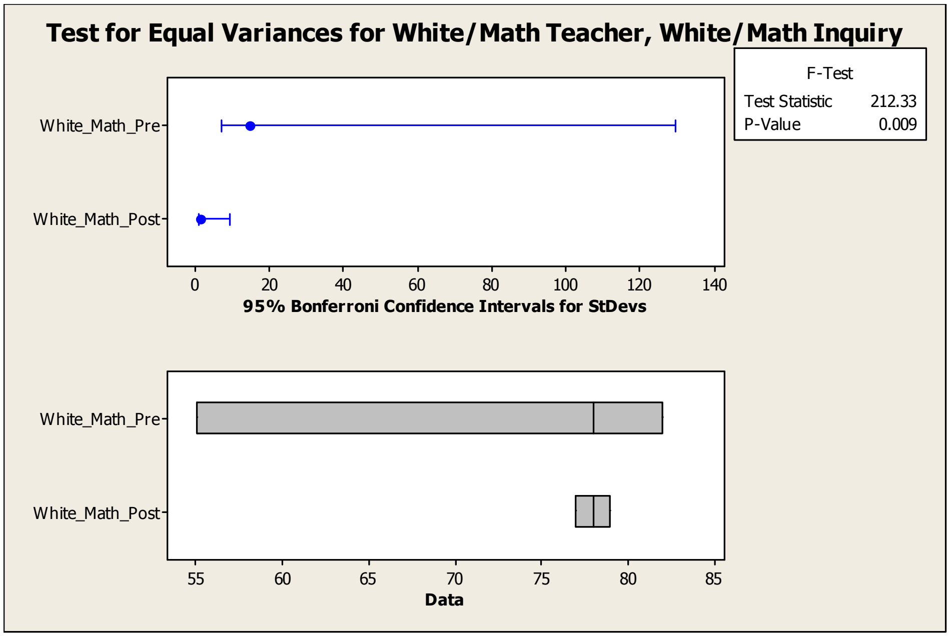

Figure 7: Test for equal variances for White Teacher-based versus Inquiry-based.

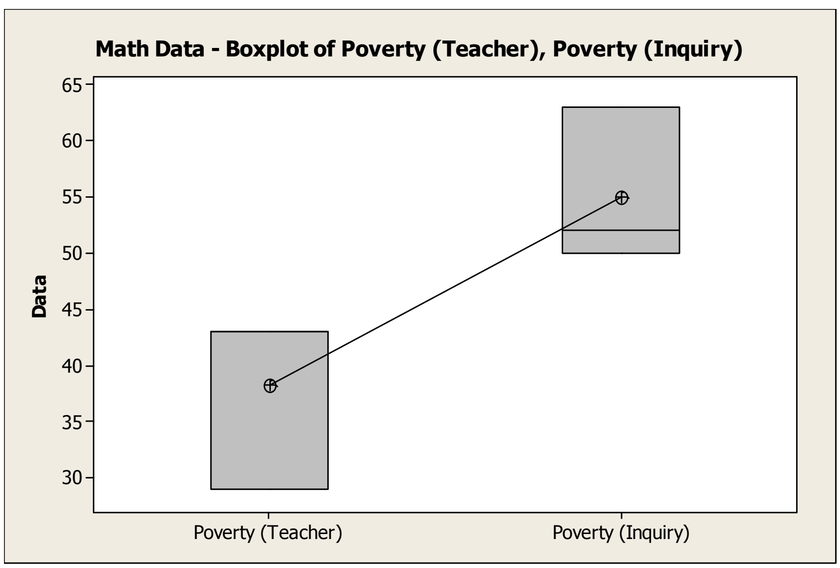

Figure 8: Plot of Method Effect on Poverty Students

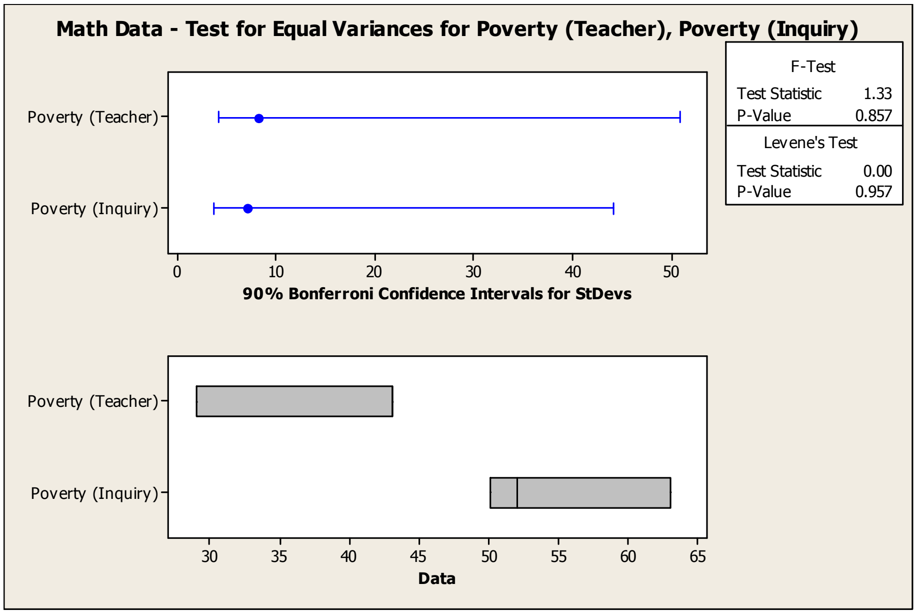

Figure 9: Test for equal variances for Poverty Teacher-based versus Inquiry-based.

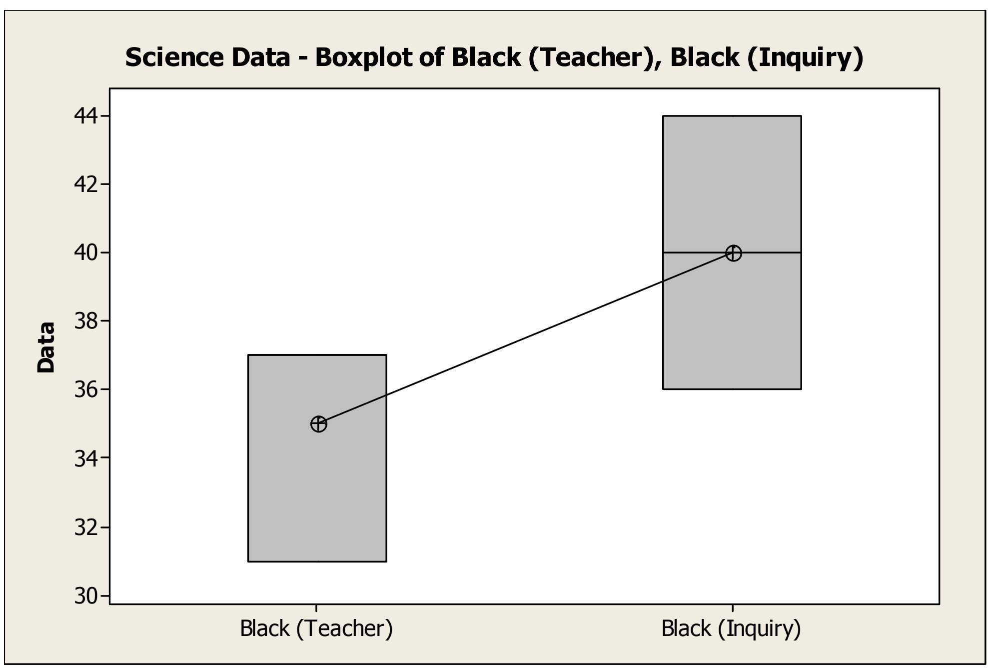

Figure 10: Plot of Method Effect on Black Students

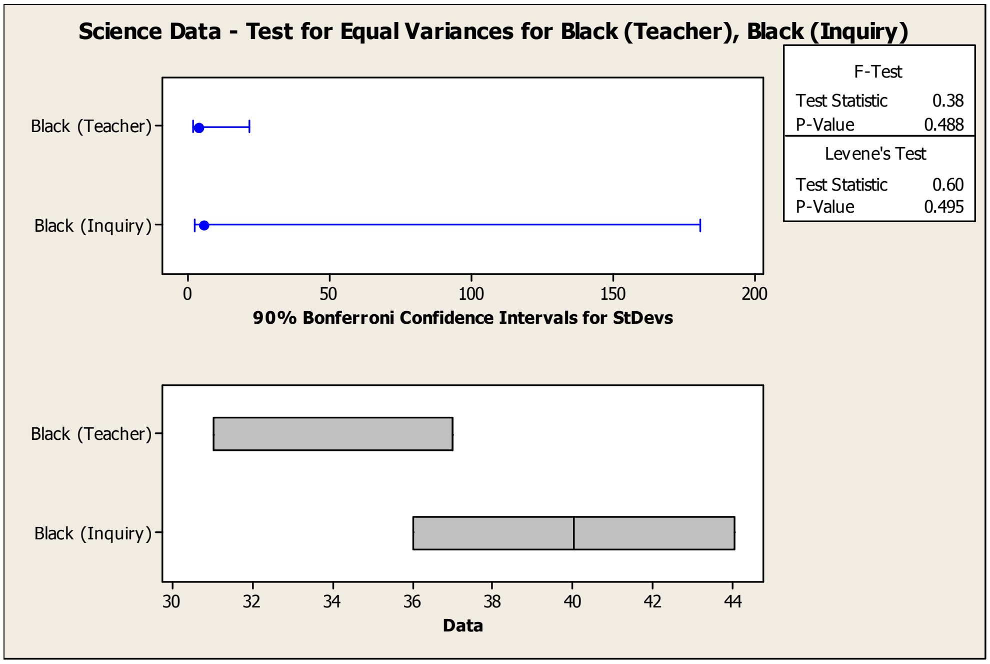

Figure 11: Test for equal variances for Black Teacher-based versus Inquiry-based.

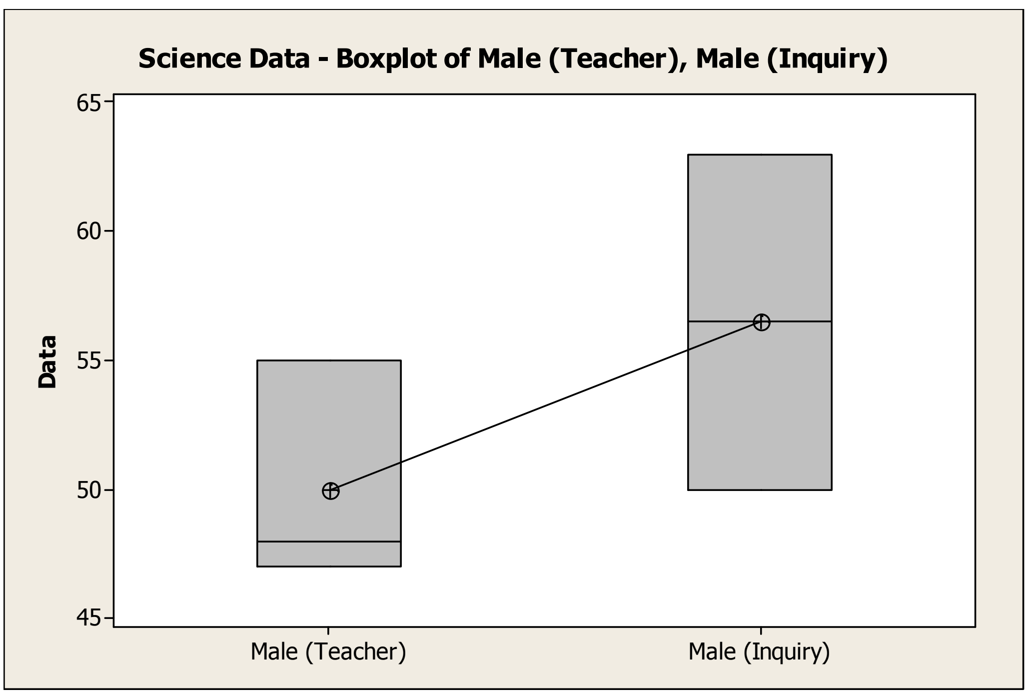

Figure 12: Plot of Method Effect on Male Students

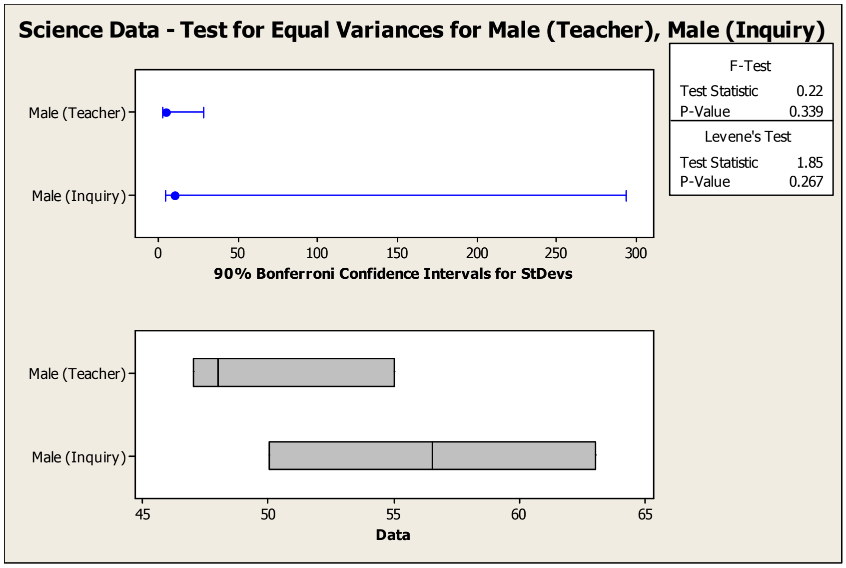

Figure 13: Test for equal variances for Male Teacher-based versus Inquiry-based.

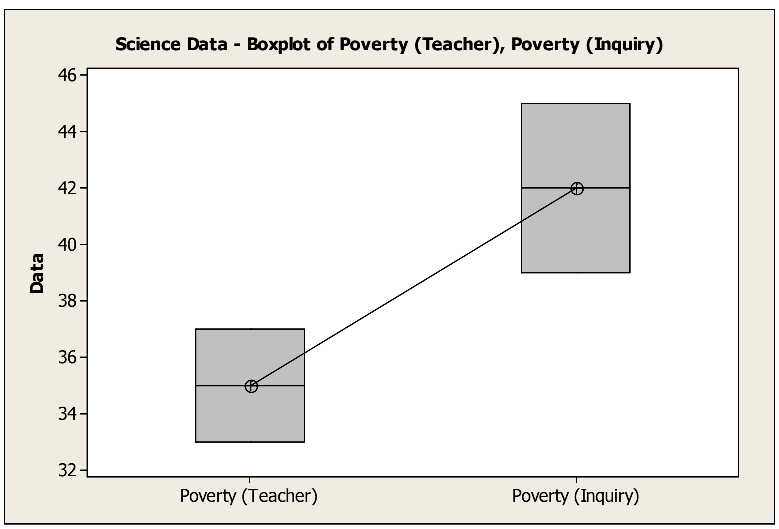

Figure 14: Plot of Method Effect on Poverty Students

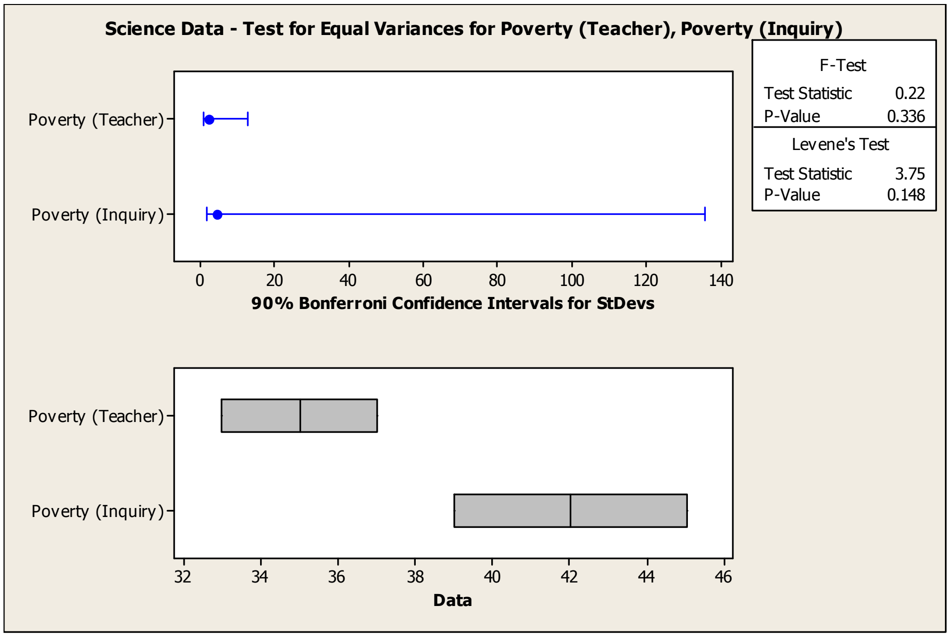

Figure 15: Test for equal variances for Poverty Teacher-based versus Inquiry-based.