RESEARCH & INQUIRY-BASED CURRICULUM

An Exemplary and Effective Approach to Teaching Science

WHAT IS INQUIRY-BASED SCIENCE?
THE DATA ON SCIENCE ACHIEVEMENT
RESEARCH ON TEACHING EFFECTIVENESS
PROFESSIONAL DEVELOPMENT
WHY RESEARCH IS SO IMPORTANT
CONCLUSION
What's the Problem?

While the statements here are perhaps funny to read, to realize that they are the result of a lack of understanding of science concepts immediately takes the humor out of any statement of this kind. These statements, taken from actual school science tests, essays, and papers,\footnote{1} clearly illustrate that these students have not had meaningful experiences with water, gas, or plant growth and development. Consequently, it is difficult, perhaps impossible, for these students to apply the knowledge they have to questions on a test.

The success of students who participate in hands-on science activities suggests that if students have first-hand experiences with science, concepts are easier to understand and apply. For example, if a student can actually watch germination occur, watch the parts of the flower develop, and participate in the pollination of that flower, then that student can define the relative terms meaningfully in the context of those experiences and apply the concept to other relevant topics.

Traditionally, teachers use textbooks to teach science. Teacher and students open the book to page one and sequentially work their way through the chapters. Sometimes teachers are more innovative, diverging from the text to incorporate video clips, presentations, school curriculum, or their own lesson plans. Despite attempts to engage students in different ways, traditional methods of teaching science are failing students. Data shows that it becomes increasingly difficult for students to understand and apply scientific concepts as they continue the course of their science education. This is exactly the opposite of what should happen. Students should have opportunities to develop existing knowledge and improve science process skills throughout their careers as student scientists.

Research shows that inquiry-based curriculum materials, in comparison with traditional teaching methods, work better to help students engage in, reflect on, and apply scientific knowledge and science process skills and perform better on assessments than traditional methods.\footnote{2} In addition, students in classes where science is taught using hands-on methods are generally more favorable to science and have a better understanding of the nature of science than students in textbook classes.

Based on the research of both textbook curriculum and inquiry-based curriculum across many states, districts, and demographics, it is becoming evident that the most exemplary and effective way to teach science is through hands-on, inquiry-based curriculum and materials. But what are exemplary and effective materials? What does an inquiry-based classroom look like? This document will define inquiry-based learning and illustrate how it compares with traditional methods of teaching by sharing the results of a variety of research studies, assessments, and analyses of course materials.
What Is Inquiry-Based Science?

Inquiry-based science is an approach to science education that is student-constructed as opposed to teacher-transmitted, hands-on as opposed to lecture-based. Students learn science by using methods, adopting attitudes, and applying skills as scientists do when conducting scientific research. Students are able to find their own problems and generate their own questions, formulate their own hypotheses, design and implement their own methods for testing their hypothesis, and use their own data to answer their original questions. There is a progression from teacher-guided inquiry to completely student-directed inquiry. Even though students direct the course of study, the teacher still assesses progress and introduces critical skills and concepts. An inquiry-based classroom enables students to actively construct meaningful knowledge rather than passively acquire facts. Because students learn by connecting information to their own experiences, inquiry-based learning allows students to have experiences with germinating seeds, maintaining an aquarium, and working with circuits to light bulbs. After engaging in such activities, students are able to apply the information from the experience to new science concepts and life in general.

H₂O IS HOT WATER.
CO₂ IS COLD WATER.
WATER IS COMPOSED OF TWO GINS: OXYGIN AND HYDROGIN.
OXYGIN IS PURE GIN.
HYDROGIN IS GIN AND WATER.
Percentages of grade 4th-grade students at or above each achievement level for science, and how often those students do hands-on science activities

Science Achievement at the National Level: The 2005 NAEP Test and Pedagogy Survey Results

As part of the national assessment in 2005, the National Association for Educational Progress (NAEP) surveyed students and teachers to gather information about the pedagogy of various classrooms and conducted a nationwide assessment of what students know in various subject areas, such as math, reading, and science. Results showed that elementary school students performed better in science on the NAEP assessment in 2005 than they did in both 1996 and 2000 while scores for 8th graders remained unchanged and scores for 12th graders declined. In 2005, in both 4th and 8th grades, 52% of teachers reported their students participating in hands-on activities once a week or more. Figure 1 shows that the more often 4th grade teachers reported doing hands-on activities with their students, the more likely they were to score at or above Basic on the NAEP assessment. In a separate analysis, the more often teachers in North Carolina reported doing hands-on activities with their students, the more likely the students were to have a higher scale score on NAEP assessments for both reading and math (see Figure 2). In 1996, teachers of 77% of the 8th grade teachers surveyed reported their students engaging in these types of activities just as often, although this percentage dropped by 2005. The more often teachers reported doing hands-on activities with their 8th grade students, the more likely they were to score at or above Proficient on the NAEP science assessment than students who rarely did hands-on activities. For students who participate in hands-on activities, a critical component of inquiry-based learning, academic success is more likely in science, and the skills extend into other subjects, causing higher scores on assessments in other subject areas as well.

Although the data from NAEP assessments and surveys is persuasive, merely citing test scores and identifying the relationship between the presence and frequency of hands-on lessons and improved science learning does not prove that inquiry-based instructional materials make a difference in how students learn science. In order to prove the link between higher learning outcomes and inquiry-based materials, a thorough and scientifically controlled research study must be conducted.
Research on the Effectiveness of Science Programs

The National Research Council has outlined several ways to research the effectiveness of curriculum materials. Each approach reveals different, relevant information, and all are important components in generating a comprehensive study of curricula.

Content Analysis is used to evaluate whether a curriculum unit aligns with certain content standards. Such an analysis is often left to subject experts, who would be responsible for evaluating the depth of the curriculum, the logic of the sequencing, and the accuracy of the content. From a content or instructional analysis, information regarding the pedagogical approach of the curriculum can also be evaluated. If we compare inquiry-based curriculums and materials to traditional textbooks using the Project 2061 Curriculum Analysis, for example, a range of profiles emerges. For example, the two inquiry-based units in Figure 3 exhibited strong evidence of engaging students with relevant phenomenon and developing students’ scientific ideas, while the textbook did not. This indicates that the traditional textbook approach to teaching science may not promote the development of students’ ideas or thinking, nor allow students to practice or apply skills that have been presented. Regardless of how well a curriculum fares in a content or instructional analysis, however, it is no guarantee or proof that a particular curriculum will achieve better learning outcomes for students if it is adopted and implemented in a classroom or district. To know this, we need a study that looks at student outcomes.

Case Study, a type of pre-experiment used to evaluate curricula, investigates specifically how a particular curriculum material affects a particular school district at a particular time while considering what factors influenced the implementation of the curriculum, how the evidence was collected, and what information was omitted and why. Case studies can provide statistical information on a case-by-case basis and document success in places where a particular curriculum was used, but cannot prove that a particular curriculum was directly responsible for an increase in test scores or that the curriculum will generally produce the same results in other schools or districts. Nevertheless, specific instances of success for inquiry-based programs help build a case for its success as an instructional method.
4

4th-graders in Green Bay using Einstein Program (STC) scored higher on Wisconsin Knowledge Concept Exam

<table>
<thead>
<tr>
<th>Year</th>
<th>State A+P Scores</th>
<th>Einstein A+P Scores</th>
<th>Non-Einstein A+P Scores</th>
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<tr>
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<td>82.5</td>
<td>80.4</td>
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<tr>
<td>2003</td>
<td>80.8</td>
<td>88.5</td>
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<tr>
<td>2004</td>
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<tr>
<td>2005</td>
<td>77.5</td>
<td>84.3</td>
<td>82.7</td>
</tr>
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Average for 2002-2005

5

In 2002, Valadez and Freve found reading scores higher for 1,200 Fresno, California, 5th and 6th graders who had an inquiry-based science program for more than four years compared to students who had it for less than four years

Figure 4 presents data of state assessment scores from students in Green Bay, Wisconsin, who used Science and Technology for Children™ (STC) with success. Responding to a lack of hands-on science curriculum in Green Bay, the Einstein Project implemented a trial of inquiry-based science units in a particular district and conducted a series of case studies on the use of STC in those classrooms. A comparison between the test scores for districts that used the program, districts that did not, and the statewide averages shows that at the end of the year for four consecutive years, students who learned science using STC scored higher than students in districts that did not use STC and surpassed the statewide average on the Wisconsin Knowledge Concept Exam. The relevant data in this study included the percentage of students in each district who scored Advanced or Proficient each year the test was administered, referred to as A+P Scores in the table in Figure 4. Regardless of the success the Einstein Project found in the districts that used STC, there is not enough data to prove that the higher scores those students achieved were the result of using STC. Similarly, research that shows that 5th grade students in Fresno, California, who used an inquiry-based science program for more than four years had significantly higher scores on the SAT 9 than students who used an inquiry-based program for less than four years (Figure 5). The researchers who conducted the study can present the results of their case study in terms of the success that the Fresno students had, but they cannot claim that the students scored better because they used the program longer. Although it seems easy to interpret case study data in this way and one would like to conclude that the programs were responsible for the higher scores, these studies do not tell us if the inquiry-based programs caused the outcomes. To know this, we need a more rigorous, scientifically controlled study.
**Comparative Studies** compare two sets of schools, students, or classrooms. One set uses the program in question (Treatment) while the same number of matched schools, students, or classrooms do not use the program but conduct business as usual (Comparison). The National Research Council recommends at least five pairs, but rigorous tests require a “power analysis”—that is, an analysis to determine the minimum number of schools, classrooms, or students required to accept the results with confidence. Comparative studies are experiments, and can be quasi-experimental or true experiments. A quasi-experiment might match schools, classrooms, or students that are using the treatment unit with demographically similar schools, classrooms, or students who are not using it. A true experiment is one in which the schools, classrooms, or students are randomly assigned to use or not use the treatment program. The data and statistics gathered through these extensive experiments are used to show that if groups are similar at onset, then any differences in learning outcomes between the two groups at end of the experiment resulted from the program used by the treatment group.

To evaluate the effectiveness of STC in the teaching and learning of science, the Einstein Project commissioned a comparative research study to look into whether students who used STC learned better than students who were taught using traditional textbook-driven curriculum. Teaching five classrooms with inquiry-based STC units and five classrooms with a traditional textbook approach, the St. Norbert College Survey Center matched both class demographics (including English proficiency, class size, gender, socioeconomic status, ethnicity, and the number of students with disabilities) and the amount of teacher training and experience rather than using a random selection of students. Statistically, those students using STC in the Einstein Project showed a 4% increase in general science knowledge between their pre- and post-test scores compared to an only 1.7% increase in general science knowledge for non-STC students. Those same students were also able to use correct and appropriate scientific terminology 81% of the time, compared to non-STC students, who were only able to do so 20% of the time. The St. Norbert College Survey Center concluded from its research that students who learned science using inquiry-based programs like STC were able to “do science” better than students who learned from textbooks, meaning that inquiry-based classrooms produced students who were better able to perform tasks, investigate questions, and classify, arrange, draw, label, and describe scientific phenomena. Because this study was controlled, with both a treatment and a comparison group, the Einstein Project can conclude that the higher learning outcomes (76.8% compared to 64.0% on the post-test) for the students who used STC were directly related to the implementation of the program in those districts.
The Alabama Math, Science, and Technology Initiative (AMSTI) compared a set of schools that used STC and other inquiry-based programs and participated in intense professional development with a demographically matched set of control schools that did not have either inquiry-based programs or the intense professional development. Figure 6 compares the scores from math and science assessments after the third year of program implementation. It is clear from the graph that those students who were provided with inquiry opportunities scored better on the test than students who received traditional science instruction. Because variables were controlled and the groups were demographically matched, it can be concluded that the reason for the success of those students was the use of inquiry-based curriculum programs like STC, coupled with intense professional development. Figure 7 illustrates the effectiveness of kit-based science on student achievement. Kit-based science provides more hands-on learning opportunities than traditional textbook learning. In this particular study, the amount of professional development did not have an impact on how well students achieved; in this situation, it was the presence of the kits in the classrooms that impacted student achievement. Although only post-test scores are shown on the graph, those students who used science kits scored significantly higher on both pre- and post-tests than the demographically matched group who learned science without kits—even though there were more minutes of science instruction in the non-kit classrooms. Clearly, the research here supports the effectiveness of inquiry-based science programs over traditional approaches to teaching science.
Professional Development

While the focus is often on the learning outcomes of students, a topic that deserves just as much attention is the understanding and knowledge teachers have when they enter the science classroom. Do teachers feel prepared to teach students about electric circuits? To teach about the forces of motion? Too often, they do not. In Pennsylvania, the State Department of Education implemented a program called Science: It's Elementary (SIE) to address the growing need for better early education science instruction. They commissioned an independent research study to investigate the effectiveness of the program in its first year of implementation. The study revealed that prior to the implementation of the program, more than one out of six elementary-school science teachers who participated in SIE (17%) taught zero science lessons per week because they felt unprepared to teach the material to students. Providing professional development opportunities for teachers in which they receive support, information, skills, and techniques to better serve their students encourages teachers and prepares both teachers and students for success. Using kit- and inquiry-based science programs lends itself well to professional development. Like STC, SIE offered hands-on professional development training to teachers before they implemented the modules they were to teach. After participating in such training, 95% of SIE teachers felt that professional development increased their confidence in teaching elementary-school science. Figure 8 shows the increase in teachers’ perceptions of their science content knowledge and their ability to teach before and after participating in professional development training. Figure 7 also shows the benefits of professional development for teachers on student learning outcomes. Students of teachers who participated in three days of professional development training for SIE scored approximately 5% higher on their post-test than students of teachers who participated in only two days of the professional development training. These data point to a significant and positive relationship between student achievement and full participation in SIE professional development. Figures 9 and 10 both show the pre- and post-test scores for students who learned about rocks and minerals and electric circuits, respectively, one group using traditional instructional methods and one group using SIE’s inquiry-based modules, which were coupled with professional development. While pre-test scores were the same or similar, the post-test scores were drastically different, with students who received traditional instruction from teachers who did not attend professional development training scoring significantly lower than the inquiry-based students whose teachers received professional development training.
Why Is Research of Inquiry-Based Programs Important?

Research of inquiry-based science programs is important for two reasons. First, schools must evaluate instructional programs using scientifically based research and reject programs that are unproven fads. Federal funding supports programs whose success is backed by evidence from scientific research. Thus, research that presents evidence that inquiry-based science programs are more effective than textbook teaching will help gain support for inquiry-based programs like STC. Inquiry-based science programs improve the quality of instruction in K–8 classrooms and engage every child, and the research continues to show that inquiry-based programs do this better than textbook-based curricula. Without research to support the fact that inquiry-based instruction increases learning outcomes for students, inquiry-based science might not overcome traditional textbook teaching as the primary method of teaching science. A scientifically controlled research study will help to bring inquiry-based learning into more classrooms in more schools in more cities.

In addition, the U.S. Department of Education states that the nation must research the best way to teach science and measure student progress, as it has done with reading. As educators, we need to find the most comprehensive and effective way to teach our students so they can succeed. To prove the link between inquiry-based science curricula and increased student learning outcomes there must be a rigorous, far-reaching, controlled study of such programs. No single study should be interpreted as infinitely conclusive on whether inquiry-based science actually works. As many studies as possible should be conducted and analyzed to compile statistics that can be read as “the best estimate of what is known about that topic.”

Conclusion

While the research up to this point presents a strong case for the effectiveness of inquiry-based science curriculum, there is still a long way to go. Many more studies are necessary so that the link between such programs and greater student achievement in science, as well as other subjects, can be proven without question. The research presented in this document illustrates that inquiry-based science curriculum is effective: students who use these programs are performing better in science than their traditional “business-as-usual” textbook counterparts. The research also shows that inquiry-based programs address more than just facts about science, including critical thinking skills, scientific attitudes, and the ability to design, execute, and analyze experiments. In short, students who learn through inquiry are able to do science better.
Visit our web site for more information on Inquiry-Based Science Programs.