Reversing the Swing from Science: Implications from a Century of Research

ITEST Convening on *Advancing Research on Youth Motivation in STEM*

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by Cary Sneider, Portland State University, Portland, OR

Abstract

For at least the past 100 years science educators have been concerned about how best to encourage children's natural interests in science; but the problem of waning interest through the middle school and high school years persists. Research on how best to maintain interest in what is now more broadly conceived of as science, technology, engineering, and mathematics (STEM) is more important than ever. These studies can be categorized as deductive research that begin with theories of action and lead to interventions to be tested; or inductive studies that begin with existing programs, and lead to theories about why some are more effective than others. Given the importance of this issue for preparing a scientifically literate population and strong technical workforce, it is essential that researchers build on each others' work and communicate findings so as to influence policy and practice.

Part I. A Brief History of Research on Youth Motivation in STEM

John Dewey Lays the Foundation

John Dewey's seminal 1913 essay, *Interest and Effort in Education*, laid the foundation for educational theory and intervention in science education based on the central question of how to best motivate learners. The starting point of his theory of action was a definition of interest as "being engaged, engrossed, or entirely taken up with some activity because of its recognized worth." Dewey discounted the typical approach of motivating students by relying on a list of topics, such as dinosaurs, that most children find fascinating, and focused instead on a deeper level of engagement more recently referred to as "flow" (Chixantmihaly 2000) in which a person becomes so absorbed—think of what it must be like to be a rock musician performing for a thousand roaring fans— that passage of time has no meaning.

In Dewey's theory of action, interests can motivate people to undertake efforts that may not be immediately engaging (such as *practicing* the guitar) which enable the individual to develop further skills and knowledge, leading to intellectual growth and development. Also, he is explicit about the teacher's job—the intervention—that supports student motivation to continue learning and developing. Dewey presents his recommended intervention as a series of dos and don'ts that can be paraphrased as follows:

Don't…

- Use fear or coercion to make students learn difficult subjects, such as math.
- Sugar-coat learning by bribing students with goodies or affection.
- Assign tasks that are too difficult so that students give up.
- Assign tasks that are too easy, such as repetitive drills that bore students.

Do…

- Make an effort to understand what your students find intrinsically interesting.

- Provide an environment where students can pursue and extend their interests.
- Relate science to human concerns.
- Provide tools and materials for students to do real work.
- Challenge students to innovate and invent in order to pursue their goals.

Although Dewey's essay seems remarkably modern in its ideas about how to motivate students in STEM (notice the references to technology, engineering, and mathematics), it differs from modern articles in that it does not deplore students' lack of interest in science. Rather, Dewey takes a positive approach, implying that all students are naturally interested in learning about the world, and it's the job of a sensitive and capable science teacher to build on that interest in order to support students' intellectual growth.

Research on the genesis of interest in science

Interest in students' attitudes towards science was a major topic of educational research throughout most of the 20^{th} century according to a research review of more than 400 studies by Oremod and Duckworth (1975). The first study they cited, published in 1874, was a study by Francis Galton of 100 Fellows of the Royal Society entitled *Men of Science: Their Nature and Nurture*, was that interest in science began very early, and in fact most scientists could not recall when they were *not* interested in science.

The number of research studies of schoolchildren's attitudes towards science increased substantially in the 1930s, including a survey of science interest among 9,000 elementary age children in Worcestershire, England. Further work in the 1940s and 1950s attempted to pin down the age at which children became interested in science related careers. A key study by Chown (1958) reported two peaks in the time of occupational choice—ages 13 and 16 for boys, and ages 11 and 15 for girls, who tended to mature earlier. Oremod and Duckworth concluded that: "The widely used evidence all points to the conclusion that, in the United Kingdom and the United States, at least, the critical ages at which pupils' attitudes to science can be influenced extend from about 8 years of age to about 13 or 14." (p. 4)

Sputnik Sparks Interest

Prior to the launch of Sputnik in 1957 science educators were aware that many students tend to lose interest in science sometime before high school, but it was not a major cause for concern for the nation. However, once the importance of a strong scientifically minded workforce came to be associated with national security at the start of the cold war, what was then called the "swing from science" began its climb to the top of the agenda for science education research.

A more recent review by Osborne (2003) that summarized findings from a selected group of about 150 key studies focused on the importance of a scientific-technical workforce for continued economic prosperity. The review pointed to the finding that students' interests in science tend to decline from age 11 onwards and expressed serious concern about the decline since 1990 in the number of students in the US and UK who choose to pursue STEM fields in college and graduate work in STEM fields.

Osborne found that various researchers conceived of "attitudes toward science" in different ways. Some emphasized the affective aspects of the construct, such as feelings, beliefs and values about science. Others emphasized the cognitive aspects, such as a questioning approach to the world, a search for data and their meaning, a demand for verification, and a respect for logic.

The affective dimension is generally referred to as “attitudes towards science” while the cognitive dimension is commonly referred to as “scientific attitudes.”

A key finding of Osborne’s review was the apparent contradiction between students’ attitudes towards science in general and their attitudes towards science in school, especially at the high school level. That is, most teenagers, including both boys and girls, find science interesting and useful in everyday life. On the other hand most teenagers find school science, and especially physics, to be difficult, boring, and disconnected from society. Research studies strongly suggest that the reason for this apparent contradiction is the poor quality of school science teaching, and that the most important single factor in engendering positive attitudes is a knowledgeable and enthusiastic teacher.

The second most important factor in reversing the swing from science is the curriculum—how teachers engage students in science, both in school and informal science settings such as afterschool, Saturday and summer programs. Given that choosing an effective curriculum is somewhat easier to control than recruiting, training, and retaining the best teachers, it is not surprising that the largest number of studies by far have been comparisons of different science curricula, numbering in the hundreds, and possibly thousands. Osborne’s review is critical of such studies because the great majority of them compared an experimental intervention with the normal curriculum, but failed to analyze the essential ways in which the two instructional approaches differ.

Part II. Inductive Approaches: Theories Leading to Testable Interventions

Taking Osborne’s analysis to heart, this section focuses on three interventions and their theories of action that provide exceptional insights into what works in motivating youth to engage in STEM activities, to develop a personal interest in STEM subjects, and aspire to STEM careers.

DESIGNS: Focus on Teaching

Swartz and Sadler (2007) compared three instructional methods for engaging student interest in science while increasing their knowledge of science concepts. The interventions involved same content matter, the same hands-on activities, and many of the same instructional supports, so that they could analyze the effect of a single variable—the way that teachers and students shared responsibility for guiding instruction.

1) In the **traditional method** the textbook specified the instructional goals, strategies for students to use in reaching the goals, and the order of activities.
2) In the **discovery method** the students had the freedom to choose the instructional goals as well as the strategies to reach the goals.
3) In the **balanced method** the teacher set the goals while the students determined the strategies they would use in reaching the goals.

The unit being tested was about electromagnets, drawn from the DESIGNS curriculum that the researchers had developed. Two theories of action guided development of the instructional materials. The first was perceptual control theory, which emphasized the importance of goals that enable students to marshal their resources towards a specific end, to continuously evaluate their progress, and to make decisions about their own learning. Perceptual control theory predicted that the discovery approach would be the most motivating.

The researchers also wanted students to develop science concepts and skills. The theory of action to support that purpose was skill theory, which emphasized the importance of beginning at the level of action so that the students would become familiar with the various materials and properties of the electromagnet, and scaffolding their efforts to represent single then multiple variables, and finally advance to abstract thinking. Skill theory predicted that the balanced method would be best.

Student engagement was assessed by systematically observing the number of students on task (in “flow”) and growth in knowledge was measured by a concept questionnaire that tested their understanding of electromagnetism and their ability to solve new problems that they had not encountered during the intervention.

The results of the study were that the balanced method, in which the teacher sets a well-structured goal, but the students have freedom to control their strategies and procedures in reaching the goal was most effective in motivating students and in gaining knowledge and skills. In contrast, students in the traditional condition were bored and tended to focus on what the teacher wanted, asking questions such as: “Is this right?” “Will this be on the test?” The students in the discovery condition were highly motivated, but at the end of the unit they had little grasp of how electromagnets worked.

The Schwartz and Sadler study provides an excellent example of a research design that avoids the methodological problems pointed out by Osborne, and that yields valuable information about how to accomplish affective as we as cognitive goals. However, its usefulness is limited to what can be done with the relatively short-term interventions that can take place in a science classroom. Such interventions rarely address the more profound obstacles met by youth of color, by girls who have received little incentive to engage in STEM, or by youth from communities of poverty. Consequently, we turn next to a pair of studies that—although variables are not controlled as they were in the Schwartz and Sadler study—nonetheless shed light on the kinds of interventions that may have substantial impacts on youth who are otherwise difficult to reach.

YouthALIVE! Focus on Multi-Year Engagement

YouthALIVE! (Youth Achievement through Learning, Involvement, Volunteering, and Employment) was a response by a small group of individuals within the science center community to a series of reports in the late 1980s that the talent and potential of too many young people was being lost. The result was *YouthALIVE*!, which may well be the largest experiment ever undertaken to engage youth from populations underrepresented in STEM fields. During the 1990s, the DeWitt-Wallace Reader’s Digest Fund awarded grants to 72 institutions to establish programs that would primarily serve teens of color, youth from low-income communities, and girls from age 10 to 18.

Unlike most programs that would last a week or two, or occasionally an entire summer, the teens who joined *YouthALIVE*! were welcome to remain in the program from the time they joined (which could be as early as middle school) until they graduated high school. A typical program might involve the teens in both attending and teaching afterschool and weekend science classes, working in summer camps, serving as exhibit interpreters on the museum floor, or helping scientists conduct research. Common factors among programs were frequent contact, a club-like atmosphere, dedicated staff with youth development experience, and a focus on learning, teaching, developing a strong work ethic and a sense of community (ASTC 2001).

Although institutional grants ceased more than ten years ago, a recent retrospective study (Sneider and Burke, 2011) found that the number of youth programs at museums and science centers has grown to 163, demonstrating that philanthropic initiatives that are thoughtfully planned in collaboration with museums and science centers, meet multiple needs, and are based on clear principles, can survive and thrive when major funding ends.

Although not all programs have been evaluated, those that have present a remarkable record of success at greatly reducing the number of high school dropouts and increasing the number of minority youth and girls who choose careers in STEM fields. For example, Chi and Snow (2010) conducted a ten-year longitudinal survey of former participants from Project Exploration (PE), a nonprofit organization in Chicago that recruits minority youth and especially girls to go on field expeditions with paleontologists and to work with visitors in the city’s science museums. The researchers found that 95% of the respondents have graduated high school or are on track to graduate, nearly double the overall rate of Chicago Public Schools. In addition, 61% of students currently enrolled in a four-year college reported pursuing degrees in STEM-related fields; and 59% of four-year college graduates reported earning a degree in a STEM-related field. These findings are especially remarkable since PE recruits students who do not necessarily do well in school or who are not initially interested in science.

A theory of action that helps to explain the success of multi-year programs for youth is the Trilogy of Success theory (Jolly, Campbell, and Perlman 2004) which identifies three factors as essential for all students—and especially youth of color, those who come from communities of poverty, and girls—to succeed in science: *engagement* to increase student interest and motivation; *capacity* to gain knowledge and skills, and *continuity* of material resources and guidance by caring individuals. The *YouthALIVE*! model provides all three factors, including the very rare factor of continuity, over a period of several years.

However effective and important such programs may be, they are resource-intensive, and consequently available to only a small fraction of the many youth who could benefit. Consequently the next program to be reviewed requires very few resources and could therefore affect a great many youth.

Perceived Relevance: Focus on Introspection

Hulleman and Harackiewicz (2009) designed a rigorously controlled experimental study to determine if personal relevance would affect high school students’ interest in science, performance in the course, and interest in science related careers. The researchers based their study on an expectancy-value theory of action that predicted students who had low expectations of success in science would benefit more from an intervention that increased the perceived relevance of the course than students who had high expectations of success, and therefore did not need a motivational boost.

The study was conducted with the assistance of seven high school science teachers from two high schools and 262 students enrolled in biology, integrated science, and physical science. All of the students received. Although the notebooks appeared to be the same, half the students in each class received notebooks that instructed them to write about the usefulness and value of the course material to their own lives; while the other half of the students received notebooks that instructed them to summarize the course material. The teachers did not know which students received which instructions.

All students were administered questionnaires about their interests in science and their expectations of success at the beginning of the semester. At the end of the semester they answered questions about their interests in science and their career aspirations. As predicted, the students who had low expectations of success at the beginning of the course had significantly more positive attitudes towards science. Students in the experimental condition improved their science grades an average of two-thirds of a letter grade during the subsequent quarter. The intervention was equally effective for boys and girls and for students of all races. In contrast, there were no significant pre-post differences for students who entered the course with high expectations.

The researchers noted that this degree of improvement for students who were most in need was comparable to other social-psychological interventions aimed at reducing the back-white achievement gap. In contrast with the high cost of multi-year programs that could serve relatively few students, having students occasionally write about how the course they are taking is relevant to their lives is a low-cost and easily implemented intervention that could be implemented by any teacher in either formal or informal science education settings.

III. Deductive Approaches: Explorations Leading to Theories of Action

Each of the studies reported in Part II tested a specific intervention that followed logically from a theory of action. Consequently they each exemplified a *deductive* approach to the science of motivation. An alternative approach is *inductive*—to explore the results of many different programs, look for positive effects, and formulate theories about why the effective ones work and the ineffective ones don't. The advantage of an inductive approach is that the researcher is not limited to testing their own hypotheses; but instead is open to what the data have to say. This paper ends with a brief summary of three inductive lines of research that are currently ongoing.

Longitudinal Studies of Multiple Programs and Pathways

A line of research by Robert Tai and his colleagues, based at the University of Virginia have taken an approach similar to the earliest researchers in the field. They interviewed 116 scientists, engineers and graduate students in STEM fields and find out what influenced them (Maltese and Tai 2010). Consistent with the findings of the Royal Society study in 1874, interest in science began very early. The majority (65%) reported that their interest in science began before middle school. Women were more likely to say their interest was sparked by school-related activities, while most of the men credited activities they initiated themselves. The researchers concluded that current efforts to increase our nation's scientific and engineering workforce by focusing efforts on higher test scores and encouraging more students to take advanced science courses may be misguided; and it may be more important instead to focus efforts on engaging boys and girls in science at the elementary and middle school levels.

In one of the most widely cited research studies on motivation in STEM Tai, Liu, Maltese, and Fan (2006) conducted an analysis data from the National Education Longitudinal Study (NELS). NELS surveyed 24,599 eighth graders in 1988, and followed up with surveys of the same youth in 1990, 1992, 1994, and 2000, when the participants who were 13 years old in 1988 were 25 years old. The study also collected data on the students' performance on mathematics and science achievement tests. By the end of the study period 3,359 of the youth surveyed in 1988 had obtained four-year college degrees. College majors for these students were coded into three broad categories, physical and general science, life science, and non-science.

The 8th grade survey asked the participants: “What kind of work do you expect to be doing when you are 30 years old?” Students were given a list of career options and asked to select just one. Responses were categorized as with “science” or “non-science.” Findings were that students who expressed interest in science-related careers in 8th grade were 1.9 times more likely to go into the life sciences, and 3.4 times more likely to go into physical sciences or engineering than those who chose non-science career expectations.

To follow up on the implications of the earlier studies Tai and his colleagues are currently researching the effects of 50 or more different programs aimed at engaging children and youth in science, and in longitudinal studies that connect the dots between early engagement and later achievement and career choices.

The Science Learning Activation Lab

Rena Dorph and colleagues at the Lawrence Hall of Science, UC Berkeley, have undertaken an ambitious program to determine how to activate children’s interest and persistent engagement in science learning and inquiry (Dorph, Schunn, Crowley, and Shields 2011, p. 16). Noting that nearly all research on this important topic is confined to specific programs or take place within limited categories of science setting (schools, museums, afterschool programs, etc.) the purpose of the Science Learning Activation Lab is to investigate the features of excellent science education that apply across settings. In an effort to identify measurable outcomes, the researchers identified the following dispositions that together describe a science-activated learner: curiosity, motivation, responsibility, persistence, science capable, identity, appreciation, and interest in science. A major goal of the Science Learning Activation Lab is to develop a valid and reliable battery of test instruments to measure all eight constructs.

These lines of research will come together in a series of coordinated longitudinal studies to provide valid, reliable, and predictive measures of dispositions that signify activated science learners, and features of educational programs that foster those dispositions. The researchers will use both quantitative and qualitative research methods to study the features of effective educational interventions in a variety of different settings, and the various pathways through different settings taken by individuals on their way to becoming activated science learners.

The Synergies Project: Investigating Science Motivation in Situ

Falk and Dierking at Oregon State University have undertaken a study of how the full spectrum of formal and informal learning experiences affect individuals’ interest and engagement in science during the critical years between 5th grade and 8th grade The researchers have identified the Parkrose School District, a large neighborhood with its own school district in Portland, Oregon, as the unit of study. The research method will be to study a single cohort of about 300 children as they attend school, take part in activities outside of school, go on field trips with their families, watch television, and all of the experiences that the children are typically exposed to. The children will be interviewed individually, as will their siblings, parents, and friends. Local formal and informal science educators will also be interviewed to understand their goals and the kinds of programs they offer. In all about a thousand people will be interviewed, and a focal group of about 50 children will be interviewed several times during the course of the study. A unique element of the study is to engage some of the high school participants in collecting and offering their own hypotheses about the factors that contribute to motivation in STEM.

What Have We Learned in a Century of Research?

This paper only brushed the surface of an extensive and multifaceted body of literature on how to motivate youth to engage in STEM related activities, courses, and careers. Consequently, it does not serve the purpose of an extensive review of the literature, such as those provided by Ormerod in 1975, or Osborne in 2003. Nonetheless, some consistent findings are apparent:

Attitudes are malleable. Thousands of studies how demonstrated that a wide variety of interventions can increase young people's engagement, interest, and career aspirations in STEM fields. These studies have ranged across a wide variety of formal and informal settings, with boys and girls of various ages, from different ethnic and cultural backgrounds.

The critical period for influencing students is between 8 and 13 years old. Perhaps the most consistent finding throughout the century is that people who eventually succeed in STEM careers developed their interest early in life. Formal and informal programs to increase interest and engagement in elementary and middle school have been very successful, and the current focus on test scores at all age levels may be counterproductive.

Young people like science—though not necessarily in school. Osborne's extensive review (2003) highlighted findings that the great majority of boys and girls like science and related fields; but are turned off by poorly taught courses in school, especially high school physics. So even if they come to high school with high hopes of engaging in a pathway leading to a career in science or engineering, young people can discouraged by a negative high school experience.

Teachers, teaching methods, and curriculum can make a difference. Whether in formal or informal settings, knowledgeable and skillful teachers have tremendous power to get kids interested in STEM. Teaching methods that succeed in tapping students' personal interests and engaging them at a deep level ("flow") can be very effective in increasing the pool of science-interest learners.

A diversity of research methods is needed for further progress. Educational research can be sliced and diced in a variety of ways, such as qualitative vs. quantitative, formal vs. informal, evaluation vs. research, etc. This paper used the distinction between deductive vs. inductive approaches to illustrate two very important and valuable approaches that ask different research questions. *Deductive* approaches start with a theory of action for how to motivate youth, and ask, "which interventions are most effective?" *Inductive* approaches begin with existing interventions and ask, "What theories of action can best explain why some youth become motivated science learners and others do not?" The two approaches are complementary, an together help to ramp up the quality of STEM education programs—provided that communication among researchers, practitioners, and policy makers is effective and timely.

Given what is at stake—the scientific and technological literacy of our population, and the future of our nation's technical workforce—it is important that we pay attention to findings from the full range of prior studies, think deeply about the kinds of research that still need to be done, and communicate effectively both within the research community and with those who are well positioned to put these findings (incomplete though they may be) to work by improving practice and formulating national policy.

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