A Large-scale Survey of K-12 Students about STEM: Implications for Engineering Curriculum Development and Outreach Efforts (Research to Practice)

Dr. Eric N. Wiebe, North Carolina State University

Dr. Wiebe is a professor in the Department of STEM Education at NC State University and Senior Research Fellow at the Friday Institute for Educational Innovation. A focus of his research and outreach work has been the integration of multimedia and multimodal teaching and learning approaches in STEM instruction. He has also worked on research and evaluation of technology integration in instructional settings in both secondary and post-secondary education. Dr. Wiebe has been a member of ASEE since 1989.

Malinda Faber, The Friday Institute for Educational Innovation

Malinda Faber is a Research Associate on the Evaluation Team at the Friday Institute for Educational Innovation at North Carolina State University. She works on multiple research teams, including evaluations of the Golden LEAF Foundations' STEM Initiative, North Carolina's Race to the Top STEM Initiative, and the North Carolina Department of Public Instruction's IMPACT-V model for capacity-building in instructional technology.

Jeni Corn, Friday Institute for Educational Innovation, NC State University

As the Director of Evaluation Programs at the Friday Institute for Educational Innovation at NC State University, Dr. Corn serves as PI of several large, statewide evaluation and research studies of innovations in K-12 schools and districts, including leading the evaluation of initiatives funded under North Carolina's Race to the Top grant. Her research interests focus on leadership, professional development, teaching and learning, infrastructure, and evaluation for technology-enhanced innovations in public school settings.

Mrs. Tracey Louise Collins, North Carolina State University

Tracey Louise Collins is the Project Coordinator for the MISO Project. Responsibilities include implementing activities of the project, coordinating efforts among K-12 science, technology, engineering, and mathematics (STEM) outreach programs, and working closely with university enrollment management and data management professionals at the Friday Institute at North Carolina State University (NCSU). She works closely with both large and small NCSU outreach groups offering K-12 outreach to teachers and students. She also assists with planning, implementing, managing, and reporting of project activities which include survey development, coordination of data collection, interfacing with data managers, coordination of meetings and workshops for outreach providers to gather feedback, identify best practices, and disseminate findings to stakeholders. In addition, she assists with annual report writing and conference presentations. She has been a member of the American Society of Engineering Educators since 2011.

Alana Unfried, North Carolina State University

Alana Unfried is a Graduate Research Assistant at the Friday Institute for Educational Innovation at North Carolina State University. She works on the Data Analytics team for the MISO Project (Maximizing the Impact of STEM Outreach through Data-Driven Decision Making). Alana's responsibilities include the development of statistically sound evaluation instruments for teachers and students involved in these campus outreach programs. She also analyzes survey results and related data to understand the collective impact of these pre-college STEM outreach programs. Alana is also a full-time Ph.D. student in the Department of Statistics at North Carolina State University.

LaTricia Townsend

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Abstract

This paper reports on the use of a new survey instrument, the S-STEM survey, as a model for data-driven decision making both formal and informal K-12 STEM education initiatives. Current national policy and research findings regarding K-12 STEM pipeline initiatives note the importance of enhancing both cognitive (i.e., content) and affective outcomes of students with regards to STEM subject areas, and that both formal and informal education strategies are likely to be needed to address the larger goals. The Friday Institute for Educational Innovation's Evaluation Group and the MISO project at North Carolina State University jointly undertook the development of a set of common instruments that could be used to assess the affective impact of K-12 STEM educational innovations in both formal and informal settings. Over 10,000 4-12th grade students from across North Carolina that were in special STEM initiative schools were surveyed, providing baseline data on STEM attitudes towards STEM subjects and career trajectories. These results were discussed in terms of how they can be used by K-12 STEM outreach programs that have partnered with the MISO project to help guide the formative assessment of the efficacy of their programs and guide future strategies.

Introduction

Innovations in the fields of science, technology, engineering, and mathematics (STEM) have and will play a central role in improving the quality of life for citizens of this country and around the world. Engineering, in particular, will play a central role in many of the challenges facing preserving and improving the quality of life for all citizens[1]. However, addressing these grand challenges will require the creation of a new, highly qualified cadre of engineers and supporting technologists. For this reason, there has been renewed interest in improving both the quality and quantity of students engaged in challenging STEM coursework and activities during their K-12 education. High engagement in STEM learning in K-12 is foundational to future success in engineering and technology degrees and occupations for individuals and a competitive global position for the nation[2,3].

Addressing this issue of global competitiveness has led the nation's policy makers to call on scientific and educational research organizations to investigate and innovate around ways to increase the number of students prepared to pursue demanding engineering and allied STEM career trajectories[3]. Addressing this STEM pipeline issue has historically pointed at issues surrounding academic rigor and preparation. However, there is an increasing realization that a crucial component to the solution involves psychological engagement on the part of students with this endeavor. The *President's Committee of Advisors on Science and Technology*[4] report came to this finding when they concluded that the issue is not just one of proficiency, but a lack of engagement leading to positive attitudes towards STEM degree paths. A key criterion for an effective STEM instructional program must include actively engaging students in STEM practices while learning, and to devote adequate time for doing so.

National STEM education leadership also recognizes that formal educational innovations are only going to be part of the equation for addressing the STEM pipeline. Informal learning initiatives such as summer camps, museums, competitive events, and after school clubs, are also a central strategy for re-empowering students to engage in STEM learning in ways that enhances engagement and motivation[5]. Informal contexts offer approaches that differ from classroom environments and provide opportunities for identity development around all the STEM areas through role-playing, interaction with professionals, authentic problem-solving scenarios, and depth of involvement. Because of these differences, STEM outreach initiatives that involve informal learning environments have often been used as a strategy to incorporate both conceptual development and 'ways of thinking' that are the goals of national standards and policy reports, but use approaches or cover content that are often perceived as incompatible with traditional classroom instruction. As a case in point, K-12 engineering curriculum has been offered as often through informal learning settings via STEM outreach initiatives[6] as it has through more traditional formal instructional settings[7].

It is also important to note the strong complementary roles that formal and informal learning environments can make when focused on a particular area of the STEM educational pipeline. While informal education is often the only avenue for older adults who have completed their formal schooling, school-aged children have ample opportunity to engage in both formal and informal programs of study, especially when the informal component is co-located at their school, such as an after-school club[5]. Informal opportunities can be just as intellectually powerful as formal classroom material but experientially approach in ways that are logistically difficult for classroom settings. Because informal programs are voluntary, they create a dynamic for motivations for engagement different than classroom. It means that students can have the latitude to direct their study at a depth and breadth that serves their personal needs.

Collectively, supporting the STEM pipeline through educational innovations will be an integrated approach across both formal and informal education settings. Ideally, evaluation methods measuring the efficacy of these innovations would also span across both formal and informal settings. Historically, summative assessment of K-12 educational innovations has focused on cognitive, or learning outcomes, such as end-of-course exams or similar proficiency tests. These types of assessments are often ill-suited for gauging the impact of informal educational innovations, in part because the goal of these programs are intended to focus on impacting affective measures such as attitudes towards STEM topics and activities[8]. Coupled with the increasing recognition of supporting these very same affective dimensions in formal educational settings[4], emerging policy goals points to the need for both the development and application of assessment tools that measure affective dimensions of STEM educational engagement across both formal and informal settings.

The Friday Institute for Educational Innovation's Evaluation Group and the MISO project[9] jointly undertook the development of a set of common instruments that could be used to assess the affective impact of K-12 STEM educational innovations in both formal and informal settings. Over the course of the past year, final validation of these instruments has also provided a vehicle for piloting ways data could be shared across program assessments—both formal informal—in ways that could provide both formative and summative feedback to these innovative programs. The remainder of this paper reports on the findings of this effort to transform the research and development of these assessment instruments into a model for effective guidance of innovative STEM educational practices in both formal and informal settings.

Method

The initial goal of the survey instrument development process was to develop an instrument that measured changes in students' confidence and efficacy in STEM subjects, 21st century learning skills, and interest in STEM careers. The STEM attitudes and careers sections were adapted from an evaluation of women-in-engineering program[10]. The careers section was further developed using the Bureau of Labor Statistics' Occupational Outlook Handbook[11]. The section on 21st century learning was adapted from the Friday Institute's Student Learning Conditions Survey[12]. Early in the development process, the decision was made to create two parallel versions of the survey: one for 4-5th graders (upper elementary), and one for 6-12th graders (middle/high school). The instruments—the Student STEM, or S-STEM, surveys—have undergone two rounds of validity and reliability testing. Details of the results of the reliability and validity analysis are reported on in the following publications[13, 14]. The finalized survey instruments can be found at the Friday Institute's web site[13].

As part of the second round of validity and reliability testing of the S-STEM survey instrument, over 10,000 4-12th grade students from across North Carolina were surveyed. Students surveyed were in schools that had received funding from the Golden LEAF foundation[15] to implement STEM teaching and learning initiatives in their schools. In 2010 the Foundation launched a STEM Initiative to support "successful models that increase STEM education for students in grades four through nine in rural, economically distressed and/or tobacco-dependent counties of North Carolina." One of the primary objectives of the Golden LEAF STEM Initiative evaluation was to provide information about the quality of implementation and extent to which the Golden LEAF STEM Initiative achieved its stated goals. The S-STEM survey was one of the data sources used to address this evaluation goal. However, this data also more broadly provides a valuable data source for a general assessment of the state STEM attitudes and orientations among students in North Carolina. This data can, in turn, be used as an analytic tool by policy-makers and practitioners engaged in STEM pipeline initiatives both in formal and informal educational settings. The MISO project[9] is specifically focused on supporting STEM outreach initiatives directed by North Carolina State University faculty and staff, many of which constitute informal educational opportunities for students. The results from the Golden LEAF survey[16] becomes both a strategic starting point for planning STEM outreach program initiatives and a benchmark against which programs can measure their effectiveness.

Results

10,448 students responded to the Golden LEAF S-STEM survey (Table 1). Approximately 90% of the respondents took the Middle and High School (6-12) instrument while the remainder took the Upper Elementary (4-5) instrument. This sample was taken from 43 public school districts participating in the Golden LEAF Initiative, representing 225 schools, from across the state of North Carolina. These school districts, by and large, represented rural, economically under-resourced parts of the state—the primary target of Golden LEAF grants.

Table 1. Student Response Rates, December 2011-February 2012

Student Attitudes toward STEM Survey	Number of responses	Estimated potential respondents	Estimated response rate*
Upper Elementary School (4-5th)	967		
Middle and High School (6-12th)	9,481		
TOTAL	10,448	12,800	82%

Results from the baseline administration of the student surveys also showed that students overall had moderate to high expectations for their performance in their English, science, and math classes the year the survey was administered. Students varied only slightly when compared by gender, race or ethnicity, or school-level (Table 2).

With regards to performance in science class, there were only slight differences between genders (less than a percentage point). There was some range between racial/ethnic groups of students. White/Caucasian students expressed the highest expectations (92.9% responded "OK/Pretty Well or Very Well"), with Black/African American students slightly lower (90.1%) and Hispanic/Latino students slightly lower still (89.1%). Similarly, in math class, students' levels of confidence were mixed. Female and male students differed by less than one percentage point; Asian students had the highest expectations (94.1% responded "OK/Pretty Well or Very Well"), with Hispanic/Latino students slightly lower (91.6%), and Black/African American students slightly lower still (90.8%). By school-level, students varied slightly: elementary students had the most confidence (92.9% responded "OK/Pretty Well or Very Well") and high school students had the least confidence (88.1%). Overall, though, these demographic differences were relatively small with regards to self-efficacy in these core STEM areas.

Table 2. Upper Elementary and Middle and High School Student Demographic Characteristics

Demographic Characteristic	Percentage of Respondents			
	Upper Elementary (*n*=774)	Middle School (*n*=7,855)	High School (*n*=923)	TOTAL (*n*=9,552)
Gender				
Male	50.9%	50.3%	49.8%	50.3%
Female	49.0%	49.6%	50.2%	49.6%
Ethnicity				
American Indian/Alaska Native	9.9%	6.9%	4.1%	6.9%
Asian	0.4%	3.0%	0.5%	2.5%
Black/African American	7.6%	8.9%	20.0%	9.9%
Hawaiian/Other Pacific Islander	0.6%	0.6%	0.4%	0.6%
White/Caucasian	69.6%	70.7%	67.2%	70.3%
Hispanic/Latino	6.5%	9.3%	7.6%	8.9%
Multiracial	5.3%	5.4%	6.2%	5.5%

Note: Respondents were able to select more than one race/ethnicity; percentage totals for middle and high school students by race/ethnicity are slightly greater than 100%. Upper elementary results include students in grades 4-5; middle school results include students in grades 6-8; and high school results include students in grades 9-12.

Combined baseline data from the pilot student surveys show that in general students were interested in STEM content (Table 3). While the differences in total number of respondents means we should interpret the results conservatively, upper elementary school students did report the most confidence and interest, or most positive attitudes, toward mathematics, science, and engineering and technology. High school students reported the least positive attitudes, and middle school students' attitudes toward STEM subjects fell between the two.

Table 3. Mean Composite Scores of Upper Elementary and Middle and High School Student STEM Attitudes by School-level

STEM Attitudes	**Upper Elementary** (*n*=785)	**Middle School** (*n*=7,698)	**High School** (*n*=926)	**All students** (*n*=9,409)
Math Attitudes	3.7	3.6	3.4	3.6
Science Attitudes	3.6	3.4	3.4	3.4
Engineering and Technology Attitudes	3.5	3.4	3.3	3.4

Note: Responses were recorded on a five-point Likert scale: "strongly disagree" (1), "disagree" (2), "neither agree nor disagree" (3), "agree" (4), and "strongly agree" (5). Upper elementary results include students in grades 4-5; middle school results include students in grades 6-8; and high school results include students in grades 9-12.

In terms of future aspirations, a high percentage of middle and high school students indicated that they plan on going to college (Table 4). Interestingly though, this percentage dropped from 86.6% to 80.0% from middle to high school. Role models can be important for pursuing a future STEM major in college. A majority of students knew an adult that worked as an engineer (Table 3), but fewer knew an adult scientist or mathematician.

Table 4. Upper Elementary and Middle and High School Student STEM Education Characteristics

Survey Item	**Percentage of Respondents**		
	Upper Elementary (*n*=744)	**Middle School** (*n*=7,560)	**High School** (*n*=896)
Do you plan to go to college?			
Yes	--	86.6%	80.0%
Yes, I know an adult who works as a/an …			
Engineer	57.0%	60.5%	57.3%
Scientist	19.4%	23.7%	33.4%
Mathematician	32.4%	42.5%	49.4%

Note: Upper elementary results include students in grades 4-5. Middle school results include students in grades 6-8, and high school results include students in grades 9-12.

These results, indicating only moderate levels of confidence in STEM subjects and only some exposure to adult STEM professionals, is reinforced by only a generally mild interest in STEM careers. Only 40.5% of students on average, across 12 career areas, indicated that they were “interested” or “very interested” in a STEM-related field. There were some notable differences between genders for some of the career paths. There were no STEM fields for which male students, as a whole, expressed interest levels lower than a 30% proportion being “interested/very interested.” Female students, however, had interest levels lower than a 30% proportion being “interested/very interested” for four career fields: engineering, computer science, energy, and physics.

Differences in levels of interest in various STEM careers between students of different races/ethnicities are smaller than the differences between male and female students. Asian students had the largest, average level of interest in STEM careers (47.0%) and White students and Black/African American students had the smallest average levels of interest (39.8% and 40.0% respectively). The largest differences between expressed interests were in the fields of: biology and zoology, in which Asian students had the most interest (57.8%) and Black/African American students had the least interest (36.3%); medicine, in which Asian students had the most interest (60.1%) and American Indian/Native Alaskan students had the least interest (43.0%); and chemistry, in which Asian students again had the most interest (51.9%) and White students had the least interest (35.8%).

Informing Practice

The results of this state-wide in-school survey provides valuable advice for STEM outreach practitioners. Many of the participant outreach providers in the MISO project have specifically designed interventions that address findings from this survey. These interventions often are providing complementary informal educational opportunities that complement the work of schools and provide support for improving student attitudes and engagement in STEM subject areas and future career pathways.

Findings from this survey point to a need for outreach providers to continue to raise student awareness of STEM careers and increase the frequency of opportunities for students to engage with STEM industries. While these sort of opportunities can happen within the context of the traditional school day, programming that happens outside of the classroom may have greater flexibility to engage STEM professionals and businesses with students. There is also a clear need to specifically target populations that are currently under-represented in STEM professional pathways. Results from the survey indicate that current student attitudes very much reflect current representation in certain STEM professions. Perhaps the most notable finding is the continued lack of engagement of females in nationally important engineering and computer science pathways. While there were differences between different ethnic/racial groups with regards to engagement of STEM career pathways, it is clear that all constituent groups from these mostly rural, under-resourced areas of the state could use additional support.

More complex is thinking about how informal educational interventions might support student self-efficacy and engagement with their current STEM coursework. Clearly the answer is a holistic one that involves innovations in curriculum, teacher professional development, in addition to supplemental outreach activities. These outreach activities can directly work with students on their proficiency and attitudes towards these subject areas, but may do so in ways that take advantage of the flexibility afforded by informal programs such as summer camps and after-school activities. Outreach activities that provide direct support to classroom instruction through tutors, teacher professional development, and other interventions can also provide potential pathways for intervention.

Any of these potential approaches need to be evaluated for their efficacy of impacting key affective dimensions of students' attitudes, engagement and orientation toward future STEM career pathways. Instruments such as the S-STEM survey not only provide insight into the current state of student affect across the state, but also provide opportunities to benchmark changes in students participating in these outreach activities. Outreach programs can use the same S-STEM surveys as both a pre and post-measure, not only to analyze changes with participating students, but also to benchmark them against the larger pool of students across the state. This can provide the program directors with valuable information about whether they were able to target students most in need of support and what kind of change might be expected. Of course, the duration and intensity of the outreach program, in addition to the specific goals of the program, need to be accounted for in interpreting expected effects.

Limitations and Future Work

This paper reports on a model of how a common survey instrument used across formal and informal educational programs can be used effectively to guide STEM pipeline initiatives. The specific results and interpretations reported here should be interpreted with caution based on some clear limitations of the work. While the survey results reported here were large, they still represent a targeted sample of students: those from rural, under-resourced schools already participating in targeted STEM initiatives. As such, the sample leaves out a large percentage of students attending suburban and urban school districts. Perhaps most immediately relevant is the fact that many of the MISO project outreach partners target students from communities geographically close to the university and thus represent suburban/urban demographics. Because informal education outreach programs are by and large voluntary, they represent a self-selected population that will differ from the Golden LEAF school population sample. However, survey instruments such as the S-STEM provide valuable information concerning how the outreach program participants do differ from other populations.

MISO project participants are currently using the S-STEM survey instruments to help guide their program review and development process. Individual programs will be able to both compare their data against the Golden LEAF state-wide data and an aggregate of MISO project participating programs. In addition, agreement has been reached for one of the largest urban/suburban school districts in the state to use the S-STEM instrument with a cluster of elementary, middle and high schools that have ongoing STEM initiatives. This will provide a different demographic sample of data against which to benchmark. Work is also underway finalizing a teacher STEM (T-STEM) survey instrument that will also measure many of the same affective dimensions as the S-STEM instrument, providing data that will be of particular use to the MISO project outreach partners that target STEM teachers and teaching rather than directly working with students.

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