# Nanotechnology Experiences for Students and Teachers (NEST): Enhancing Teachers' Self-Efficacy and Their Understanding of STEM Career Opportunities

Brandon Sorge[1,2*], Grant Fore[2], Eric Nunnally[2], Gina Gibau[3], and Mangilal Agarwal[4*]

[1] Department of Technology Leadership and Supervision, School of Engineering & Technology, IUPUI
[2] STEM Education Innovation and Research Institute (SEIRI), IUPUI
[3] Department of Anthropology, School of Liberal Arts, IUPUI
[4] Department of Mechanical Engineer, School of Engineering & Technology, IUPUI
*Corresponding Authors: bsorge@iupui.edu, agarwal@iupui.edu

*Abstract—*

The Nanotechnology Experiences for Student and Teachers (NEST) summer learning opportunity at Indiana University-Purdue University Indianapolis (IUPUI) connects faculty, staff, and students from the Schools of Engineering and Technology, Science, and Education with high school teachers of STEM subjects in a two week teacher professional development experience. In the summer of 2016, eleven teachers participated in a series of NEST program activities that were designed to model instructional strategies while engaging the teachers in hands-on nanotechnology research experiences. Teachers were also provided tours and exposed to research being conducted and equipment being used in labs incorporating nanotechnology across campus. Additionally, the participants worked with other teachers involved in a Research Experiences for Teachers (RET) project, to develop nanotechnology lessons to incorporate in their classroom during the following school year. Primary outcomes from this professional development were not limited to the developed lessons. Data collected through pre- and post-content knowledge assessments and pre- and post-self-efficacy surveys (T-STEM), show statistically significant increases in teacher nanotechnology content knowledge, nanotechnology self-efficacy, science efficacy and beliefs, and understanding of STEM careers. Observations and focus groups also provided data on potential program enhancements to facilitate greater support and experiences for the participating teachers.

*Keywords—nanotechnology education; teacher professional development; teacher self-efficacy*

## I. INTRODUCTION/BACKGROUND

Meeting the educational demands for a rapidly changing technological market not only requires advanced problem-solving skills, but also necessitates new teaching and assessment approaches [1-4]. In conjunction with declining applied science literacy, the ubiquity of nanotechnology reinforces the need to prepare students for advanced technology; a need that requires students and teachers to be well-informed on STEM opportunities and pathways [5, 6]. Multidisciplinary experiences are expected to imbue students with interest in STEM studies and careers and will enable high school teachers to develop integrated STEM modules for classroom use. However, urban teachers face challenges providing successful student learning strategies due to limited and divergent educational opportunities for marginalized communities that are commonly underrepresented in science fields [7, 8]. This challenge is especially evident in Indiana, with disparity in school funding and a large achievement gap among racial groups (24-28% difference in math proficiency between Caucasian and African American or Hispanic students) [9, 10]. IUPUI's urban location, residing among several high-needs school districts, should enable NEST to effectively serve marginalized and low-income groups. Local demand for STEM graduates (Eli Lilly, Cummins, IU Health, et al) is as high as the national demand, yet locally decreasing K-12 science scores have resulted in a disturbing statistic: *39% of freshman at universities in Indiana enroll in remedial science and math courses [11, 12]*. Nationally, Indiana ranks 34th in Average Freshman Graduation Rate (AFGR), lower than any of the surrounding states. Indiana is also seeing the *lowest* AFGR since monitoring began in 1970 [13]. Even more concerning, marginalized populations, representing over 50% of all students in the urban school districts surrounding Indianapolis, typically have lower average math and science scores [11], lower AFGRs [12], and are outnumbered 2:1 in STEM careers [14].

To address these patterns, the Integrated Nanosystems Development Institute (INDI) and the STEM Education Innovation and Research Institute (SEIRI) at Indiana University-Purdue University Indianapolis (IUPUI) have established an NSF-ITEST Strategies program—Nanotechnology Experiences for Students and Teachers (NEST)— to introduce high school students and teachers to the rapidly emerging and interdisciplinary field of nanotechnology. This project was originally designed to accommodate 20 students and 15 teachers. However, over the summer of 2016, 35 students and 11 teachers from school districts in Indianapolis and the surrounding area participated in separate 2-week nanotechnology-focused summer camps. Teachers were recruited from high-needs schools serving a high percentage of students underrepresented in STEM. These teachers were then to recruit one or two of their own students.

NEST aimed to provide real-world research experiences as well as extensive post-camp opportunities to ensure continued student participant interest in STEM fields. Moreover, NEST teachers, who are the primary focus of this paper, were tasked with producing nanotechnology teaching modules to teach their own students about nanoscience/nanotech throughout the academic year. Teachers were also to be provided with

effective tools to aid in the preparation of students for STEM-related careers through inquiry-based, integrated STEM learning. NEST's intensive summer program was and is intended to consist of the following:

*WEEK 1* – introducing nanotechnology concepts, applications, career options (students and teachers), and instructional practice strategies (teachers) through hands-on activities;

*WEEK 2* – immersion in academic research (students and teachers) and module development (teachers) by interacting with faculty/graduate student researchers in laboratory- based experiences, workshops, and oral presentations;

*POST-CAMP* – linking both students and teachers to support networks comprised of faculty mentors, graduate students, and other teachers to facilitate the production of independent research projects (students) and the design and implementation of nanotechnology modules (teachers), of which at least one per year should contain virtual reality components. These virtual reality modules should be broadly disseminated and utilized in classrooms that lack the space and/or finances to conduct modules requiring laboratory equipment and supplies.

Of the three specific aims of this ITEST site, two were directed specifically at teacher professional development (PD). First, NEST for teachers is intended to *implement, research, and refine an original professional development (PD) program for STEM secondary teachers using nanotechnology content.* This PD dimension of NEST is to include material that facilitates increase in teachers' nanotechnology content and pedagogical content knowledge and self-efficacy and confidence in teaching nano-content. Second, NEST for teachers is intended to *create, implement, refine, and disseminate teacher developed nanotechnology modules to reach high school students in Indiana and across the U.S.* During the summer experience, teachers were to have high-quality instructional practice modeled for them and adequate time to brainstorm/produce modules in teacher working groups. They were then to refine and implement modules at some point during the academic year.

Specifically, this program attempted to aid teachers in the production of 'instructional strategies' as opposed to 'tactics.' Tactics are produced when teachers attempt to 'make do' or 'get by' [15] when external factors are perceived to be overwhelming or constraining in relationship to their teaching. On the other hand, instructional strategies are thoughtfully and coherently integrated into a teachers' curriculum. Moreover, Fore, Feldhaus, Sorge, Agarwal, and Varahramyan [16] argue that professional development that fails to accurately recognize external or exogenous variables that the teacher – as a subject with a unique historical trajectory – must negotiate in their everyday teaching will result in the implementation of tactics as opposed to instructional strategies.

## II. Methods and Results

### A. Data Collection

In year one of the NEST program, research was undertaken using a convergent mixed methods design in which quantitative and qualitative data were gathered concurrently at different participant milestones and analyzed explanatorily so that qualitative results explain quantitative patterns [17]. Teacher data collection time periods included: throughout the duration of summer programming, during the fall semester follow-up workshop, and concurrent with the implementation of modules.

Quantitative data were collected through pre- and post-summer program surveys and post-module implementation surveys (May 2017, incomplete at the time of writing) in order to measure change. SEIRI's already developed and demonstrably reliable pre- ($\alpha$=.847) and post- ($\alpha$=.863) nanotechnology comfort and confidence survey for teachers was used along with the NCLT nanoscience content knowledge test.

Qualitative data were collected through observations, focus groups, and interviews. The protocol for observing module implementation was constructed from the NEST module rubric to assess module fidelity to best practices. Since nanotechnology modules will necessarily integrate the STEM fields, NEST module rubrics were developed from the integrated STEM characteristics identified by Moore et al [18]. These characteristics included, but were not be limited to, 1) a "motivating and engaging context," 2) hands-on inquiry-based practice through an "engineering design process," 3) the potential to "learn from failure," 4) the integration of "meaningful mathematics and science content," 5) the incorporation of "student-centered pedagogies," and 6) the use of "teamwork and communication" [18]. These characteristics are based upon best practices for encouraging the advancement of student STEM understanding and interest. As a guiding force, the NEST module rubric was intended to aid teachers as they attempted to implement nanotechnology modules with fidelity.

Both the nanotechnology content knowledge and the STEM/Nanotechnology self-efficacy surveys were given online using Qualtrics. The nanotechnology content knowledge test was originally designed by the National Center for Learning and Teaching in Nanoscale Science and Engineering [19]. The test was then modified to ensure questions aligned with the teachers' nanotechnology experiences. However, when possible, questions were kept as the original or only slightly modified.

The nanotechnology and teacher STEM efficacy survey was a modified version of the Maximizing the Impact of STEM Outreach Through Data-Driven Decision-Making (MISO) Teacher science, technology, engineering, and mathematics (T-STEM) self-efficacy instrument for science developed by the Friday Institute at North Carolina State [20]. The T-STEM Science includes scales on science teaching

efficacy and beliefs, science teaching outcomes expectancy, student technology use, science instruction, 21st century learning attitudes, teacher leadership attitudes, and STEM career awareness. The nanotechnology self-efficacy scale ($\alpha$=.840) contains nine questions and was developed internally and modified over several years of use. The nanotechnology scale was added on at the beginning of the T-STEM science survey. The nanotechnology self-efficacy questions were modeled after the existing questions already in the survey.

### B. Participating Teachers

Eleven teachers representing nine high schools participated. Three of the participants were women while one person was African American, one was Asian, and the rest were white. Table 1 provides a breakdown of the subjects teachers anticipated they would be teaching the following academic year. Table 1 provides an overview of these results

TABLE I. EXPECTED COURSES TAUGHT BY PARTICIPATING TEACHERS

| Biology | PLTW Biomed | Chemistry | Physics | Earth Science | ICP |
|---------|-------------|-----------|---------|---------------|-----|
| 3 | 1 | 5 | 3 | 1 | 2 |

### C. Teacher Content Knowledge

To understand growth in teacher content knowledge related to nanotechnology, a paired-sample t-test was run using SPSS (v23). A statistically significant increase t(9)= -7.732, p<.001 was found. The pre-test mean score was 12.10 (SD = 6.557), while the post-test mean score was 19.90 (SD = 6.674). The maximum score on this assessment was 30. All of the teachers (N=10) who took both the pre- and post-test performed better on the post-test. Table II shows the pre- and post-content knowledge scores.

TABLE II. PRE- AND POST-NANOTECHNOLOGY SCORES

| Pre-Score | Post-Score | Increase |
|-----------|------------|----------|
| 7 | 13 | 6 |
| 5 | 16 | 11 |
| 17 | 22 | 5 |
| 10 | 23 | 13 |
| 18 | 26 | 8 |
| 18 | 26 | 8 |
| 3 | 8 | 5 |
| 11 | 15 | 4 |
| 23 | 29 | 6 |
| 9 | 21 | 12 |

When discussing the acquisition of nanotechnology 1content knowledge and pedagogical content knowledge during the focus groups, teachers explained that NEST provided significant insight into the content but very little practical guidance in terms of pedagogical application. As one teacher acknowledged, with little guidance on how to implement this in a high school classroom, it could be quite difficult to find ways to insert nano into the curriculum, especially if the teacher is new to the profession. Since producing and implementing nanotechnology/nanoscience modules is a key objective of this grant, the Research Team and the external evaluator recommend that more time is spent on pedagogical application and module development. While an increase in nano content knowledge was found, the needs of secondary teachers, relative to introducing nanotechnology to their own students, must be made a priority to ensure that they not only have sufficient nanotechnology knowledge but that they also have the ability to integrate that knowledge into their curricula.

### D. Teacher Self-Efficacy

To investigate teacher self-efficacy, paired sample t-test were run on each subscale of the modified T-STEM science survey using SPSS (v23). The analysis compared pre- and post-scale scores. For the nanotechnology scale score, a statistically significant difference, t(8)=-4.307, p<.01 was found. The pre-scale mean was 31.8889 while the post-scale mean was 37.667. Nine of the ten teachers demonstrated gains on their nanotechnology scale score from pre- to post-survey. Observational and focus group data complement the survey data indicating that teachers' self-efficacy towards nanotechnology increased. However, the qualitative data also captured additional themes that are critical to a more nuanced understanding of increasing nanotechnology self-efficacy for teachers.

For science efficacy and beliefs a scale also showed statistically significant change t(7)=-2.481, p<.05. The pre-scale score mean was 44.25 (SD=3.412) while the post-scale score was 47.375 (SD= 4.307). The only other scale to show a statistically significant change was for STEM related career awareness t(8)=-.2766, p<.05. Where the pre-scale score mean was 15.222 and the post-mean was 17.6667. It was interesting to note that the science outcomes post-scores were slightly lower than the pre-scores but it wasn't statistically significant (p=.406). Table 3 provides the pre- and post-scale scores for all sub-scales.

Table III. Self-efficacy scale scores

| Scale | Pre-Mean | Post-Mean |
|---|---|---|
| Nano | 31.89 | 37.67 |
| Efficacy | 44.67 | 47.37 |
| Careers | 15.222 | 17.67 |
| Outcomes | 33.11 | 32.25 |
| 21st Century | 49.33 | 50.22 |

## III. DISCUSSION

While more confidence with nanotechnology is evident, there was little evidence that teachers had produced *rigorous* nano modules that could be immediately inserted into their curriculum by the end of the program. The production of exceptional modules is one way in which teacher self-efficacy in nanotechnology could be demonstrated. The NEST Research Team suggests that more time be provided during the program for teachers to operationalize their growing self-efficacy through the production of complete modules. The NEST Implementation Team is encouraged to:

1) Model instructional practice by aligning activities with the NEST Module Rubric;

2) Provide teachers the opportunity to practice these instructional practices with students after having it modeled for them;

3) Have teachers work in teams to produce their own nano modules;

4) Integrate time at end of the NEST camp for teachers to present their self-designed modules to students for feedback.

While increasing teachers' content knowledge and self-efficacy is critical, programs must also help teachers develop practical skills through which they can (and will) integrate nanotechnology into their curricula. Teachers deal with profound constraints that impact what and how they teach. NEST teachers detailed these constraints and their concerns about integrating nanotechnology into their classrooms in the focus groups. For example, teachers expressed concern about 1) the relationship between nanotechnology the state standards they are required to meet, 2) the capacities of their students to readily grasp nanotechnology concepts, 3) the time and space allotted to them for their classes, 4) the need for consistency across courses and, therefore, the perceived need for any new module to be adopted by an entire department, and 5) the resources available in their school to deliver nanotechnology content. Based upon these concerns, future summer professional development workshops will provide more time and resources for identifying strategies to overcome the school and state level policies teachers must negotiate as they seek to educate their students.

Additionally, since the "change environments" in which teachers must learn and act can be constraining, providing a supportive structure is essential for the facilitation of teacher professional learning [18]. Moreover, a teacher's pre-existing knowledge, beliefs, and attitudes do not necessarily change just by virtue of having participated in an exceptional PD intervention. Long-term professional learning is enabled through experimentation in accordance with new knowledge [22]. If new knowledge cannot be practiced, outcomes cannot be generated and lasting changes in knowledge and beliefs cannot be supported [16]. Teacher working groups providing collaborative opportunities [23, 24], and researchers or faculty mentors providing room for reflection [25] can be effective modalities for achieving professional growth.

REFERENCES

[1] P. C. Blumenfeld, J. S. Krajcik, R. W. Marx, and E. Soloway, "Lessons learned: How collaboration helped middle grade science teachers learn project-based instruction," in The Elementary School Journal, vol. 94, no. 5, 1994,pp. 539-551.

[2] R. Elmesky, and K. Tobin, "Expanding our understandings of urban science education by expanding the roles of students as researchers," in Journal of Research in Science Teaching, vol. 42, no. 7, 2005,pp. 807-828.

[3] J. B. Kahle, J. Meece, and K. Scantlebury, "Urban African‐American middle school science students: Does standards‐based teaching make a difference?," in Journal of Research in Science Teaching, vol. 37, no. 9, 2000,pp. 1019-1041.

[4] R. W. Marx, P. C. Blumenfeld, J. S. Krajcik, B. Fishman, E. Soloway, R. Geier, and R. T. Tal, "Inquiry‐based science in the middle grades: Assessment of learning in urban systemic reform," in Journal of research in Science Teaching, vol. 41, no. 10, 2004,pp. 1063-1080.

[5] R. Duschl, "Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals," in Review of research in education, vol. 32, no. 1, 2008,pp. 268-291.

[6] N. Feinstein, "Salvaging science literacy," in Science education, vol. 95, no. 1, 2011,pp. 168-185.

[7] L. V. Hedges, R. D. Laine, and R. Greenwald, "An exchange: Part I*: Does money matter? A meta-analysis of studies of the effects of differential school inputs on student outcomes," in Educational researcher, vol. 23, no. 3, 1994,pp. 5-14.

[8] O. Lee, "Science education with English language learners: Synthesis and research agenda," in Review of Educational Research, vol. 75, no. 4, 2005,pp. 491-530.

[9] L. V. Hedges, and A. Nowell, "Changes in the black-white gap in achievement test scores," in Sociology of education, 1999,pp. 111-135.

[10] E. Week, "'If I Can't Learn from You'': Ensuring a highly qualified teacher for every classroom," in Education Week: Quality counts 2003, vol. 22, 2003,pp. 17.

[11] R. W. Chien, T. E. Spradlin, and J. A. Plucker, "Indiana's Mathematics and Science Performance: Do We Measure Up?," in.

[12] J. Plucker, R. Wongsarnpigoon, and J. Houser, "Examining college remediation trends in Indiana," in Education Policy Brief, vol. 4, no. 5, 2006.

[13] K. R. Stanley, T. E. Spradlin, and J. A. Plucker, "Calculating High School Graduation Rates. Education Policy Brief. Volume 6, Number 5, Spring 2008," in Center for Evaluation and Education Policy, Indiana University, 2008.

[14] D. N. Beede, T. A. Julian, B. Khan, R. Lehrman, G. McKittrick, D. Langdon, and M. E. Doms, "Education supports racial and ethnic equality in STEM," in, 2011.

[15] M. de Certeau, "The practice of everyday life," University of California Press,1984.

[16] G.A. Fore, C.R. Feldhaus, B.H. Sorge, M. Agarwal, and K. Varahramyan, "Learning at the nano-level: Accounting for complexity in the internalization of secondary STEM teacher professional development," in Teaching and Teacher Education, vol. 51, 2015, pp. 101-112.

[17] J. W. Creswell, Research design: Qualitative, quantitative, and mixed methods approaches: Sage publications, 2013.

[18] T.J. Moore, K.M. Tank, E.A. Siverling, and C.A. Mathis, "Engineering to enhance STEM integration efforts," presented at the American Society for Engineering Education Annual Conference, 2014.

[19] SEARLE Center for Advancing Learning and Teaching. "National Center for Learning and Teaching in Nanoscale Science and Engineering," Retrieved 04/21/2017, 2017; http://www.northwestern.edu/searle/research/grants/Collaborative%20Grants/research-with-the-national-center.html.

[20] M. T. L. Collins, "MISO (Maximizing the Impact of STEM Outreach Through Data-Driven Decision-Making): Building and Evaluating a Community of Practice," in.

[21] Minority Engineering Advancement Program (MEAP). "Minority Engineering Advancement Program," Retrieved 11/03/2014; http://www.engr.iupui.edu/infofor/community/summer-camps/meap.php.

[22] D. Clarke, and H. Hollingsworth, "Elaborating a model of teacher professional growth," in Teaching and teacher education, vol. 18, no. 8, 2002,pp. 947-967.

[23] L. L. Hadar, and D. L. Brody, "The interaction between group processes and personal professional trajectories in a professional development community for teacher educators," in Journal of Teacher Education, vol. 64, no. 2, 2013,pp. 145-161.

[24] D. Sparks, and S. Loucks-Horsley, "Five models of staff development," in Journal of staff development, vol. 10, no. 4, 1989,pp. 40-57.

[25] D. M. Clarke, "The changing role of the mathematics teacher," in Journal for Research in mathematics Education, 1997,pp. 278-308.