VANDERBILT UNIVERSITY
PEABODY COLLEGE

INTEGRATED ENGINEERING EDUCATION

EMPOWERING K-12 TEACHERS TO MEET THE NEXT GENERATION SCIENCE STANDARDS IN PROFESSIONAL DEVELOPMENT PROGRAMS

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BRIEF

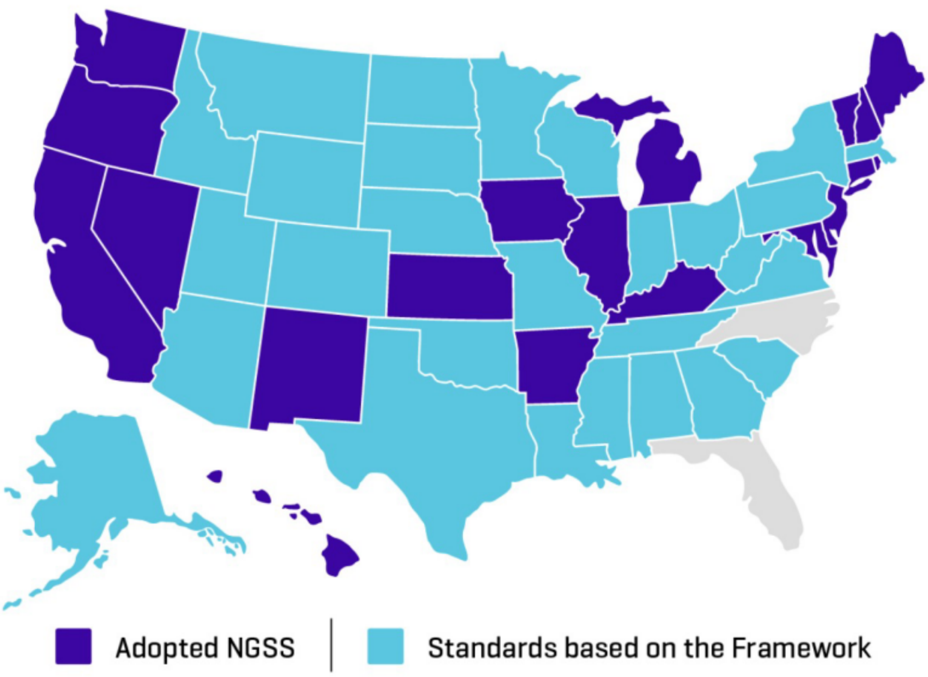
CONTENTS

POLICY
BACKGROUND

In 2013, the National Research Council (NRC) released the Next Generation Science Standards (NGSS), a set of K-12 science standards based on the Framework for K–12 Science Education. These standards aim to prepare K-12 students in the U.S. for education and careers in the 21st century and to improve their competitiveness in both global academic assessment and international industry.

As of 2023, 20 states and the District of Columbia have adopted the NGSS, and 24 states have established their standards according to its recommendations.

K-12 Science Standards Adoption Across the U.S.



TEACHER DEVELOPMENT

The NGSS emphasizes the integration of science, technology, engineering, and mathematics (STEM) and highlights engineering. Since the introduction of these standards, there has been a growing body of research exploring the role of teaching professional development (TPD) in facilitating this integration.

Professional development programs play a crucial role in supporting K-12 teachers.

- ## TO SUPPORT POLCY

Standards alone are not sufficient to transform instructional practices. Key factors for effective implementation of STEM policy include staff motivation, administrative support, professional development, and team-lesson planning.

- ## TO PREPARE TEACHERS

Science teachers lack mental preparedness for developing engineering skills among students. A study in a high school found that 52.6% of chemistry teachers were either hesitant or unwilling to incorporate engineering into their curricula.

In addition, teachers require additional resources and professional development for successful STEM teaching. Educators identified gaps in their background knowledge, pedagogical knowledge and need for guidance on designing STEM curriculum. Teachers expected pre-service and in-service training in preparation, and active engagement in integrated STEM activities through TPD.

CURRENT
PROGRAMS

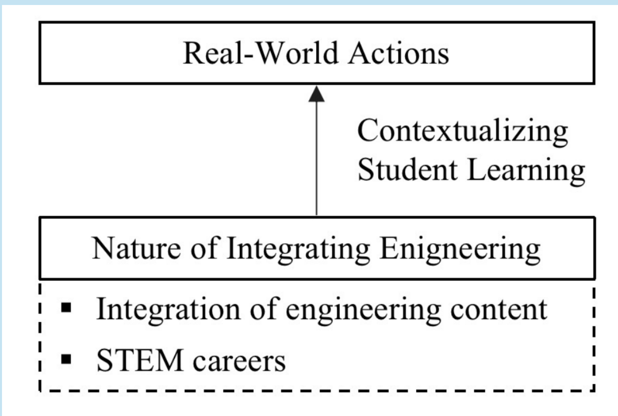
Current TPD programs encompassed a range of topics pertaining to the integration of engineering. During and after the programs, teachers collaborated with faulty and experts to gain real experience from STEM careers. They also linked content to real-world challenges by creating integrated teaching plans, implementing instructional techniques, and engaging in design activities and fieldwork. Moreover, the practical sections in PD programs enabled educators to emulate the learning process of students with hands-on activities.

• NATURE OF INTEGRATING ENGINEERING

The training programs contained curriculum material across different themes, including biomedical engineering, biotechnology, mechatronics , polymer science and engineering, nanotechnology, astronomy, entomology, earthquake engineering, and 3D scanning.

Moreover, the developed curriculum - INcreasing Student Participation, Interest, and Recruitment in Engineering and Science (INSPIRES) - provided curriculum materials, practices, pedagogy, and reflection. In another case, a local science pacing guide acted as a foundation material for adaption in TPD to align with the NGSS. Moreover, a national program, QuarkNet, provided accessible resource of over 50 programs tailored to the interests of local teachers.

THREE DIMENSIONS OF INTEGRATED ENGINEERING EDUCATION



CURRENT
PROGRAMS

TPD programs also emphasized the connection between curriculum content and STEM careers by collaborating with university faculty, engineers, and scientists. During the training, teachers witnessed demonstrations from industrial experts and received suggestions for developing lessons. After TPD, educators invited faculty and experts as guest speakers or members of assessment panels. Moreover, teachers engaged in dialogue with experts who had authentic experience, thereby gaining insights, and developing skills related to assessments and advertising for students' future careers.

- **CONTEXTUALIZING STUDENT LEARNING**

To make the connection, educators engaged in a variety of practices. They adapted curriculum to align with the NGSS and audited demonstration classes, contextualized the content based on students' grades and received coaching and consulting support to incorporate their learning experiences, research topics, or lab experiences into teaching. Teachers also had access to pedagogy knowledge, instruction based on problem-based learning, or discourse strategies.

Moreover, design tasks allowed for the application of interdisciplinary content, including biology and engineering. Teachers also worked as scientists or engineers, such as emphasizing the importance of market needs. In addition, educators visited real working scenarios, including high-tech industry plants, environmental centers, engineering laboratories, medical centers, and NASA laboratories. In a program centered on entomology, teachers and faculty conducted fieldwork by visiting a retention pond, observing sample collection, and returning to test their designs after finishing research and design work in a lab.

CURRENT

PROGRAMS

Additionally, most real-world issues were shared or defined by participants and faculty. Two exceptions were a design task for local habitat restoration and an issue about fish living around the Tellico Dam, a project in the 1970s.

- **REAL-WORLD ACTIONS**

In TPD, teachers engaged in hands-on activities that mirrored the learning process of students.The process was structured into identifying challenges, designing scientifically, and defining criteria for solutions. Facilitators in TPD modeled expected classroom practices. In a design of a soda can crusher, participants investigated needs with community members and engaged in group design. They then constructed, tested, and improved their design according to criteria such as reliability, portability, aesthetics, and storage space. Participants manufactured their final design in an engineering shop.

Similarly, teachers in a program focusing on creating a drawing robot followed a process that included pre-reading, brainstorming, identifying needs, discussing, creating a model, expressing solutions, and testing and revising, while also emphasizing the importance of creativity, innovation, and learning from failure. Additionally, through experiencing the design process, educators gained insights into the anticipated challenges that they may encounter in the classroom. Furthermore, TPD programs incorporated learning models such as distributed learning strategies in group settings to promote debate, discussion, and problem-solving, which improved the quality of reasoning.

FUTURE
SUGGESTIONS

One of the challenges for integrated engineering education is the combination with science subjects. A knowledge map would be helpful for teachers to adapt or develop new projects according to students' knowledge level. Second, TPD programs should tailor training materials to varying backgrounds of teachers, promoting program effectiveness and equity. It is also necessary to track how training experiences transfer from teachers to students. Cross-grade collaboration and strategies for managing interactions between teachers and students are suggested, along with designing topics relevant to local issues and resources to increase the realism of design. Moreover, TPD programs should include content that assists teachers in evaluating and advising students for their future STEM career.

- ## ENHANCE THE INTEGRATION WITH SCIENCE

While the themes of integrated engineering education are diverse, their relationship to science subjects remains relatively independent, necessitating further effort towards effective integration. In the context of TPD programs, the primary approach for integration involves providing teachers with interdisciplinary knowledge or module knowledge for specific engineering projects. However, the programs lack a knowledge map that enables teachers to identify the required level of prior knowledge necessary for implementing different engineering designs in their classroom. The absence of such a map may impede teachers' ability to adapt or develop new projects according to their students' knowledge level.

FUTURE

SUGGESTIONS

Moreover, TPD programs should consider the varying backgrounds of teachers. Presently, the content is either tailored to teachers with a specific subject background or provided uniformly to teachers with diverse backgrounds. However, teachers prioritized engineering design topics differently depending on their prior knowledge, necessitating differentiated training to enhance program effect and promote equity in the future. Furthermore, existing curriculum systems and project resources are underutilized, and efforts to fully leverage these resources may serve to reduce training costs and increase accessibility.

- **TRACK EXPERIENCE FROM TEACHERS TO STUDENTS**

In TPD, there is ample exchange of resources and expertise between teachers and industry professionals. However, it is worth exploring how these experiences can benefit students. While teachers observe demonstrations from experts and participate in field trips during training, there is little follow-up investigation on the extent to which educators replicate the procedures for students in their teaching. Moreover, resources utilized in teacher training, such as field visits, may not be suitable for students in terms of accessibility or content design. Furthermore, it is unclear if the collaboration between teachers and professionals continues beyond the TPD programs to provide sustained improvement in course design. Additionally, TPD programs need to include content that assists teachers in evaluating and advising students on their future STEM career development.

FUTURE

SUGGESTIONS

- **CONNECT STUDENTS WITH REAL WORLD ISSUS**

Currently, teachers connect content with practical issues through developing teaching plans in workshops with peer, subject groups, grade-level teams, and external consultant support. However, cross-grade collaboration is rarely mentioned which could be helpful for understanding students' prior knowledge. Additionally, TPD programs should increase special pedagogy content customized for the scenario in engineering education. Though teachers mimicked the learning process in design tasks and anticipated problems students may encounter, strategies for dealing with these problems need to be explored further. Given that one of the characteristics of engineering design is to seek solutions through compromise between stakeholders, skills for manage the interaction between teachers and students, and among students themselves would be crucial.

In addition, although teachers engaged in practical designs similar to real-world problem, these projects rarely take into account local natural resources, community asset, and students' background. Future TPD programs could design the topics relevant to local issues in training and provide guidance with teachers to help them identify natural resources available in their communities. Therefore, they would be able to integrate students' real-life experiences with engineering tasks to increase the realism of design.

FUTURE

SUGGESTIONS

Furthermore, TPD programs could extend to administrators in schools. Current programs primarily aim at teachers and rarely address the problem of coordinating resources within schools. Given that teachers struggled to implement integrated curricula without the support from schools (Kelley et al. 2018), future programs could include school administrators together to mobilize resources for teaching.

KEY WORDS OF THE BRIEF

- TO SUPPORT POLCY
- TO PREPARE TEACHERS
- NATURE OF INTEGRATING ENGINEERING
- CONTEXTUALIZING STUDENT LEARNING
- REAL-WORLD ACTIONS
- ENHANCE THE INTEGRATION WITH SCIENCE
- TRACK EXPERIENCE FROM TEACHERS TO STUDENTS
- CONNECT STUDENTS WITH REAL WORLD ISSUS

ENHANCE THE INTEGRATION WITH SCIENCE → TRACK EXPERIENCE FROM TEACHERS TO STUDENTS → CONNECT STUDENTS WITH REAL WORLD ISSUS

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