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Contents

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Current Trends in K-12 Engineering Education

Guest Editors

Wei-Fan Chen, The Pennsylvania State University, USA.

Pao-Nan Chou, National University of Tainan, Taiwan.

Wei-Fan Chen and Pao-Nan Chou	285–286	Guest Editorial
Howard Kimmel, Linda Hirsch, Levelle Burr-Alexander and Ronald Rockland	287–294	Engineering & STEM: Complementary Areas of Study

Many K-12 educators approach STEM disciplines as if each one (Science, Technology, Engineering, and Mathematics) exist in isolation from each other integrate the content and skills of the disciplines that can engage students on many levels. STEM education is meant to be an interdisciplinary area of study that integrates the four disciplines rather than achieving skills and knowledge independently in each subject area. This paper examines the several attempts to define STEM and discusses the basics and issues related to the implementation of STEM programs and how engineering is a suitable vehicle for development and implementation of STEM programs, whether the focus of the course is science, technology, engineering, or mathematics. The value of the Next Generation Science Standards in this endeavor will be detailed. In addition, the paper will examine the relevance of STEM Career Technical Education (CTE) programs.

Keywords: STEM implementation; interdisciplinary approach; Next Generation Science Standards; curricula integration; K-12 education

Christine M. Cunningham and Gregory J. Kelly	295–307	Framing Engineering Practices in Elementary School Classrooms
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The introduction of engineering in K-12 education in the United States offers new potential and challenges for schools interested in teaching engineering in the elementary grades. This study examines how a teacher frames engineering practices for her students through the teaching of an *Engineering is Elementary* (EiE) instructional unit. Discourse analysis of conduct was undertaken based on a set of classroom videos and artifacts. The method entails detailed analysis of the talk and actions of classroom members. Codes were developed to characterize the work on framing and engaging in engineering practices. Drawing from the materials provided in the curriculum, the teacher in this classroom used a set of discourse moves (e.g., posing questions, revoicing student responses, giving directions) to frame aerospace engineering as a field that is dedicated to principled uses of data to support design. This was accomplished by modeling ways of collecting data, controlling variables, and treating anomalies. Classroom activities in support of data use included analysis of science concepts and engineering designs, sharing within and across groups for collective decision making, and comparing data to draw inferences for engineering redesign. The teacher in this study was able to provide learning opportunities in this fourth-grade classroom by developing common foci around science concepts and engineering processes, holding students accountable to common standards of quality in engineering work, and encouraging students to develop agency as engineers.

Keywords: elementary; engineering; epistemic practices; discourse

Vivien M. Chabalengula, Sonia A. Bendjemil, Frackson Mumba and Jennifer Chiu	308–320	Nature and Extent of Science and Engineering Practices Coverage in K-12 Engineering Curriculum Materials
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The integration of science and engineering practices in K-12 science education is currently an area of growing national interest in the United States, as evidenced in the recently published document titled *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. However, to date, little is known about the extent to which these practices are covered in the widely used K-12 engineering programs. As a response to the dearth of research in this area, this study investigated the nature and extent to which science and engineering practices are covered in the widely used K-12 engineering programs in the United States. Nine programs that are widely used in the United States were analyzed via document content analysis method using the K-12 science education framework. The results revealed important findings showing the similarities and disparities in the coverage of science and engineering practices in the analyzed programs, grade levels, and in different science discipline units. This study is significant because an understanding of the current status of science and engineering practices coverage would be helpful to educators and curriculum designers as they strive to further the development of integrated science and engineering curricula, as well as shaping the scope and sequence of engineering design thinking learning activities in the K-12 science curriculum.

Keywords: engineering practices; science practices; K-12 engineering education; K-12 science curriculum

Mike Ryan, Jessica Gale and Marion Usselman	321–331	Integrating Engineering into Core Science Instruction: Translating NGSS Principles into Practice through Iterative Curriculum Design
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The Next Generation Science Standards now integrate science and engineering through their Core Ideas and Practices dimensions. Portions of the engineering design process included in these standards emphasize: (1) defining problems through identifying criteria and constraints, (2) developing solutions to those problems, and (3) optimizing those solutions to best fit the criteria and constraints. The Science Learning Integrating Design, Engineering, and Robotics (SLIDER) project, funded through the NSF DRK-12 program for five years, set out to investigate this integration through the use of robotics and design to develop conceptual understanding among 8th grade physical science students. Through three years of curriculum development and iteration, the SLIDER curriculum faced several challenges in making this integrated approach both effective and practical in a diverse array of

schools. This paper presents that story and makes suggestions critical to others designing for the NGSS and developing theory around integrated STEM learning.

Keywords: science education; engineering education; design; integrated STEM; curriculum development; Next Generation Science Standards

Carlos García-García, Vicente Chulvi Ramos and Julia Galán Serrano 332–345 Sculpture Development as an Informal Activity for Learning Engineering Abilities in K-12 Students

The social changes that have taken place in recent decades have determined the evolution of the educational system. Society nowadays demands new learning methods, focused on an appropriate selection and processing of information instead of memorization. The rise of the Information Technologies has led to different “Emergent Pedagogies”. One of them is Informal Learning, which proposes shifting the generation and acquisition of knowledge from the individual to the collective plane.

The present research expects to raise K-12 students’ interest in engineering by adopting some methods that are typical of informal learning in the field of formal learning. The objective is to stimulate the group learning processes for the generation of collective knowledge through multidisciplinary team interaction and dialogue. For this purpose, a group of 25 K-12 students organized in subgroups carried out a co-creative project. This project consists in the development of a sculptural assembly made of glazed ceramics over a steel structure, which will be installed in the educational centre. A concurrent project methodology was used to create the sculptural assembly. Here, each student must perform different tasks related to design engineering. An educational model based on Blended Learning was used, which proposes the combination of in-person sessions with virtual work by means of social networks as a group communication medium. Thus, each creative team member contributed with their own Personal Learning Environment in order to enrich the group learning process and provide it with their own personal singularities, thereby turning it into a Personal Learning Network.

The experience allowed K-12 students to discover the working process typical of design engineering through a recreational methodology based on Informal Learning. The students were able to make up for their shortcomings in terms of technical and creative skill, while becoming aware of their chances within the field of engineering. The project has been shown to be an incentive for K-12 students regarding their interest in starting engineering studies once they finish their K-12 stage.

Keywords: informal learning; K-12; engineering project; collaborative design; b-learning; PLE; social networking

Lyn D. English and Donna King 346–360 Engineering Education with Fourth-Grade Students: Introducing Design-Based Problem Solving

This article reports on fourth-grade students’ approaches to solving an introductory engineering design-based problem, namely, *Tumbling Towers*, which was implemented at the beginning of a three-year, longitudinal study. Set within a civil engineering context, the problem required student groups to design and then build the tallest tower within given constraints. The stability of their towers was tested by removing one pylon at a time, with the goal being to determine the minimum number needed for the tower to remain stable. Students completed a second design iteration in an effort to maximise the number of pylons that could be removed while still maintaining stability. A framework comprising five sets of engineering design processes was developed as a theoretical base and facilitated data analyses. Findings illustrate how fourth-grade students, for whom such problems were new, engaged in design processes in an iterative manner and applied mathematics and science content knowledge in doing so. Four levels of design were identified in the students’ design sketches with the highest level being the most frequent in both initial designs and redesigns, with some decline in the latter. Students’ application of content knowledge included an awareness of stability and load distribution, together with spatial reasoning involving pylon positioning, removal, and repositioning. Other findings include ways in which group negotiations and students’ addition of meaningful contexts assisted in the designing and redesigning phases, and how students spontaneously used gestures to convey their design and construction ideas.

Keywords: design processes; engineering education; engineering-based problem solving; elementary/primary school

Roxanne A. Moore, Sunni H. Newton and Amanda D. Baskett 361–370 The InVenture Challenge: Inspiring STEM Learning Through Invention and Entrepreneurship

The InVenture Challenge seeks to bring design, engineering, invention, and entrepreneurship to K-12 education by providing a framework, curriculum, and competition that can be used by teachers in different disciplines with support from Georgia Institute of Technology faculty and staff. Modeled after Georgia Tech’s InVenture Prize, a ‘Shark-Tank’ style competition for Georgia Tech undergraduates that is televised throughout Georgia, the InVenture Challenge attempts to deliver the same authentic experience to younger participants by providing resources and mentoring to K-12 teachers to implement engineering, design, and entrepreneurship lessons. In this paper, we present the motivation for the InVenture Challenge, lesson plans, resources, teacher survey feedback, and teacher focus group themes from the third year of implementation. The teacher survey data is related to perceptions of the program, self-efficacy for teaching engineering and entrepreneurship, observed student outcomes, challenges experienced during implementation, and recommendations for implementation within different schools and classroom settings. In general, teachers perceive the InVenture Challenge as an engaging way to introduce students to engineering and find value in the connection to the Georgia Tech community.

Keywords: invention; engineering; entrepreneurship; design; K-12; informal learning

J. Chiu, A. Gonczi, X. Fu and M. D. Burghardt 371–381 Supporting Informed Engineering Design across Formal and Informal Contexts with WISEngineering

This paper describes the design of WISEngineering, a computer-based engineering design environment focused on helping learners in formal and informal settings engage in informed engineering design activities. This paper compares and contrasts results of implementing WISEngineering projects in both formal and informal learning settings. In particular, this paper reports on insights gleaned from implementing WISEngineering middle school science and math classrooms as well as in after-school settings with Boys and Girls Clubs. We discuss design principles guiding the development of WISEngineering for school settings and how these principles were adapted and refined for youth and facilitators in informal learning contexts. We provide implications for the design of technology-enhanced engineering learning environments across school and out-of-school time settings.

Keywords: computer-based learning environments; K-12; formal and informal learning

Pao-Nan Chou, Wei-Fan Chen, Chong-Yan Wu and Robert P. Carey 382–388 Utilizing 3D Open Source Software to Facilitate Student Learning of Fundamental Engineering Knowledge: A Quasi-Experimental Study

This study explored the effect of Google SketchUp on students’ learning achievements in spatial visualization. A quasi-experimental with pre-test and post-test design was used to conduct the research. Eighty-four fifth graders from a public elementary school in Taiwan voluntarily participated in the study. Students from different classes were divided into three instructional modules: Google SketchUp (with full features), Google SketchUp (with limited features), and traditional instruction (hand-held objects). Students in each of the three experimental groups were instructed to manipulate various 3D objects that were created by a class teacher. A criterion test was developed to measure students’ understanding about basic concepts of spatial visualization. The educational experiment was completed within three weeks. The results showed that Google SketchUp (with full features) was an effective learning tool to support students in developing spatial visualization skills ($F = 8.20, p < 0.01$).

Keywords: spatial visualization; Google SketchUp; open source software; K-12 engineering education

Liliana Fernández-Samacá, Nelson Barrera, 389–397 Engineering for Children by using Robotics
Luis Ariel Mesa and Wilson Javier Pérez-Holguín

This paper presents an approach for K-12 Engineering education aimed to facilitate the concept learning in preschool and elementary school using simple robotic prototypes developed with active participation of children. The approach focuses on strategies for imparting engineering knowledge dealing some concepts related to subjects such as physics, electricity, electronics, mechanics and other fields related to engineering education by means of an open and affordable technology. The designed approach considers four stages to motivate the learning: sensitization, robot design, robot construction and evaluation. The paper also presents results about the impact assessment of the proposed K-12 approach through qualitative data gathering to know the children's impressions and a survey intended to know the opinion of the children's parents and schoolteachers about robots as a didactic resource.

Keywords: educational robotics; K-12 engineering education; STEM

Linda S. Hirsch, Suzanne Berliner-Heyman 398–407 Introducing Middle School Students to Engineering Principles and the Engineering Design Process Through an Academic Summer Program
and Jacqueline L. Cusack

Forty-seven 5th, 6th and 7th grade students from traditionally underserved and typically underrepresented populations participated in a two-week residential engineering program. The ExxonMobil Bernard Harris Summer Science Camp at New Jersey Institute of Technology during the summer of 2015. Working in small cooperative groups, students were introduced to the Engineering Design Process, taught how to apply the process in developing and testing a prototype and received instruction in how to keep an engineering logbook. Results of evaluations indicate that, in addition to significant increases in Science, Technology, Engineering and Mathematics content knowledge, students showed significant increases in their attitudes toward science, mathematics and engineering and demonstrated increased knowledge about careers in engineering and an understanding of the engineering design process at the conclusion of the program. A rubric has been developed to evaluate students' understanding and application of the engineering design process. Correlations among students' responses to content knowledge pre/post tests and the rubric have been found. The Draw an Engineer Test was also used as a more qualitative assessment of what students think engineers actually do and to capture cognitive changes in their perceptions of engineers as a result of attending the camp.

Keywords: engineering design process; Next Generation Science Standards; problem-based learning; 21st Century skills

Andreja Drobnič Vidic 408–419 Teachers' Beliefs about STEM Education Based on Realisation of the "Energy as a Value" Project in the Slovenian School System

The cross-curricular project *Energy as a Value* described in this study involved almost all subjects in the K-12 curriculum of the so-called technical gymnasium. It became the framework for an effective Science, Technology, Engineering and Mathematics (STEM) education. Although the project offered interdisciplinary connection of all STEM subjects, promoted problem-based learning and pointed out to applications of subjects' contents to engineering profession it was not added up as a successful one. Teachers' satisfaction was questionable at the end of the four-year project time. Teachers were not initiators for a new project. The Engineering Education Beliefs and Expectations Instrument for STEM education is used in order to find the reasons for such an ambitious project not being carried out again. The instrument documents teachers' beliefs and expectations about pre-college engineering instruction, college preparation, and career success in engineering, and compares teachers' views. It is applied to teachers of technical gymnasiums in Slovenia that teach STEM subjects in order to find out if there are differences between beliefs of teachers that carried out the *Energy as a Value* project and teachers from other technical gymnasiums, as well as differences between beliefs of mathematics/science teachers and technology-based/engineering teachers. The results of statistical analyses give answers about obstacles that teachers who carried out the ambitious STEM education in a particular school system might be confronted with.

Keywords: STEM education; teachers' beliefs; K-12 curriculum; interdisciplinary engineering project; project-based learning

Nuri Balta, Sevda Yerdelen-Damar and Adam R. Carberry 420–429 Vocational High School Students' Engineering Epistemological Beliefs

This study investigates the engineering epistemological beliefs (EEB) of Turkish vocational high school students. The goal of this research is to reveal changes in these beliefs across grade levels, discipline, and gender. The present study included 314 vocational high school students from five schools in two Turkish cities. A Turkish version of the epistemological belief assessment for engineering (EBAE) questionnaire was created and used to assess student EEBs. Descriptive results indicated that as grade increased, average scores of students' EEB decreased with respect to almost all dimensions of the EBAE. Males reported more sophisticated beliefs than females for all EEB dimensions except for justification for engineering knowing. Participants studying the metal technology discipline reported the most naïve EEB, while those studying information technologies displayed the most sophisticated beliefs. The results of inferential statistics showed that while the effect of gender, discipline and grade level were not significant with students' EEB, the effect of interaction of grade level and discipline on students' EEB was statistically significant. This study implies that the vocational school curricula in Turkey should be reconsidered in terms of student engineering epistemological growth.

Keywords: epistemological beliefs; engineering epistemological beliefs; vocational high school

Wen-Jye Shyr, Wei-Chin Liu, Po-Wen Liu and Chi-Feng Feng 430–440 Development and Validation of Energy Technology Competency Survey for Vocational High School Student in Taiwan

This study developed and validated of competency required for the education of energy technology for vocational high school students in Taiwan. The energy technology competency survey developed through this research is based on a conceptual framework that emphasizes the current definition of the field. Following the conceptual framework, behavioral event interviews and the Delphi technique were used to ensure consistency in the indicators, while the Kolmogorov-Smirnov one sample goodness of fit test was used to ensure consistency in the opinion of experts. This study identified sixty competency indicators covering knowledge, skills and attitudes domains. These competencies were validated by thirty students and ten domain experts by a nonparametric Mann-Whitney U test. The proposed competency indicators are applicable to the development of curriculum for industrial vocational high school in Taiwan.

Keywords: behavioral event interviews (BEI); Delphi technique; Competency analysis

Meltem Alemdar, Jeremy A. Lingle, Stefanie A. Wind and Roxanne A. Moore 441–452 Developing an Engineering Design Process Assessment Using Think-Aloud Interviews

Early exposure to engineering has been found to help students in their decision-making regarding engineering education and career pathways. Subsequently, an NSF-funded project is underway that is focused on development of an engineering curriculum for students in grades six through nine. The Engineering Design Process (EDP) frames this curriculum. The current study presents the validation methods and results of a multiple-choice assessment created to measure students' understanding of the EDP. The utilization of Think Aloud Interviews and the application and analysis of qualitative coding schemes for the purpose of systematically gathering evidence about the psychometric quality of the assessment are described. Findings from this study support the validity of the EDP assessment through evidence of alignment between the intended skills and the skills elicited in the student interviews.

Keywords: engineering design process; assessment; validation; cognitive interviews

Morgan M. Hynes, Corey Mathis, Şenay Purzer, Anastasia Rynearson and Emilie Siverling 453–462 Systematic Review of Research in P-12 Engineering Education from 2000–2015

Nations throughout the world have recognized the importance of having a Science, Technology, Engineering, and Mathematics (STEM) competent workforce in today's highly competitive and technical economy. As such, the past fifteen years have seen a sharp rise in introducing pre-college (P-12) students to engineering and engaging them in learning engineering principles. Policy decisions to include engineering in national curriculum and standards have not been informed by as rich a body of research as subjects such as mathematics and science; however, research on P-12 engineering education is on the rise. This paper presents a systematic review of the engineering education research in P-12 published in journals from 2000–2015. A systematic review follows a set of replicable, detailed procedures that describe how the articles were selected, reviewed, and analysed. The results of this review included 218 peer-reviewed journal articles. The paper details the kinds of research and research questions these papers focused on, and synthesizes and discusses findings of across different topics, and proposes research topics ripe for further work.

Keywords: systematic review; pre-college; literature synthesis

Holly M. Matusovich, Cheryl A. Carrico, Marie C. Paretti and Matthew A. Boynton 463–475 Engineering as a Career Choice in Rural Appalachia: Sparking and Sustaining Interest

Research shows that interest is often reported as a primary reason for career choice selection among majority students but not necessarily for underrepresented students. At the same time, research focused on rural Appalachian youth in Virginia and Tennessee (students underrepresented in higher education broadly and specifically within engineering) has shown interest as preferentially important in engineering fields though not in other fields. To better understand how interest in engineering is sparked and sustained among Appalachian students, we used a qualitative multi-case study approach to first compare interest in engineering and healthcare fields among high school students and then to compare high school and college student interest in engineering careers. For high school students, our findings reveal interest sparks in engineering were more likely to be associated with organized experiences, while health care interests were primarily associated with personal experiences. We also found an association between engineering interests and a preference for math and science classes, but the same association did not exist for interests in health care fields, despite the potentially equivalent math/science intensity of these career fields. With regard to interest development phases among high school students, individual rather than situational interests tend to be associated with intention toward engineering majors, whereas the opposite was true for healthcare fields. For college engineering students, we identified a greater balance between individual and situational interest than in the high school sample of students interested in an engineering career. College students were also more likely than high school students to indicate a personal experience as sparking his or her interest in engineering than an organized activity. Finally, though we compared two case sites in rural Appalachia, our findings revealed commonality in interest levels and sparks across sites. In combination, these findings have implications for designing interventions intended to spark interests in engineering such that the interests can also be sustained.

Keywords: interest; Appalachia; career choice

Pao-Nan Chou and Wei-Fan Chen 476–488 Elementary School Students' Conceptions of Engineers:A Drawing Analysis Study in Taiwan

This study investigated elementary school students' conceptions of engineers by conducting the Chinese-version of the Draw-an-Engineer Test (CDET) in classrooms. A mixed methods research methodology was adopted for achieving the research objective. In the quantitative part of this study, a content analysis method was used for analyzing students' drawing contents; in the qualitative part, a phenomenology approach was employed for collecting interview data. A total of 750 Taiwanese students voluntarily participated in the study. Quantitative findings showed the presence of gender stereotypes of engineers, specific types of engineers, and major conceptions of engineers in the drawings. Qualitative findings indicated that family members and mass media strongly influenced students' conceptions. Overall, most findings were supported by previous research results. However, the information on the proportion of stereotypes, types, and conceptions of engineers was unique to the current study.

Keywords: K-12 engineering education; conceptions of engineer; engineering epistemology

Michelle R. Oswald Beiler 489–503 Sustainability Interest and Knowledge of Future Engineers: Identifying Trends in Secondary School Students

Sustainability is an innovative topic within the field of engineering and is becoming a fundamental component of the engineering curriculum in the twenty-first century. As global challenges arise, the development of sustainable design techniques is timely as engineers aim to address issues such as population growth and climate change. This research evaluates secondary school students based on their understanding of sustainability concepts with a focus on education level, gender, and ethnicity. Over three years, a pre- and post-assessment is provided to high school students who attend a summer engineering camp and participate in a ninety-minute lesson on sustainable engineering. The assessment results (based on 334 students) are compared over the three years to identify trends in demographics, pre-existing knowledge, post-module knowledge, as well as interest in sustainability and engineering. Demographic comparisons are explored using statistical analyses. Education level was found to be significant in terms of knowledge of sustainability topics and sophomores indicated a higher level of interest in sustainable engineering in comparison to all demographic groups. Three major recommendations are identified: (1) integrate sustainability education earlier on in the secondary school curriculum and continue integration of material throughout their junior and senior years, (2) focus on enhancing sustainability education for minority groups (such as camps, workshops, science fairs, outreach programs, etc.), and (3) continue to emphasize women in engineering disciplines and encourage all student groups to pursue engineering through exposure to sustainability topics.

Keywords: sustainability; engineering recruitment; high school; assessment