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Cutting Edge Resources for Engineering Education: The Pedagogical Potential

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Abstract

Engineering is a popular, yet rigorous field of study. From various engineering courses such as mechanical, electrical, civil, electronics, computer systems, etc., students choose courses focusing on their interests and opportunities. According to the National Science Foundation, there are approximately
7.5 million engineers and science graduates in the world [1]. There has been a significant proliferation of innovative resources for 21st Century engineering education, and learning strategies are undergoing a shift from traditional methods to active, hands-on learning methodologies [2]. This rapid transformation is impacting educators and students. Leveraging valuable resources has yielded profound changes and substantive advances. This presentation and manuscript examine varied resources for both engineering students and educators including project-based learning, case studies, digital technology and open educational resources. The goal of this study is to strengthen content knowledge, the development of practical engineering skills, and encourage critical thinking. These resources will be explored, assessing their contributions to engineering education. To engage students, educators are moving beyond the standard methodologies and best practices to provide high levels of student achievement through authentic real-world experiences making positive connections by engaging with the complexities of engineering practice. The proliferation of open and online educational resources results in high-quality learning opportunities that are globally accessible. Students and educators are often challenged by a variety of unique and diverse factors, and engineering educators must address unique situations to make a significant impact by taking approaches that will meet the wide range of student needs—cognitive and affective. Varied resources in engineering create an opportunity for practitioners and researchers of engineering education to collaboratively learn to foster learning centered on the vision that learners construct their knowledge based on meaningful activities [2]. The opportunity to investigate cutting edge resources and focus on the multidimensional aspects of these resources provides valuable information that contributes to expert teaching and learning. Embracing engineering pedagogy, including new technologies, and initiating change through proactive educational strategies including a paradigm shift to incorporate critical thinking coupled with application of theoretical knowledge leads to relevant and purposeful accomplishments in engineering education.

Keywords: *Engineering. Resources, Pedagogy, Methodology, Technologies*

1. Introduction

Engineering is a highly valued field where contributions are critical to problem-solving and innovation. Its dynamic potentialities through tangible and significant impacts are realized focusing on infrastructure and technology as global challenges are embraced. Rapid technological changes, a challenging economy, and evolving workplace skills strongly impact the field of engineering. In engineering classrooms around the world, students and educators are examining ways to strengthen programs and accelerate learning to develop interactive processes that will lead to innovative and engaging accomplishments in numerous aspects of their field of interest. An overarching theme addressed by engineering program designers and curriculum specialists focuses on incorporating problem-based activities to challenge students and stimulate higher order thinking skills. By incorporating innovative pedagogy and developing methodology that will relate to the multifaceted talents of students in the engineering field, highly capable students will excel and achieve numerous accomplishments. This manuscript and presentation reflect the combined results of educators and practitioners in the engineering field and explore challenging activities relevant to motivation and exploration in addition to content knowledge. Engineering students of all ages have made valuable contributions and offered perspectives that researchers and professors may not have considered. Throughout this investigation, words like collaboration, hands-on, active learning and engagement continue to surface. Problem or inquiry-based learning is embraced as a preferred method of learning. Students demonstrate enthusiasm for engineering activities shared globally as they interact with international colleagues. While engineering becomes far more advanced at the university level it has opportunities for introduction and cultivation at a young age. By starting young and engaging in a variety of ages and levels, students' preparation, expectations and performance in engineering coursework will strengthen the relationship between subject material knowledge and interdisciplinary methodologies. Examples of activities for various age groups are included from young learners to university students enrolled in prestigious university programs.

2. Review of the Literature

Research in engineering is a dual-faceted exercise that drives significant innovation while simultaneously navigating substantial operational and pedagogical challenges. Engineering research often addresses successes and challenges at the university level and is conceptualized according to workforce disciplines. such as engineering from a learner-centered approach [3]. For much of the history of the profession, the evolution of engineering education has mirrored changes in technology and society. Disciplines have been added and curricula modified to yield a workforce capable of meeting the needs of society [4]. It is crucial to acknowledge that the engineering workforce fuels high-pace technology developments in all aspects of human life. A quality engineering education today is essential to building engineers for tomorrow. This raises standards for pedagogical training for professors and other staff of engineering educational institutions [5]. Having general proficiency in Artificial Intelligence (AI) tools and methods is becoming an increasingly critical need for engineering employers in various engineering areas, including civil, industrial, mechanical, electric, systems, and aerospace. Rutgers University faculty in the School of Engineering address the question, "How Is AI Driving a Revolution in Engineering?" They suggest that engineering and technology are closely interconnected in a continuous cycle. Advancements in engineering lead to new technologies, which in turn propel further engineering innovations. Impactful and new technological developments are happening every day [6]. Furthermore, AI has had a particularly strong impact on industrial, systems, mechanical, and aerospace engineering processes, which aim to safely, efficiently, and effectively manufacture components, parts, and machinery that drives everyday life. Improving engineering processes using AI impacts everyone, making not just technology more effective, but making life better for engineers and the public [6]. Additionally, there is the challenge for engineers in the global workforce who do not speak the native language of the country in which they are employed. In the case of English language proficiency, Kausar points out that, "Despite the global emphasis on English proficiency, the majority of engineering students whose first language is not English often encounter significant specific obstacles such as limited vocabulary, pronunciation issues, anxiety, inadequate practice opportunities, linguistic deficiencies, psychological factors, institutional constraints and pedagogical shortcomings" [7]. Kausar presents a study examining the challenges faced by non-native engineering students in acquiring English language skills and explores the role of English for Specific Purposes (ESP) in engineering education, emphasizing its impact on academic success, employability, and professional communication [7]. Transforming engineering education through real world application is at the forefront of current pedagogy and curriculum design. Project Based Learning (PBL) in engineering education represents a paradigm shift from traditional lecture-based instruction to hands-on, experiential learning that mirrors the complex, interdisciplinary challenges engineers face in the modern workplace. This pedagogical approach has become a highly effective strategy for encouraging students' teamwork, creativity, and problem-solving abilities in real-world contexts while enhancing student participation in the learning process and promoting critical thinking [8]. Engineering is not only for university students and professionals. According to the USA National Science Foundation, there are numerous resources for students and educators. A review of their website reveals engaging videos, lessons and material to encourage and innovate younger students considering educational pathways leading to a career in engineering [9].

3. Resources and Learning Strategies

Learner acquisition of critical knowledge is the goal at any age and can take many directions based on the area of engineering that interests students. As with any subject area in the field of science, methodology related to engineering will focus on curriculum and content to strengthen knowledge and skills in this profession. Mathematical and language expertise in the specific language addressed is also essential. It is incumbent upon educators to acknowledge and address opportunities that will cultivate engineering interests and allow students to make valuable contributions to the field. This can begin at a young age and incorporate activities in the home that will provide a base for expansion as students grow and gain further knowledge. Educators who incorporate engineering subject specific labs and exercises according to their learners' abilities will promote development of content skills. Engineering resources at all ages and abilities are valuable for encouraging students to enter this field at a young age and continue to grow their interests and accomplishments. For example, hands-on active learning opportunities engage students and challenge them to high ideals. In the engineering classroom, relevant, critical and analytical thinking is essential for success. Multilevel approaches to learning that encourage collaboration, teamwork and problem solving are necessary for coverage of this complex field and to spark an interest in all learners.

4. Methodologies and Pedagogy

For the purpose of this manuscript, addressing authentic learning experiences that incorporate problem solving and active learning will be featured. Inquiry and problem-based learning opportunities and instructional strategies abound for stimulating students' specialized interests in engineering and allow practical application of critical knowledge. Problem-based learning encourages numerous avenues to ensure practical application in students' chosen fields of engineering and capture their enthusiasm. Communication, collaboration and teamwork encourage independent learning focusing on self-directed learning strategies in engineering that are student centered. An educational curriculum based on Science, Technology, Engineering and Math (STEM), focused on teaching the basic principles of STEM-related subjects provides a foundation for students to expand their abilities and concentrate on the engineering field. The key to teaching these disciplines is an inquiry-based approach that is incremental and responsible for the development of a unique set of skills. Students develop the ability to think independently yet work collaboratively [10]. Careful planning coupled with numerous kits and building projects that are found online will focus on engineering and mathematical competencies to encourage learners of all ages. At an advanced level, multiple sites exist with university level engineering activities building skills transferable to the workplace.

5. Engineering Inquiry and Hands-On Learning Activities

What follows is a variety of sample activities for various age levels focusing on engineering. Each of these activities should include activity-oriented tasks reinforcing engineering concepts with concrete experiences that are applicable to the field.

Elementary and Middle Level (Ages 6-13)

Intrinsic motivation is strengthened for younger learners when activity-oriented lessons reinforce engineering concepts with concrete experiences. Transforming technological understanding is key for younger learners. STEM engineering toys are educational projects and activities designed to teach students about STEM principles through hands-on discovery and exploration. They increase the development of critical thinking, problem-solving, creativity, and analytical skills by encouraging students of all ages to build, experiment, and discover [11]. One of the most popular that has been observed in the area of engineering for younger students relates to various types of rockets. Rockets are a fascinating and innovative category of educational tools designed to ignite young minds and introduce them to the world of engineering [11]. "STEM rocket toys teach physics (Newton's Laws, aerodynamics) through fun, hands-on building and launching, featuring types like air-powered stomp rockets, water rockets, and motorized kits, with popular brands including Stomp Rocket, *National Geographic*, and do it yourself options from stores like the Museum of Flight, offering experiences from simple foam launches to complex construction" [12].
There are several types of Rocket Engineering Kits including:

- **Stomp Rockets:** Use air pressure from stomping on a foot pump to launch foam rockets, perfect for active outdoor play and demonstrating thrust.
- **Water Rockets:** Utilize water and air pressure in bottles to launch, teaching principles of pressure and propulsion.
- **DIY/Construction Kits:** Involve building the rocket from materials, such as plastic bottles or specialized kits, to learn about assembly and design.
- **Motorized Rockets:** Feature rechargeable batteries for electric motor launches, offering a different power source for flight.

Key STEM Learning Concepts

- **Physics:** Air pressure, thrust, gravity, Newton's Laws of Motion (action/reaction).
- **Aerodynamics:** How rocket shapes and fins affect flight.
- **Engineering:** Building, assembly, and problem-solving [12].

Secondary and High School Level (Ages 14-18)

Challenging engineering activities for high school should be interactive, hands-on, visually oriented, and encourage collaboration to build both technical skills and serve as preparation for university coursework. Interactive tasks stimulating intrinsic motivation and a more sophisticated knowledge of technology reinforcing engineering concepts and concrete experiences is suggested. An interview with Evan Caspary, age 15, an engineering student in Athens, Georgia, described fusion modeling software to design a model for a case that could be made on a 3d printer and used with USB drives. Evan elaborated that "they could only be made of 3d printed materials needed to become part of the USB and be able to cover the entire USB when storing." Further investigation of fusion modeling software revealed Fusion Modeling Software for High School Engineering Projects available for purchase. One is described as Fusion 360, a powerful tool for high school engineering projects. This software includes modeling, simulation, and manufacturing capabilities. It is particularly beneficial for students who are interested in mechanical engineering, product design and manufacturing [13]. Autodesk Fusion 360 and related engineering packages are available for free to eligible students and educators. They provide access to an integrated CAD, CAM, and CAE platform for design and engineering education. An investigation on the internet reveals numerous packages designed for specific engineering areas, i.e. Fusion for design, Fusion for manufacturing, Civil engineering design and construction documentation, and Revit Plan, to design, construct, and manage buildings with powerful tools for Building Information Modeling [14]. This is just a sample of the material available for secondary school students in this aspect of engineering education. Numerous activities are available to challenge and provide direction reinforcing abstract concepts with concrete experiences. By integrating technology and hands on learning activities into students' lives, subject matter is reinforced and engineering understanding is transformed.

University Level

The following activity is designed for advanced engineering students to prepare them for the field of engineering in the workplace and is inspired by engineering coursework at the University of Georgia in the USA.

Capacitors

What are they?

Capacitors are another one of the main components used in electrical circuits. They are in many ways the opposite of an inductor. While inductors resist change in current, capacitors resist a change in voltage, however instead of storing energy in a magnetic field like inductors, capacitors store energy in an electric field. If voltage is increasing, they store extra voltage to decrease it, and when voltage is decreasing, they release stored voltage to increase it again and try to keep it stable.

How are they made?

One of the most common types of electrolytic capacitors is made by rolling paper backed aluminum foil that is then soaked in electrolyte.

Real world use:

Capacitors are used in many devices and the power grid to offset the effect of inductors. Inductors cause voltage to lead the current. This can be offset by capacitors which cause voltage to lag behind the current. This is desirable because when the voltage and current phase angles are the same, we get maximum power transfer. Another use for Capacitors is to filter DC, high frequency, or low frequency signals out of circuits. They can be used to filter each of these based on how they are connected into the circuit.

Capacitor formulas:

Formula for energy stored in a capacitor:

$E = \frac{1}{2} CV^2$

Ohms law:

V=IR

Formula for Time constant:

$$\tau = RC$$

Variable meanings:

C = capacitance

V = voltage

I = current

R = resistance

τ = time constant

Important notes for making circuits with LEDs, LED stands for Light Emitting Diode. A diode is a device that only allows current to flow in one direction; this means that if you connect an LED backwards it will not turn on because it will block the flow of current. Most LEDs' current direction can be seen by looking at the length of the wires coming out of them. The long wire is the positive side; the shorter wire is the negative side. We want the current to flow from the positive to the negative.

In the LED and the capacitor, wire length differences show which direction current should flow. Using conventional current flow, current flows from high (positive) to low (negative) potential. The long wire represents high potential (positive) and the short wire represents low potential (negative). Unlike the LED the capacitor will still let some current through if connected backwards but might explode.

Activity:

First, we will make the capacitor charging circuit. Connect the positive side of a 9v battery to a 10k ohm resistor. Then we connect the other end of the resistor to the positive side of the capacitor (long wire). Next, we will connect the other end of the capacitor (short wire) to the positive side of an LED (long wire). Finally, connect the negative side of the LED (short wire) to the negative side of the battery. Once connected, the capacitor will initially offer little resistance, so we will see the LED turn on, but as the capacitor charges up to 9v it will increase its resistance until the LED is barely visible.

Now we will make the capacitor discharging circuit. Connect the positive side of the LED (long wire) to the 10k ohm resistor. Then connect the other end of the 10k ohm resistor to the positive side of the capacitor (long wire), Finally, connect the negative end of the capacitor (short wire) to the negative end of the LED (short wire). When the circuit is completed, the LED will initially light up and then slowly get dimmer as the capacitor discharges. In this configuration, the capacitor acts as a battery.

When connected to a battery, a capacitor will charge to the voltage of the battery it is connected to. Their charging speed is determined by the resistance of the circuit. Increasing resistance will allow us to see the capacitor charging. A good estimate for how long it will take for the capacitor to charge is this formula:

τ = RC,

τ is in seconds and after one τ the capacitor should reach 63 percent charge, then after 5 τ it should reach 99 percent charge so if we use a 470uf capacitor and a 10k resistor it would look like this: $470 \cdot 10^{-6} \cdot 10 \cdot 10^3 = 4.7s$. Then if we multiply that number by 5, it would theoretically take around 23.5 seconds to charge to 99 percent. If we considered more factors, we could get a more accurate formula. The important idea that this formula shows is that as we change the resistance or change the capacitors, charging time changes. For example, if we change the resistor to be a 5k resistor then the capacitor will charge much faster. These charging speeds become increasingly important in AC circuits where τ can determine what frequencies will be filtered out by the capacitor.

7. Conclusion

Superb accomplishments can be realized for students of all ages through innovative resources in engineering education and learning strategies that are active and hands-on. Perceptions regarding engineering education are often presented through the lens of different institutional stakeholders [15]. Instructional methodologies designed to enable students to engage in authentic learning experiences encourage multifaceted decisions and accomplishments. New paradigms are emerging that focus on challenging engineering students of all ages and preparing them for the global, evolving workplace. Key instructional components of project-based performance including collaborative endeavors will invoke successful student-centered instruction. Educators are key to providing educational experiences that stimulate critical and analytical thinking. As students take ownership for their own work and contributions, opportunities increase for their acquisition of critical knowledge in the field of engineering. Active rather than passive learning leads to a goal-oriented approach to engineering education as students assume increasing responsibility for their learning. Incremental steps from an interest at a young age to sophisticated university academic achievement will transform our global workforce and strengthen rigor and outcomes. Successful and innovative performance in the engineering field is essential in the 21st century transformational global workforce.

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