Engineering Concepts

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Abstract Competencies people need to be well-educated will vary in response to societal waves of change. As STEM education grows in popularity worldwide, interest is increasing in using this paradigm to break down the traditional conception of the four component subjects as individual "silos" of science, technology, engineering, and mathematics (Vest, 2009). In the United States, Engineering and Technology education (ETE) is seen as a route through which the four disciplines can be integrated (NGA, 2007). In Europe, 30 countries promote and support STEM collaboration (Kearney, 2015).

The evolution of ETE from its craft-oriented and industrial roots (Industrial Arts in the U.S.; Craft, Design, and Technology in the U.K.; Handicrafts in Finland; the "Industrial Projects Method" in France) (Jones & de Vries, 2009) has resulted in a demand for new curriculum—driven not only by contemporary workforce and employability demands, but by other values-driven aspirations that educators, parents, and policy makers hold for students.

Since the 1980s, conceptual learning has been defined by curricular learning standards and associated performance expectations (often quite numerous) that when attained, are presumed to provide disciplinary competence. In this chapter, the author suggests that revisiting a small set of transferable ETE thematic ideas in different contexts can complement learning of standards-based domain-specific concepts and skills. Doing so would make instruction more manageable and enable students to assimilate a more holistic understanding of engineering and technology.

The chapter draws upon research studies (Rossouw, Hacker and deVries, 2010; Hacker, 2014; Hacker & Barak, 2017) that established a consensus of expert opinion about the most important ETE competencies high school students should attain within five thematic categories that consistently appear in the literature: (a) design, (b) modeling, (c) systems, (d) resources, and (e) human values.

Two case studies are offered as examples. The first exemplifies how a cutting-edge technology company looks to hire new employees with a broad mix of skills. The second describes a new ETE curriculum model that integrates important concepts within authentic social contexts and supports the fundamental purposes of education.

Introduction

There is growing recognition that school-based ETE experiences can be pedagogically valuable for all students—not only in providing an effective way to contextualize and reinforce STEM skills, but also in mobilizing engineering thinking as a way for young people to approach problems of all kinds (Brophy and Evangelou, 2007; Forlenza, 2010).

A literature review indicates that transferable concepts in engineering and technology education relate to five broad categories of knowledge, including design, modeling, systems, resources, and human values (Katehi, Pearson, & Pearson, 2009; Custer, Daugherty & Meyer, 2010; NRC, 2010; Rossouw, Hacker & de Vries, 2010; NGSS, 2012; NCES, 2012; Hacker & Barak, 2017).

A Comparison of Perceptions Delphi study (Hacker, 2014) identified 38 competencies within those five ETE categories that are most important for students to understand, based on a consensus of opinions of expert university-based Academic Engineering Educators (AEEs) and high school Classroom Technology Teachers (CTTs) (see Table 2, p. 7).

However, conceptual learning must be embedded in contexts that are important and authentic to students for them to be truly engaged in the learning process. Moreover, instructional interventions must not lose sight of the fundamental purposes of education to remain focused on meeting individual and societal needs.

Conceptual Learning

Many books and papers have been written to explain the essence of a concept (Bealer, 1998; Smith, 1989; Peacocke, 1992; Rey, 1995; Earl, 2006). Concepts can be thought of as ideas; abilities (the concept TREE implies the ability to distinguish a tree from a bush); or referents and senses (Frege, 1892) where a *referent* is the proper name of an object, and the *sense* is what the name expresses. A concise definition is that a concept is “a general idea about a thing or group of things, derived from specific instances or occurrences” (vocabulary.com, 2016).

According to Merrill, Tennyson, and Posey (1992), “a concept is a set of specific objects, symbols, or events which are grouped together on the basis of shared characteristics and which can be referenced by a particular name or symbol.” (p. 6). Naming a concept makes the concept understandable and useful, and is critical to discussing it.

Margolis and Laurence (2011) define concepts as the constituents of thought. Fodor (1998) considered concepts so fundamental to cognition that he declared that “the heart of a cognitive science is its theory of concepts.” (p. vii). Dogar (2015) suggests that “a concept is a generalization from experience.” (p. 3). Webster’s Dictionary defines a concept as “an idea, especially a generalized idea of a class of objects; a general notion” (Webster & McKechnie, 1979, p. 376).

Conceptual Understanding

Conceptual understanding occurs when broad concepts are revisited in different contexts and deepens through inductive reasoning. Thus, conceptual understanding depends upon people having the ability to generalize from their experiences—and argues for the need to *teach for transfer*. According to Earl (2006), conceptual understanding and cognition are related in that:

> Our understanding and interaction with the world involves concepts and our grasp of them. Our understanding that a given thing is a member of a given category is at least partly in virtue of our grasp of concepts, and so are our acts of categorizing. (p. 1).

Teaching for Conceptual Understanding

Erickson (2008) stated that “Concepts are the foundational organizers for curriculum design. They serve as a bridge between topics and generalizations. A conceptually organized curriculum helps solve the problem of the overloaded curriculum” (p. 23).

Bransford, Brown, and Cocking (2000) maintain that to develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application (p 16).

Donovan and Bransford (2005) concluded that “concepts must be placed in a conceptual framework to be well understood and take on meaning in the knowledge-rich contexts in which they are applied.” To deepen conceptual understanding and facilitate learning transfer, students should encounter the same concept in a variety of contexts (de Vries, 2010; Bransford, Brown, & Cocking, 2000).

The development of conceptual understanding includes placing content knowledge and skills within universal themes and engaging students in active learning (Erickson, 2008 as cited by Edwards & Edwards, 2013). Conceptual learning, therefore, implies an understanding of broad, overarching ideas in context, rather than the learning of discrete bits of content. Parker (2013) asserted that:

> There are two key parts to concept formation. Students begin by studying multiple examples of the concept to be learned, and the teacher helps them see the similarities across the examples. When the similarities are established in students’ minds, they form the concept. But the teacher needs to find examples that students of a particular age can grasp, and simplify the critical characteristics as needed.

Teaching for deep conceptual understanding in engineering and technology education therefore invites teachers and students to (a) place big ideas into thematic categories such as design, systems, modeling, resources, and human values; (b) identify how big ideas manifest themselves in a variety of apparent and familiar contexts; and (c) revisit these big ideas in contexts that may be more complex and less familiar.

Content Standards and Performance Expectations

Rather than focusing on teaching for deep conceptual understanding, professionals in education have instead developed and relied upon sets of discipline-based content standards, performance indicators, and high-stakes assessments mapped to these standards and performance indicators. Frequently, the standards are atomistic in nature.

Content standards are “descriptions of the knowledge and skills students should acquire in a particular subject area” (NRC, 2008) and standards have been developed within most school disciplines. These have largely been developed by highly regarded educators representing communities of interest (discipline-based practitioners). The excellent reputations of these highly experienced experts lend great credibility to their development efforts, but we are often impelled by standards (and the high-stakes assessments based upon them) into addressing competencies that even highly-educated people outside the community of practitioner-developers, might question as being necessary for *all* students to attain as part of their fundamental education.

Questionable examples from the Common Core Standards for Mathematics (NGA, 2010) include the following performance expectations:

> **HSN-CN.A.3:** Use conjugates to find moduli and quotients of complex numbers.
> **HSF.LE.B.5:** For exponential models, express as a logarithm the solution to $ab^{ct} = d$ where a, c, and d are numbers and the base b is 2, 10, or e.
> **HSA.APR.C.4:** Prove polynomial identities and use them to describe numerical relationships. *For example, the polynomial identity* $(x^2 + y^2)^2 = (x^2 - y^2)^2 + (2xy)^2$ *can be used to generate Pythagorean triples.*

Educational literature is replete with long lists of thoughtfully developed learning standards and performance expectations, employability skills, and 21st Century Skills (P21, 2007) — conceived by brilliant academicians who include compelling research-based justifications—which renders a contrarian argument to basing curriculum on standards difficult, perhaps futile.

A National Academy of Education (NAoE) Policy White Paper titled *Standards, Assessments, and Accountability* opines that "the political solution of adding in everyone's favorite content area topic created overly-full, encyclopedic standards in some states, or vague, general statements in others" (NAoE, 2009, p. 3). The NAoE indicated that findings from cognitive science research make it at least *theoretically* (emphasis added) possible to focus instruction on depth of understanding, but, the report cautioned that extrapolating from small-scale, intensive studies to full-system reform was an unprecedented task.

The emphasis on standards (and high-stakes assessments based upon them) has led to what has become a hugely profitable private-sector enterprise of developing standardized tests at all levels of the education continuum. In the US state of Texas alone, Pearson Corporation will have been paid $428 million for the current five-year assessment development contract (Weiss, 2015).

The Engineering and Technology Education Conceptual Knowledge Base

There are inconsistencies and confusion about the term "technology concepts." According to Kipperman (2009):

> There is wide consensus about the necessity of teaching technology concepts, yet technology concepts are not consistently defined in the literature and there is still much confusion in the technology education community with regard to what are technology concepts and how to teach technology concepts. Although various technology concepts such as design and systems are presented in different curricula and are taught in K-12, often the nature of technology concepts as big ideas are missing or get lost in the teaching of craft skills, knowledge and problem solving (design and make activities). (p. 279).

The International Technology Education Association (ITEA), now renamed the International Technology and Engineering Educators Association (ITEEA), attempted to identify core ETE concepts in developing the **Standards for Technological Literacy** (STL) to identify what students should know and be able to do to be technologically literate (ITEA, 2000).

The publication of STL was a major step forward in identifying educational outcomes needed for life in a technological world (ITEA, 2000). However, hundreds of benchmarks have been written in STL and in national and state STEM frameworks, and standards generally have been criticized as vague, repetitive, and poorly coordinated (NRC, 2008).

An alternative to developing standards-based curriculum is to invite curriculum developers and decision makers to think less atomistically (i.e., less in terms of specific standards-based performance indicators) and more holistically (i.e., more in terms of thematic big ideas) about what is important for all students to learn as part of their fundamental education.

From Standards to Thematic Ideas

As content standards have been developed in many disciplines to include myriad student performance objectives related to specific competencies, there has also been a move toward identifying overarching and thematic understandings in STEM disciplines to emphasize transferable “big ideas” which reoccur within different contexts.

In 1963, the Commission on Engineering Education and the US National Science Foundation initiated the **Engineering Concepts Curriculum Project**. The *Man-Made World* was a book that resulted from that project and as a seminal work, identified several powerful and transferable engineering concepts, among them modeling, feedback, and stability (ECCP, 1971).

The United States **National Academy of Engineering** committee on standards for K-12 engineering education reviewed eight prior studies and identified 16 categories of engineering concepts, skills, and dispositions for K-12 education. These included: Design, STEM Connections, Engineering and Society, Constraints, Communication, Systems, Systems Thinking, Modeling, Optimization, Analysis, Collaboration and Teamwork, Creativity, Knowledge of Specific Technologies, Nature of Engineering, Prototyping, and Experimentation (NRC, 2010).

The **National Assessment of Educational Progress** (NAEP) is a representative assessment of what U.S. students know and can do in various subject areas. In 2015, the NAEP Technology and Engineering Literacy Assessment was administered to 21,500 students in grades 8 and 12 (NAGB, 2016). The assessment consists of technological content areas and technological practices among which are design and systems, information and communication technology; and technology and society.

In a study titled *Formulating a Concept Base for Secondary Level. Engineering: A Review and Synthesis*, Custer, Daugherty, and Meyer (2009) identified thirteen major engineering concepts (among them design, systems, and modeling) that were drawn from a variety of sources, and by two focus groups of engineering experts (Sanders, Sherman, and Watson, 2012).

In a report published by the Association for Science Education in Great Britain titled *Principles and Big Ideas of Science Education*, international experts in science education identified "overarching concepts that cut across domains of scientific ideas" which include systems and modeling (p. 18; p. 23); and ethical, social, economic and political implications (p. 25). Notably, the report cautions that "further breakdown into a range of narrower ideas is, of course, possible but risks losing the connections between the smaller ideas that enable them to merge into a coherent big idea." (p. 18).

In an international research study titled ***Concepts and Contexts in Engineering and Technology Education*** (CCETE) (Rossouw, Hacker, & de Vries, 2010) five overarching areas of conceptual understanding were identified in engineering and technology: design, modeling, systems, resources, human values.. See Table 1.

Table 1. Themes and Sub-concepts

Themes	**Sub-concepts**
Design	Optimization and tradeoffs; criteria and constraints; iteration.
Modeling	Representational, explanatory, predictive.
Systems	Systems/subsystems; input-process-output; feedback and control.
Resources	Materials, energy, information, time, tools, humans, capital.
Human Values	Sustainability; technological assessment; creativity/innovation; ethical decisions.

The ***Comparison of Perceptions*** study (Hacker, 2014; Hacker and Barak, 2017) furthered the work accomplished by the CCETE study by adding more specificity about the most important ETE concepts and skills within the five overarching thematic categorie**s**. The study determined where consensus existed (using two consensus factors: Interquartile Range, IQR; and frequency distribution) among two groups of experts, both concerned with educating students about engineering and technology**—**university-based academic engineering educators (AEEs, n=18); and high school classroom technology teachers, (CTTs, n=16). Using modified Delphi research methodology, the 34 expert and highly experienced educators were surveyed about their perceptions of the most important underlying ETE concepts and skills within the five ETE thematic categories. The study identified a set of 38 domain-specific competencies (12 related to design; six related to modeling; six related to systems; seven related to resources; and seven related to human values) that all high school students in the U.S. should learn as part of their fundamental education. These competencies were rated and ranked by importance. Whole-group consensus on the importance of survey items is shown in Table 2.

Table 2. Comparison of Perceptions Study Items Reflecting Strongest Whole Group Consensus about Important ETE Concepts and Skills Relating to Design (D), Modeling (M), Systems (S); Resources (R); and Human Values (HV).

ITEM	Survey Item Wording	IQR	*freq.*
R7	Identify and discuss environmental, health, and safety issues involved in implementing an engineering project.	0.79	100
M1	Use representational modeling (e.g., a sketch, drawing, or a simulation) to convey the essence of a design	0.82	100
D6	Explain why a particular engineering design decision was made, using verbal and/or visual means (e.g., writing, drawing, making 3D models, using computer simulations).	0.91	94.1
HV6	Show evidence of considering human factors (ergonomics, safety, matching designs to human and environmental needs) when proposing design solutions.	0.91	94.1
R4	Safely and correctly use tools and machines to produce a desired product or system.	1.00	95.3
D1	Iteratively design and construct a model or full-scale product, system, process, or environment that meets given constraints and performance criteria.	1.09	82.3
R3	Evaluate technological and scientific information for accuracy, and authenticity of sources.	1.15	87.8
D9	Engage in a group problem-solving activity to creatively generate several alternative design solutions and document the iterative process that resulted in the final design.	1.34	85.3
R6	Identify and discuss privacy issues involved in using information resources.	1.31	88.3
S1	Label and explain a diagram of a familiar technological system (e.g., a home heating system) that specifies inputs, processes, outputs, feedback, and control components.	1.26	88.2
S2	Identify and explain the function of the interacting subsystems that comprise a more complex system.	1.27	82.4
D2	Solve engineering design problems by identifying and applying appropriate science concepts.	1.23	88.2
D3	Solve engineering design problems by identifying and applying appropriate mathematics concepts.	1.3	82.3
M2	Develop a fair test (changing only one factor at a time) and use it to analyze the strengths and limitations of a physical or virtual model of a design.	1.29	80.0

Note: For a more in depth statistical analysis of the study results, see Hacker and Barak, 2017.

In four of the 38 survey items in the Comparison of Perceptions study, significant differences in the perception of importance (at the $\alpha = 0.05$ level) were found between academic engineering educators and classroom technology teachers. These are shown in Table 3.

Table 3. Significant Differences in Median Item Ratings between AEEs and CTTs based on the Mann-Whitney U Test.

ITEM	Survey Wording of Item	AEEs (n=18) Medians	CTTs (n=16) Medians	Mann-Whitney U Value	D.f.	p -value Exact Sig. (2-tailed)
D2	Solve engineering design problems by identifying and applying appropriate science concepts.	6.35	5.80	81.00	33	.012
D11	Provide examples of how psychological factors (e.g., bias, overconfidence, human error) can impact the engineering design process.	5.27	4.69	91.00	33	.049
S5	Explain the difference between an open-loop control system and a closed-loop control system and give an example of each.	5.17	5.85	88.50	33	.040
S6	Develop and conduct empirical tests and analyze system and analyze test data to determine how well actual system results compare with measurable performance criteria.	6.21	5.36	89.00	33	.046

Is there Still A Place for Disciplinary Concepts and Skills?

The argument that standards and key ideas should be limited in number and contextualized within holistic overarching ideas does not contravene the need for students to learn salient disciplinary concepts and skills. In the following case study, *Palantir*, a forward-looking state-of-the-art engineering company, sees domain knowledge as certainly still necessary, but clearly not sufficient.

A Case Study: Palantir Corporation

Palantir (www.palantir.com) is a company with an engineering culture that “builds products that make people better at their most important work — the kind of work you read about on the front page of the newspaper, not just the technology section” (Palantir, 2016a).

> Engineers build things that solve problems. You don't have to be a computer scientist or have any particular degree to be an engineer. You just have to speak up when things aren't right, evaluate ideas on their merits, and build things that fix what's broken. At Palantir, we're all engineers, and we're focused on solving the hardest problems we can find (Palantir, 2016b).

Palantir interviews prospective employees. The interviews include technical questions about data structures, algorithms, and software engineering. For Palantir, domain knowledge is very much the coin of the realm. One interview focuses on systems design.

> At Palantir, many of our teams give a systems design interview along with an algorithms interview and a couple of coding interviews. We don't expect anyone to be an expert in all three disciplines (although some are). We're looking for generalists with depth—people who are good at most things, and great at some. If systems design isn't your strength, that's okay, but you should at least be able to talk and reason competently about a complex system. (Palantir, 2016c).

Undoubtedly there is still a place for teaching and learning disciplinary skills and concepts at Palantir; but Palantir and many contemporary companies have a strong social conscience and expect their employees to contribute to making the world a better place. Palantir's mission is about "protecting privacy and civil liberties, to promoting open software, to pursuing philanthropic engagements, to a host of other initiatives; we put our values to work in the service of making the world a better place, every day." To that end, the company is creating slavery-free supply chains, addressing small-plot farmer food security, improving global health, fighting disease outbreaks, and providing humanitarian relief in the wake of natural disasters (Palantir, 2016d).

Palantir looks for employees who understand the problem they are asked to solve, break it down into manageable sub-problems, try different approaches, model solutions, and ask questions (Palantir, 2016e).

But consider the overarching areas of domain knowledge that Palantir seeks: The competencies are related to design, systems, modeling, resources, and human values (not surprisingly, those that were identified in the CCETE and Comparison of Perceptions studies). These overarching themes are transferable to many different contexts; and it is *context* that enables learners to make sense of their learning—to see how knowledge and skill can be applied in ways that make the world a better place.

Recalling the Fundamental Purposes of Education

Historically, formal education was propagated by institutions as a way of spreading and preserving their traditions (Nagdy and Rose, 2016). The goal of education in the Greek city-states was to prepare the child for adult activities as a citizen. According to Plato, the education of mind, body, and aesthetic sense was so that the boys "may learn to be more gentle, harmonious, and rhythmical, and so more fitted for speech and action; for the life of man in every part has need of harmony and rhythm" (Guisepi, 2012). But evidently, not all pedagogy was gentle and harmonious. According to Guisepi (2012), on an ancient Egyptian clay tablet discovered by archaeologists, a child had written: “Thou didst beat me and knowledge entered my head.”

Public education was and is often organized and operated to be a deliberate model of the civil community in which it functions (Nzabihimana 2010). Dewey (1897) saw schools not only as a place to gain content knowledge, but also as a place to learn how to live. The purpose of education was not so much the acquisition of a predetermined set of skills, but rather the realization of the student's full potential and the ability to use those skills for the greater good. After 1910, vocational education was added, as a mechanism to train the technicians and skilled workers needed by the expanding industrial sector (Church and Sedlak, 1976).

What we can too easily forget when focused on specific subject matter is how the enterprise of teaching and learning should at the end of the day, be fundamentally driven by (and support) the overall purposes of education.

Alfie (1966) was a film that was popular in the mid-1960s starring British actor Michael Caine. The main character, Alfie, was a Cockney chauffer who was a womanizer and a narcissist. After his misadventures, at the film’s end, he reflects on his life in the song “What’s it all about, Alfie?” (Bacharach and David, 1966).

> What's it all about Alfie?
> Is it just for the moment we live?
> What's it all about
> When you sort it out, Alfie?

What would be revolutionary (well, perhaps not revolutionary but certainly provocative and conceivably threatening to groups protecting vested interests), would be to begin our search for curricular significance with a re-examination of the fundamental purposes of education—what Alfie’s education should have been all about. We educators help learners:

Cultivate mind, body, and spirit
Respect and practice honesty and civility
Earn a living
Augur toward tolerance and social equity
Question prejudices
Derive optimal fulfillment from life’s experiences
Make the world a better place.

Education for today’s learners should not lose sight of these fundamental purposes—and it is these purposes that provide the strongest rationale for education.

Educational Change as a Response to Societal Change

What is deemed to be important for people to learn, changes over time and evolves in relation to societal waves of change. During the period of exponential growth in the industrial/manufacturing economy in the 19th Century, Johann Heinrich Pestalozzi developed a whole-child approach to education involving development of three aspects of a person: head, heart, and hands (Lindgren, 2013) and established an institute in Yverdon, Switzerland, that melded vocational and general education.

John D. Runkle, when president of the Massachusetts Institute of Technology (from 1870–1878), integrated Pestalozzi's ideas with those advocated by the Imperial Technical School in St. Petersburg, Russia. Runkle became a proponent of incorporating tool instruction into engineering education and his ideas were further developed by Calvin Woodward who is largely credited with being the "father of manual training" (Bennet & Bawden, 1910). During the Great Depression, manual training enjoyed widespread popular and political support as it prepared future workers for their jobs (Metcalf, 2007).

The new skill set necessary for a knowledge and service economy has been conceptualized by the US National Research Council into three domains: **cognitive** (cognitive processes and strategies; knowledge; creativity); **intrapersonal** (intellectual openness; work ethic; self-evaluation); and **interpersonal** (teamwork and collaboration; leadership) (Pellegrino, 2012). Lawrence Katz, a labor economist at Harvard asserts:

> The economic return to pure technical skills has flattened, and the highest return now goes to those who combine soft skills—excellence at communicating and working with people—with technical skills, but you need both, in my view, to maximize your potential (Kristoff, 2015).

Learning Important Concepts through Context-Based Learning

If our students are to be competitive in the workplace and successful in becoming fully functioning individuals, the content and learning opportunities that schools provide for students will have to emphasize cognitive, intrapersonal, and interpersonal competencies. Of critical importance is that the ways in which student tasks are designed must facilitate the development of these competencies. The temptation for curriculum decision-makers to avoid is to become enamored of curricula focused on atomistic learning standards rather than on overarching, thematic ideas that are revisited in contexts suited to the interests of the learners.

As opposed to starting the curriculum design process with "enduring understandings" (Wiggins & McTighe, 1998), in engineering and technology education, curriculum designers might consider starting with **contexts** that are perceived as by students as relevant and compelling and embed thematic ideas and related performance expectations within them. Choosing contexts wisely can serve not only to teach contemporary domain-specific skills, but can also refocus learning to reflect the fundamental purposes of education (make the world a better place, earn a living, respect honesty and civility, etc.).

Context-based learning (assuming instructional contexts are chosen to be important and relevant to learners) can promote high student engagement. Our goal as instructional leaders is to design learning environments that enable students to feel so engaged that they are in a state of "flow."

Flow Theory

Once learners are engaged and inspired, once learners are totally absorbed in an activity, learning becomes intrinsically rewarding. Psychologist Mihaly Csikszentmihalyi calls this being in a state of "flow." According to Csikszentmihalyi (2004):

> The best moments in our lives are not the passive, receptive, relaxing times. The best moments usually occur if a person's body or mind is stretched to its limits in **a voluntary effort** to accomplish something difficult and worthwhile. Flow is being completely involved in an activity for its own sake. People are at their optimal level of happiness when they are in an engaged state of "flow."

When a person is in a state of flow (Csikszentmihalyi, 1990):

- Time flies.
- There is complete involvement in the task. The person is focused, concentrated.
- The person knows that the activity is doable. Skills are adequate to the task.
- Motivation is intrinsic—whatever produces flow becomes its own reward.
- The activity becomes an end in itself.

We have all found ourselves in a state of flow at some point, doing what we love to do: writing, playing music, skiing, dancing, exercising, reading, painting, building things, solving math problems, doing research. George Leonard, a past president of the humanistic Esalen Institute in Big Sur, California and a former editor of Look Magazine, wrote a book titled *Education and Ecstasy* (Leonard, 1968). His premise was that learning could be so enhanced that students would find it to be *ecstatic*—as ecstatic as a 16-year old learning how to drive!

A great reward for us as educators would be to see the joyful learning that results from our creation of ecstatic learning environments in which our students are in a state of flow—where they have control over their own learning and where learning is so meaningful that they are inspired to plumb further depths on their own.

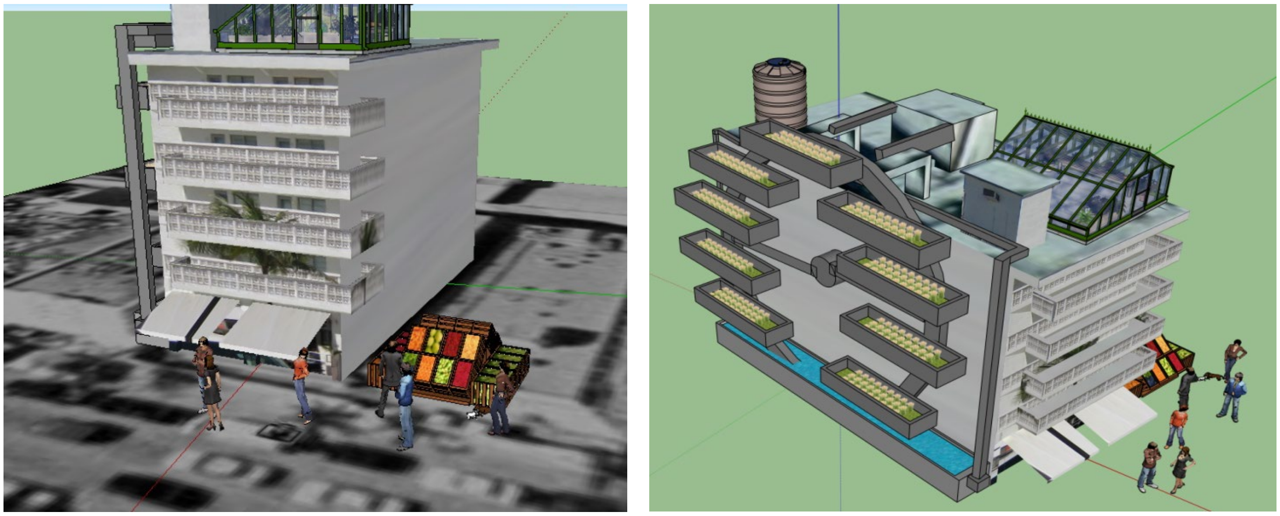
So, paraphrasing the words to Alfie, we might ask, "What's it all about for us, as educators; as technology and engineering educators?" Most would agree that it's about learning that is purposeful, engaging, meaningful, authentic, personally and societally relevant, and joyful. We collectively have the capacity to make learning ecstatic for our students.

Engineering for All: A Case Study of a Curriculum Focused on Authentic Social Contexts

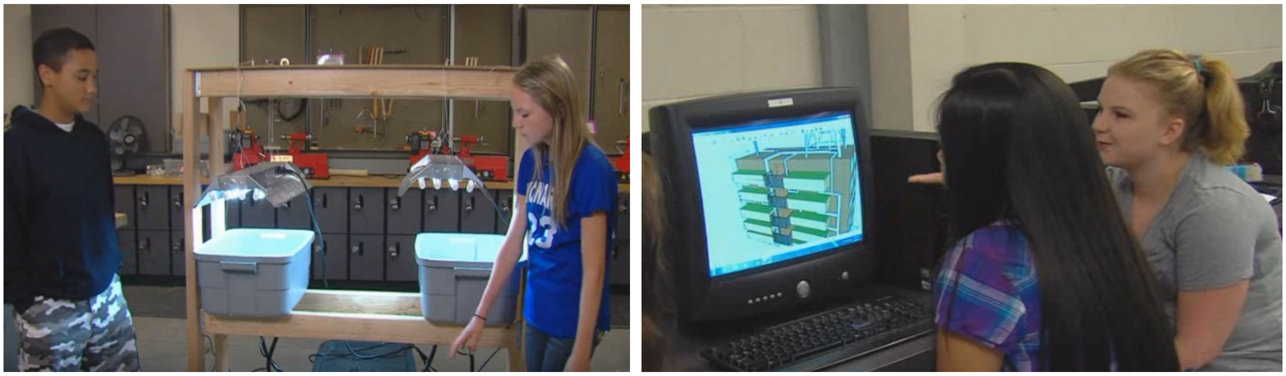
Engineering for All (EfA) (Hofstra, 2016) is a US National Science Foundation-funded project (Grant # DRL-1316601) that introduces middle school students to engineering, not only as a career path, but for its potential as a social good. Hofstra University in New York and the International Technology and Engineering Educators Association are leading the Project. EfA meets the needs of today's students who are civic-minded, team-oriented, and want to make a difference in the world (Gleason, 2008). The Project represents a new paradigm for ETE in that learning is situated in contexts that relate to *authentic social issues*—those that are felt by students to be important and relevant. EfA "big ideas" were contextualized in two important social contexts: Food and Water.

The EfA age-appropriate hands-on engineering design activities oriented toward solving problems that are globally significant have the potential to *engender a state of flow* in students and to motivate them to probe deeply into areas of just-in-time learning needed to address the design problem from a more informed perspective (Hacker & Burghardt, 2009). EfA learning activities have been explicitly designed to relate to the fundamental purposes of education, particularly to help students see that they can indeed make the world a better place.

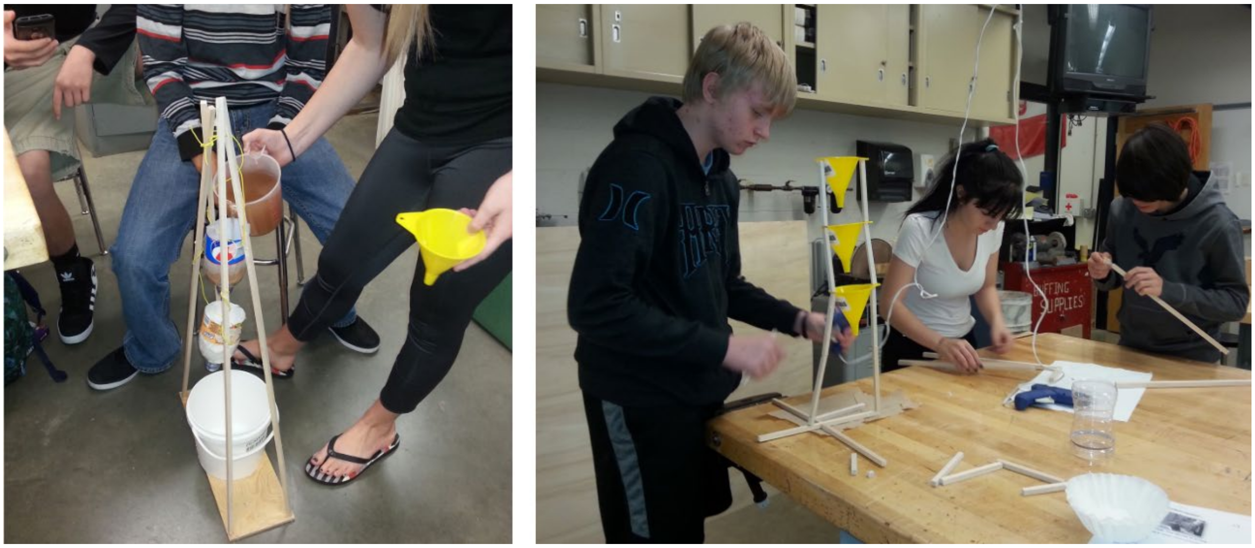
Two engineering design-based six-week curriculum units have been developed, classroom tested nationally, evaluated, and revised. The units address urban food scarcity (designing hydroponic vertical farming systems); and water contamination (designing filtering systems to provide potable water to populations in need). A video introduction is at: https://www.youtube.com/watch?v=OQkowF2g53Q&feature=youtu.be. EfA's expectation is that students will develop predispositions to forge a sustainable future and learn that engineering is a route to engage in socially significant work.



Two middle school student vertical farm designs_Figure 1. Images courtesy of Stephen Haner



Students designing hydroponic and vertical farming systems_Figure 2. Images Courtesy of Stephen Haner



Water unit students designing filtering systems_Figure 3. Images courtesy of Sandy Cavanaugh

The instructional intent of EfA is to illustrate how instruction in engineering and technology education can address important ETE ideas and still reflect the fundamental purposes of education. The curriculum units address a limited and manageable number of big ideas and revisit these ideas within both the Food and Water units. The major EfA Project drivers are to:

- Promote the potential of engineering as a social good.
- Illustrate how several overarching themes (i.e., design, modeling, systems, resources, and human values) are central to engineering and technological development.
- Use hands-on engineering activities in authentic contexts to convey STEM ideas and practices.
- Use informed engineering design as the core pedagogical methodology (see http://www.hofstra.edu/pdf/academics/colleges/SEAS/ctl/ctl_informeddesign_001.pdf).

Teachers reported that they were surprised at how unaware their students were about the social issues discussed. Teachers also learned about these issues. Following are some teacher comments about EfA:

- Students care about problems that can affect their lives and want to do something proactive about it.
- The social values aspect of it was something that jumped off the page. I had students wanting to go to other countries and help with the water crisis problem.
- Students were very surprised by the extent of the global water crisis and the negative effect on children.
- Students were surprised that the areas they live in could be considered a food desert.
- Students began discussing community gardens and pop-up farmer's markets as a way to bring in fresh fruit and vegetables to the area.
- All the themes were in there. Some big ideas were covered very well. Modeling was huge, so was systems.

EfA students commented that:

- We learn how to help people.
- We learn how to make water filters for people who don't have them.
- We are so careless with our water.
- This is what we came up with. This is what kids our age can do. It was a proud moment.

SUMMARY AND CONCLUSIONS

As disciplinary content standards have been developed to include hundreds of atomistic student performance objectives, the challenge to curriculum designers of embedding these in meaningful student experiences has become apparent. Several recent projects have tried to reduce the number of student performance expectations and to situate "big ideas" within a thematic conceptual framework.

To be well understood, concepts should be placed in contexts that are engaging and relevant to learners and "big ideas" are best internalized when revisited in several different contexts. Deep conceptual understanding depends upon people having the ability to generalize from their experiences—and this argues for the need to *teach for transfer*.

A thematic approach focused on identifying a manageable number of important concepts and skills related to five ETE domains: design, systems, modeling, resources, and human values can focus instruction on recurring and overarching transferable "big ideas" and facilitate a more holistic understanding of engineering and technology. A recent study comparing the perceptions of university engineering educators and high school technology teachers identified 38 important competencies within these five ETE domains. These can provide a basis for ETE curriculum design.

When we design instructional interventions for today's learners, we should not lose sight of the fundamental purposes of education—those that define what education should be all about. Choosing contexts wisely can serve to refocus learning to reflect the fundamental purposes of education and facilitate learning of contemporary domain-specific skills in settings that are so inspiring to students that they are in a state of "flow" when learning.

Two case studies have been offered as examples. The first exemplifies how a cutting-edge technology company (Palantir) looks for new hires with a mix of cognitive, intrapersonal, and interpersonal skills. The second describes a new middle school curriculum model, *Engineering for All*, that integrates thematic concepts within social contexts that are authentic and engaging to today's learners.

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