The Evolution of the E4USA (Engineering for US All) Engineering Curriculum

Dr. Kenneth J. Reid
R.B. Annis School of Engineering
University of Indianapolis
Indianapolis, IN, USA
ORCID: 0000-0003-2337-7495

Tina M. Griesinger
Engineering Education
Virginia Polytechnic Institute & State University
Blacksburg, VA USA
ORCID: 0000-0001-5313-5265

***Abstract*— This innovative practice full paper will describe the program's curriculum, the feedback received from teachers and evaluators, and the revisions and iterations of the e4usa curriculum.**

The nation has experienced decades of efforts geared toward alleviating a shortage of engineering students entering university programs, with some efforts designed to help alleviate technical literacy challenges or public misperceptions of engineers. Countless efforts to help alleviate the problem have been implemented, from summer camps, teacher professional development activities, and through the development of technical courses that are best described as pre-engineering courses. Programs such Project Lead the Way are technically focused courses designed as pre-engineering courses, meant to prepare future engineers as they begin an engineering program of study in a university. While these courses are arguably successful for students who seek to pursue an engineering degree, they are not necessarily designed for a broad audience of students who have little to no understanding of engineering.

The NSF-funded initiative Engineering for US All (e4usa) curriculum is intentionally designed for a diverse and inclusive body of students. The intent of the program is to engage in an *examination* and *exploration* of 'engineering' as both a noun (the profession) and verb (to engineer). The successful student is one who can "think like an engineer" within any profession; not simply to increase the number of engineers. The focus is 'what is engineering' and 'who is an engineer'. Engineering is considered as not only math, science, and design, but as an entity which must include ethics, the societal impact of engineering, communications and teamwork, and prototyping, testing, etc. Unique to this curriculum are the ideas – both in teacher professional development and within the curriculum – that failure is welcome, that problems are open-ended, and that the engineering classroom likely deals with the development of multiple solutions in parallel.

The paper will describe the curriculum, focusing on the features that make this course suitable 'for all.'

Keywords—Engineering in K-12, diversification, design, professional skills

I. INTRODUCTION

While much attention has been paid to introducing and integrating engineering into pre-college curricula, multiple reports have detailed the difficulty in doing so. Committee reports from the National Academies show that making a systemic difference will be difficult without specific educational standards and preservice teacher training. The Next Generation Science Standards (NGSS) [1] introduce engineering concepts framed within science standards, and the ITEEA has published engineering and technology standards for K-12 [2]. However, engineering rarely appears on standardized exams qualifying students for graduation, therefore remaining outside of the core curriculum. Successful integration of engineering curricula goes beyond increasing student enrollment in engineering: goals include improving technological literacy, raising awareness of engineering, and developing a problem-solving mindset for all students.

The curriculum for the NSF-funded initiative Engineering for US all was intentionally designed 'for us all'. The intent is to democratize engineering; to introduce engineering as beneficial for any student, not just students planning to major in engineering. The goal behind the e4usa curriculum is to develop the idea of an engineering mindset, rather than simply producing more engineers. The curriculum has been through its pilot year, albeit piloted as the COVID-19 pandemic hit and forced drastic changes in the pre-college classroom.

The curriculum's initial design was based on the First Year Engineering Classification Scheme [3], used to classify all possible content found in first-year, multidisciplinary Introduction to Engineering courses in general-admit (non-direct-admit) engineering programs. The curriculum provides progressively larger engineering design experiences relating to student fields of interest and real-world problems. Course objectives are organized into four major threads (Connect with Engineering, Engineering in Society, Engineering Professional Skills, and Engineering Design).

This curriculum is innovative, and this paper will describe a curriculum designed not as a pre-engineering curriculum, but a curriculum that allows exploration of the 'why' of engineering while introducing authentic engineering design. It will present a curriculum closely aligned with engineering habits of mind as described by the National Academies [4]. These include (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) ethical considerations.

This paper presents unique successes in the program and changes to the pilot version of the curriculum based on lessons learned from the COVID outbreak. This should be of interest to teams developing pre-college materials, to pre-college engineering programs, and to university programs interested in articulating credit with a goal of diversifying engineering.

II. Course Learning Outcomes

The e4usa curriculum with course outcomes was conceived during a series of workshops and meetings in 2018. The course learning objectives were initially developed based on the objectives and in consultation with the First-Year Engineering Classification Scheme [3] and framed by El Sawi's curricular development framework [5].

The course outcomes (COs) were developed within categories or 'threads', each represented by a color (there is no significance of the specific colors). The overall curriculum is designed as a spiraling curriculum; concepts are introduced and the class is given multiple opportunities for hands-on exploration or design, then brought back to reflect upon the experience. Student teams progress through complete design experiences multiple times in the curriculum with more autonomy. This necessarily implies that, in any classroom, multiple unique projects are in development as the class progresses through the designs of their solutions.

The threads (shown in Table 1) allow for groupings of similar course objectives.

A. Red thread: Connect with Engineering

The focus of the red thread is in the discovery of engineering beyond "math and science". This involves the exploration of engineering identity, engineering careers, problem solving, and critical thinking.

B. Yellow thread: Engineering in Society

The focus of the yellow thread is the exploration of society and engineering, and how society and engineering intersect. This includes examining engineering solutions as having consequences within society and the environment, and a consideration for ethics when finding a solution to a problem.

C. Blue thread: Engineering Professional Skills

Objectives in the blue thread focus on professional skills, with a focus that is very similar to those commonly found in first-year university programs. Ideas in the blue thread include effective teamwork and communication.

D. Green thread: Engineering Design

The green thread will lead students through an engineering design process. Engineering design is approached step-by-step, with progressively less guidance. It should be noted that the process itself isn't modeled after any specific design process; different processes are very similar and lead students through practically the same iterative steps [6].

Students will progress through two to three (depending on the path through the curriculum) complete designed solutions to specified problems, growing in complexity, scope, and autonomy.

The course is intentionally designed for any student. The math prerequisite for the e4usa course is algebra 1 with no other prerequisites (such as computer skills or CAD).

III. Course Modules

The e4usa curriculum is designed as a full year course with progressively less structure as student teams veer into more advanced engineering solutions.

Unit 1 - Engineering is Everywhere

Students view engineering (verb) through an exploration of the progression of products and technology. This lesson asks teachers to walk through the progression of the formats through which we listen to music: from albums, through 8-track tapes (note that few students have ever seen an 8-track) to downloads.

	Album	Cassette	CD	Download
1983	44.6%	47.8%	0.5%	
1988	8.5%	54.1%	33.4%	
1993		29%	64.8%	
1998		10%	83.3%	
2003		1.7%	93.3%	
2008			62.3%	30%
2013			30.4%	60%

Figure 1: Music Purchases by Format [6]

They discover a definition of engineering (profession) by relating it to their future plans and engaging in small-scale challenges.

The lessons in Unit 1 ask students to think of their dream job and lead them through relating that job to engineering, while intentionally not advertising every profession as engineering. Students are then asked to identify someone who might be considered an engineer, and why. Students are then asked to consider this person's life when they were at the student's age, and imagine their life. Through these activities, students discover their continually evolving) engineering identity. Care is taken not to convey the message that everyone is an engineer.

Unit 2 - Engineering is Creative

In Unit 2, the class engages in an engineering challenge tethered to a selected global issue; in this case, water filtration which is based on a discussion of the NAE Grand Challenges [7]. After the formation of teams and lessons on effective teamwork, teams go through the steps in an engineering design process step by step. Teams identify constraints and criteria for success, and brainstorm and select design solution(s) to pursue. Teams build prototype(s) and develop a test plan to test each prototype. Finally, teams have to discuss how their design can be improved and how to communicate their design to stakeholders successfully. In Unit 2, all students in the class are working on the same design challenge, so teams may develop similar designs.

Throughout Units 1 and 2, students engage in multiple short activities in groups, then in teams. The distinction between 'group' and 'team' is important, and is explored later in the curriculum. Activities include the design and construction of a robot arm, a study of shoe soles, and a dissection of a physical device. The discussion can focus on different engineering

TABLE 1: E4USA STUDENT OUTCOMES

	Connect with Engineering	
C.A	Iterate and evolve the definition of what it means to engineer and be an engineer.	
C.B	Recognize the value of engineering for all regardless of one's potential career.	
C.C	Explain and apply ethical considerations when exploring an engineering problem.	
	Engineering in Society	
S.A	Explore the impacts of past engineering successes and failures on society as a whole.	
S.B	Recognize and investigate the world's greatest challenges and the role that engineering plays in solving these challenges (e.g., Engineering Grand Challenges, UN sustainability goals, etc.).	
S.C	Integrate diverse disciplinary thinking and expertise to inform design solutions that add value to society.	
S.D	Identify and analyze issues when bringing a solution to scale.	
	Engineering Professional Skills	
P.A	Use various engineering communication methods.	
P.B	Collaborate effectively in a team.	
P.C	Develop, implement, and adapt a project management plan.	
	Engineering Design	
D.A	Identify and describe a problem that can be solved with a potentially new product or process.	
D.B	Identify appropriate stakeholders and content experts and evaluate their input.	
D.C	Plan and conduct research by gathering relevant and credible data, facts, and information.	
D.D	Model physical situations using mathematical equations.	
D.E	Evaluate solution alternatives and select a final design by considering assumptions, tradeoffs, criteria, and constraints.	
D.F	Use and recognize when to use computational tools.	
D.G	Create a prototype.	
D.H	Create and implement a testing plan to evaluate the performance of design solutions.	
D.I	Apply iteration to improve engineering designs.	
D.J	Articulate and reflect on how an engineering design process could be applied to solving a problem.	

manufacturing the product, ergonomics, etc.

The focus of this extended introduction is accurately described by Cunningham and Lachapelle: “In order to increase the interest of students-particularly those who are underrepresented in engineering and science as fields of study and as future career opportunities, educators should help students see the relevance of what they are learning to the real world and see themselves filling such roles in the future world.” [8]

The red and blue threads are prominent and heavily woven throughout Unit 1, emphasizing the ‘Connect with Engineering’ and ‘Engineering Professional Skills’ portion of the curriculum. Unit 2 continues emphasizing the blue thread, while introducing the green thread, ‘Engineering Design’ which begins to emerge as students begin to focus on their designs.

Unit 3 - Engineering is Human-Centered and

Unit 4 - Engineering is Responsive

Units 3 and 4 engage students in their first venture through a design to solve a problem for a local stakeholder. Teachers lead teams of 3-4 students to select a local problem to solve through research, sketching, and prototyping. This process encourages teams to appreciate the question “What is the real problem?”

Unit 3 begins with the identification of student teams (as opposed to groups) and the identification of an external stakeholder. Teams will engage the stakeholders with a field trip, then go through concept generation and selection. The unit culminates in a Designathon, where students, parents, and community members review designs and provide feedback. This feedback is the foundation for Unit 4.

Unit 4 begins with a Designathon debrief and a discussion on how to incorporate feedback. Teams continue to work on developing their solutions for the identified problems. Formal presentations to stakeholders and reflections round out these units.

Units 3 and 4 in tandem represent the first time through an engineering design process for many students. Units 5 & 6 and Unit 7 will allow the same process for a more open-ended problem.

Unit 3 concentrates on teams, continuing with a primary focus of ‘Engineering Professional Skills’ and ‘Engineering Design’ (blue and green threads).

Unit 5 - Engineering is Intentional and

Unit 6 - Engineering is Iterative

Community issues are the focus of Units 5 and 6; teams of 3-4 students identify a global issue and an associated local problem related to that global issue. Units 5 and 6 takes students through a design process for a second time, and examines each step more thoroughly. Students are challenged with questions challenging them to consider engineering in a global, societal sense: what inventions have changed the world? Why should we be concerned with ethics in design? Why consult with deep and diverse experts?

Student teams engage in all aspects of the design process during this unit. Students build, test, and optimize a prototype of the solution designed. Students should iterate: re-designing a solution based on results from a test plan.

Unit 6 focuses on the development of the prototype and the design of effective testing. The prototype proposed in Unit 5 is designed, critically examined, built, and tested.

Unit 7 - Engineering is Personal

Students examine their day-to-day lives to find problems that can be tackled by student teams. The process in Unit 7 leading to a design solution is student-driven, teacher-guided, and highly informed by the experiences from the previous quarters. This approach is an open-ended co-creation and is truly open-ended. Two modes are offered: completely student driven or teacher-guided project selection. Once problems are selected, students go through each step of a design process to develop a solution to that problem.

Unit 7 is a change in paradigm for teachers, where they inherently do not know the answers to these open-ended problems. The teacher serves as a coach, facilitator, networker, or someone to encourage and help guide the team as they discover how to solve problems as they appear. Final solutions are documented and presented.

Although the initial intention of the curriculum design was to progress through Units 5, 6, and 7, feedback led to a change, where teachers could choose whether they would continue through Unit 5 – Engineering is Intentional and Unit 6 - Engineering is Iterative, or move to Unit 7 – Engineering is Personal for the remainder of the semester, focusing on a student led, open-ended approach. The choice largely depends on how comfortable the teacher is with a more student-led, open-ended approach.

Unit 8 - Engineering is Reflective

Unit 8 represents an opportunity to reflect and present on the cumulative accomplishments through the year. Lessons have students reflecting and presenting through writing and presenting to an audience of teachers, parents, and community members. This offers the teacher and school a chance to showcase student accomplishments, and is an ideal venue by which to promote technological literacy.

IV. History of the Course

The e4usa curriculum was piloted in the 2019-2020 academic year in nine schools throughout the United States.

Teachers attended a two-week, in-person professional development event in the prior summer. The PD event provided multiple hands-on activities for the teachers to experience themselves prior to introducing the activities to their students. Each of the four threads were also covered in detail, connecting each activity to the corresponding threads. For example, teachers paired up with each other as their students would, then completed the Product Archaeology activity from Unit 1, dissecting everyday household items, providing insight on potential design decisions. Items were donated and purchased in thrift stores. Tools were provided, and safety glasses were required (all to mirror the student experience). During this process, the teachers were able to recognize the connection to the red and green threads and they could easily take this activity back to the classroom for their own students, having already experienced the activity themselves. As teachers reviewed their now-destroyed equipment, discussion topics were explored, including "Think about the environmental impact resulting from this [clock radio]. Why is there so much plastic? Should it be recyclable? If it were, would any of it be recycled?" and "Consider the screws that were really tough to extract. Why would this be designed in this way?" Finally, teachers engaged the discussion on different engineering disciplines involved in the design of the items, with emphasis in looking beyond electrical and mechanical; for example, petroleum (in plastics), industrial, materials, etc.

The PD wasn't limited to instructing teachers how the curriculum would work. In the spirit of "us all," teachers were challenged with social implications of teaching engineering. The PD featured rich discussions of implicit bias and stereotype threat, and their relation to teaching engineering classes.

The Engineering Design Process Portfolio Scoring Rubric (EDPPSR) also was introduced during these weeks of professional development, allowing teachers the opportunity engage with a student facing demo project.

Teachers also gathered in a face-to-face mid-year workshop which allowed the cohort to share successes and failures, and allowed for more hands-on training. Most teachers were beginning the engineering design process, so engineering design was emphasized.

The first cohort of teachers began the year with great success. Teacher and student interactions were very positive; teachers engaged with the team through Canvas (the LMS in use), and teams were generally on track. As with all other educational programs, the COVID-19 pandemic hit in March of the initial year. Fortunately, the e4usa team was able to keep in contact with the initial teacher cohort. The rest of the academic year played out very differently in different locations, from Zoom sessions with kits delivered to each student's home to classes that were outright cancelled. During the spring semester of 2021, many of the pilot year teachers reported that they were only able to complete Unit 4 or Unit 5 and were unable to exercise the improved flexible approach to the curriculum.

During the month of April 2020, the curriculum team began to collaborate with TeachEngineering (TE) and modified the existing curriculum format to fit TeachEngineering's template for the website. After adjusting all units and lessons, the teachers were given access to the site and were then able to easily access the curriculum. They were provided the opportunity to add teaching tips to the TE pages to share amongst one another who were also teaching the curriculum. These tips proved valuable during the pivot to online teaching during COVID.

Although certainly blindsided by the abrupt modality shift, teachers and students both stepped up to the challenge. The e4usa curriculum is situated in project teams, which calls for the integration of atypical projects. Along with online curriculum delivery, teachers were able to adapt and find appropriate projects for their students. For example, an e4usa teacher embraced the opportunity afforded by a pandemic and provided an opportunity for her students to work on a PPE project, fitting an eye care exam room's clinic with protective shields.

The second annual summer professional development opportunity was different due to COVID and was facilitated entirely online. The PD was developed and offered in two different versions, providing flexibility with their other summer obligations. The "sprint" model featured a condensed, fast-paced version, with all content over a two-week period. For other who wanted a slower pace which was provided during multiple weeks, a "marathon" version was provided, spreading the content over 4 weeks. The second cohort of teachers were nearly evenly split in their selection.

Regardless of which format was chosen, each teacher was mailed a professional development kit, which contained all necessary parts, packaged by lesson, allowing them to complete the assigned activities in a virtual setting, mirroring a potential pedagogical strategy they may be employing in the academic year. The activities in each kit were used to support interactive zoom modules.

The second year of the curriculum was also successful given a full academic year dealing with the COVID-19 pandemic. The lack of any face-to-face interaction meant greater difficulty establishing a community of practice. Mentor teachers and e4usa investigators serving as university liaisons kept in contact with all new teachers. Teachers were encouraged to share resources, and each lesson and activity was labeled with distance learning suggestions, describing modification teachers could make to help at a distance. Social events were added, such as a monthly happy hour, to encourage a sense of community. Teachers expressed deep appreciation toward the end of the year at an end of the year online event.

V. Teachder and Student Feedback

Student focus groups of 3-4 students were conducted, and university liaisons had the opportunity to interact with students in Zoom classrooms. These observations and teacher feedback showed that the class was generally successful. For example:

> "I do see myself as an engineer. Just what everyone else is probably gonna say, the problem-solving aspect of it. I like to feel accomplished, and if I can feel accomplish by helping somebody and just solving a problem, that makes me feel good 'cause I'm kind of a perfectionist!"

Other students said:

> "I didn't realize how broad the field of engineering was until I actually like looked into it and like googled types of engineering, and I found out about like environmental engineering or biomedical engineering and those are two categories that are really interesting to me, I'd like to figure out more."

"I also see myself as an engineer obviously, but I would say this course has definitely solidified my view on that. After doing these community-based projects and actually seeing the results and seeing how it impacted other people, our group specifically, we helped out a child with special needs where we build him something that would make it easier for him to use his communication device."

Teachers reflected toward the end of the second year on the excitement felt by their students.

"My students were excited to be in school, just for this class."

Teachers described projects developed by their students, including a support dog harness designed for a person with autism. The team had the opportunity to visit with their client and experience success as their client was able to take her support dog with her into public.

Other projects involved the design of a swing for a child who had difficulty sitting upright, the design of enrichment and feeding devices for animals at a local zoo, and a mailbox sensor for a student's elderly neighbor (Figure 2). In this case, the student's neighbor was the stakeholder, and the need was to know when or if mail had been delivered.

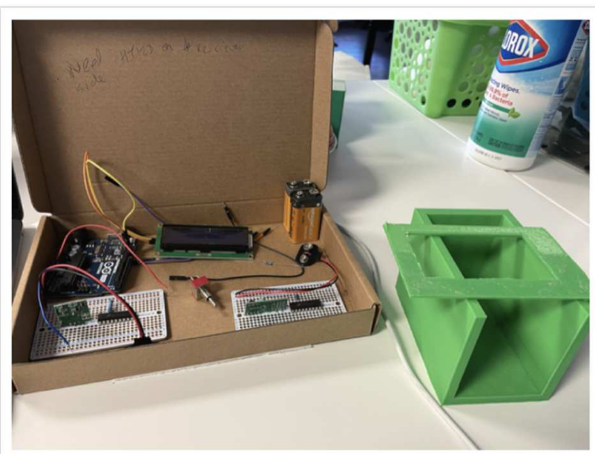

FIGURE 2: MAILBOX SENSOR

Designs truly allowed students to explore the intersection of engineering, society, ethics, and the environment.

Teacher focus groups were conducted at the conclusion of the PD, and individual teacher interviews were conducted during the 2020-21 academic year. Feedback on the curriculum was captured through these interactions as well as through direct teacher comments in the TeachEngineering interface and through targeted surveys in the Learning Management System. This feedback was reviewed regularly by members of the curriculum development team and considered as the curriculum was modified.

VI. Review by External Evaluators

The external evaluation team also undertook an extensive review of the curriculum and issued recommendations on each unit, lesson, and activity. All of this feedback was considered by the curriculum team.

The most extensive modification was an effort led by the evaluation team to develop and implement specific Student Learning Objectives under the Course Outcomes. A focused team of curriculum developers, instructors, and content experts reviewed each lesson and CO and developed a table of SLOs under the guidance of the evaluators. This effort led to revisions of the learning outcomes and assessments throughout the course.

VII. Curricular Modifications

Based on feedback from both internal and external stakeholders, the initial curriculum design and has been through multiple continuous improvement reviews and iterations. The e4usa teachers have provided an abundance of suggestions leading to many of these efforts. The e4usa external evaluation team has examined each unit, identifying gaps and misalignments, also leading to additional curriculum improvements.

For example, as a result of teacher requests, a master supply list for activities was created, helping teachers better prepare for the semester at a glance. In addition, definitions were added to the vocabulary lists at the beginning of each unit while working with teachengineering.org to make the curriculum available on their website. Some lessons and activities were moved: for example, a lesson on the value of failure in the design process was moved near the beginning of the curriculum, to alleviate fear of failure and encourage 'failure' within an engineering context (meaning the design required iteration)

The course was designed around the set of Course Outcomes (COs) shown in Table 1. While these accurately describe the objectives in the overall course, defining measurable Student Learning Outcomes (SLOs) would be of benefit to teachers charged with developing daily lesson plans, and serves to form the framework about which assessments are developed. Toward this end, each lesson and activity was examined, each CO was reviewed, and a gap analysis was performed. A set of both finalized SLOs and COs was the result. The progression of each SLO is mapped through the curriculum: teachers are given guidance on where the previous and next appearance of the SLO are within the curriculum, and guidance of level of mastery students may be expected to display at any given point. The SLOs within a lesson also serve to frame the assessments. A rubric was developed for each SLO and incorporated into each lesson in which that SLO appears.

While this is often an early step in the development of a curriculum, the project had a first cohort of teachers that functioned as stereotypical "early adopters"; they seemed to thrive in the environment where they provided real-time feedback and served as de-facto members of the curriculum development team. The second cohort was, for the most part, more typical teachers with more typical expectations.

The next iteration of the curriculum is now in place, with revisions based on feedback from teachers, students, and an external advisory team.

The third iteration of the PD is in development. This PD will be repeated as an online session, with physical kits shipped to teachers. The PD is under modification to feature the revised curriculum.

VIII. Conclusion

This high-school level course has been offered for a two-year period in approximately 50 classrooms across the United States. Feedback from teachers and students has been exceptionally positive based on online survey data, focus groups, and interviews. As the teachers in the program went from having characteristics of ‘early adopters,’ ready to implement a curriculum that was continually under development to more traditional teachers who asked for greater structure and more definition of, for example, Student Learning Objectives (SLOs). The curriculum team of e4usa has operated in a continuous improvement mode, meeting and modifying the curriculum throughout the two years of the project.

This iteration of the curriculum was driven specifically by teacher and student feedback, leading to development of SLOs via a gap analysis from the external evaluators and the curriculum team. This led to a number of improvements including

- The development and inclusion of ‘essential questions’ meant to generate discussion and frame each unit
- The refinement of assessments throughout the curriculum
- Development of SLOs and incorporation throughout the course
- The development of rubrics to accompany each SLO.

The curriculum team expects to continue to operate in the mode of continuous improvement, and continue to collect feedback from teachers, students, and evaluators.

Acknowledgment

The authors appreciate the contributions of the entire e4usa team. This material is based upon work primarily supported by the National Science Foundation (NSF) under NSF Award Number EEC-2033445. Any opinions, findings, and conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the NSF.

References

[1] NGSS Lead States. *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press 2013.

[2] International Technology Education Association, *Standards for Technilogical Literacy*, Reston, VA, 2007.

[3] K. Reid, D. Reeping, E. Spingola, “A taxonomy for introduction to engineering courses.” International Journal of Engineering Education, 35(1), 2-19, 2018.

[4] Katehi, L., Pearson, G., Feder, M., Cunningham, C. M., Custer, R. L., Daugherty, J. L., Foster, J., Schunn, C. D., Jenniches, S., & Didion, C. (2009). *The Status and Nature of K-12 Engineering Education in the United States Engineering Is Elementary Professional Development for Teachers of Engineering: Research and Related Activities The Incorporation of Technology/Engineering Concepts into Academic Standards in Massachusetts: A Case Study How Kids Learn Engineering: The Cognitive Science EngineerGirl! A Website to Interest Girls in Engineering BRIDGE K-12 EnginEEring Education*. http://www.nae.edu/TheBridge.

[5] G. El Sawi, PhD, Curriculum Development Guide: Population Education for Non-Formal Education Programs of Out-of-School Rural Youth, Food and Agriculture Organization of the United Nations, URL: http://www.fao.org/3/ah650e/AH650E00.htm, accessed 5/20/2020.

[6] K. Reid & J. Estell, Engineering Design and the Product Life Cycle: Relating Customer Needs, Societal Values, Business Acumen, and Technical Fundamentals, Momentum Press, 2017.

[7] National Academy of Engineering, NAE Grand Challenges for Engineering, URL: http://www.engineeringchallenges.org/, accessed 5/21/2020.

[8] Cunningham, C. M., & Lachapelle, C. P. (2012). *Engaging all students in engineering*. https://www.researchgate.net/publication/288138612