

# *Tinkering vs. Engineering in K-12 Education*

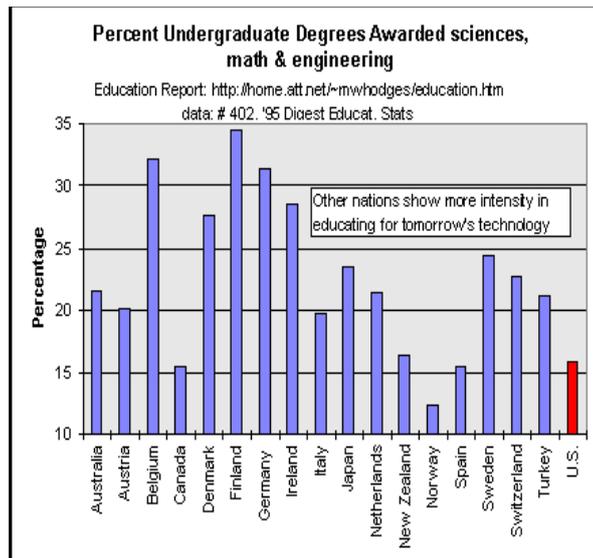
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**Abstract—** In recent years, Tinkering has taken on a new meaning the the engineering world. Tinkering is now in reference to the simple act of playing with blocks or Legos, building a Rube Goldberg Machine, and a myriad of other fun hands on activities. There are some in the world of engineering that would argue that true engineering instruction cannot occur until a student has been introduced to advanced mathematics, or design analysis and design processes. However this discredits the value of “tinkering” in relation to engineering prior the student’s introduction a majority of the advanced mathematics they will learn in engineering. By the time a student would have been introduced calculus for instance, a student’s mind may have formed an image on what they think engineering is, and what an engineer does. The report *Rising Above the Gathering Storm* specifically cites a lack of engineering material in the K-12 education of our students. It is likely a student’s exposure to advanced mathematics before the end of their K-12 education would be extremely limited, and if so, the lack of engineering material needs to be addressed, and the question becomes: Does “tinkering” in whether formal as in Project Lead the Way or informal, such as Design Squad, MythBusters, or the Rube Goldberg Challenge, constitute introduction of engineering material in our current K-12 curriculum? That is the focus of this research; to define tinkering in terms related to engineering, and propose a definitive answer whether or not it constitutes engineering material in our current school curriculum.

**Keywords—***Engineering; Engineering Education; Tinkering; Maker; Advanced Mathematics; Rising Above the Gathering Storm;*

## I. INTRODUCTION

In our current day and age a nation’s prosperity can be directly related to its advances in technology, and its ability to market those advances to an ever increasingly interconnected global economy. In recent years, the U.S. has noticed a decline in cutting edge technologies. Other countries have caught up, and become more and more competitive in world markets. With this knowledge in mind the National Academy of sciences formed a committee to look at crucial strategic issues of U.S. competitiveness that are slipping and allowing the U.S. to lose some of her former greatness. The findings were published in a report entitled *Rising Above the Gathering Storm*. The main conclusion that can be drawn from the findings is that Background “Without a renewed effort to bolster the foundations of our competitiveness, we can expect to lose our privileged position.” [1]



**Figure 1: Comparison of the U.S. and other countries in the number of degrees awarded in the sciences, math and engineering. [2]**

One of those crucial issues is the education of a new generation of scientists and engineers to help spur on technological innovation. New innovative ideas and products require a large amount of scientific work to be conducted for scientific progress to be conceived, implemented, and designed. This role, more often than not, is filled by an engineer. In recent years other countries on the rise in economic power are have experienced marked increases in the numbers of engineers entering the work force. The U.S. has experienced a decrease in new engineers entering the workforce, as well as a shortage of engineers available for employment [3][4]. As a result, it is in our nations' strategic interests to cultivate and develop an interest in math and science in the nation's youth, so that one day they might be the next batch of scientists and engineers to develop new cutting edge technologies which will help us remain competitive on a global level.

## II. BACKGROUND

With a new effort to cultivate a new generation of engineers, what is currently being done to help cultivate this interest in grades K-12? That is the topic of much debate in the field of education, and at the very core of the Engineering Education profession. Inside of that debate lays a very fundamental question that is just now being explored for the first time. The fundamental question is what is the operational definition of engineering? Does a form of "engineering education" in grades K-12 have to involve something specific for it to qualify as practicing a form of engineering? Engineering type problems generally involve a design process, analysis, and some form of advanced mathematics. There are some that would argue that for a problem or solution to said problem, to be considered engineering, the application of advanced math would have to be plausible. However, it is highly unlikely a student has much exposure to the advanced mathematics required to solve some real world engineering problems. Therefore, via the definition of engineering, engineering in grades K-12 would be non-existent. If this is indeed the case, how then are we to introduce engineering in grades K-12?

In the realm of television, there are programs in which trained professionals tackle engineering and design challenges. Programs such as *Mythbusters* and *Design Squad* weekly portray a type of engineering process in what can only be described as tinkering with scientific insight. A trial and error approach using scientific analysis occurs and at the end of the episode, these makers/tinkerers have prevailed in the engineering feat presented to them. It is vastly popular, and more and more of such type shows in which tinkerers design are appearing on our televisions.

In much the same way, there is a movement occurring in the Engineering Education field using this tried and true "makers" approach to teaching. This group see's the need for engineering principles and practice in the K-12 curriculum and is searching for a way to implement the concepts. These makers are employing "tinkering" in a guided fashion as a form of engineering, in much the same way there

television counterparts are. This approach then throws out the standard definition, and applies a more practical definition of engineering for the purposes of both encouraging interest in the field of engineering, as well as teaching engineering principles, all without the inclusion of advanced mathematics.

### III. METHODOLOGY

To examine the issue of tinkering as an engineering form an axiomatic system approach is proposed. This technique represents the standard definition of truth for thousands of years. It is appropriate in this case. We will first create a list of axioms consisting of defined terms and academic standards. With definitions for both tinkering and engineering, we will look at what defines both terms, how both are used, and whether or not the relevant definition matches with the axiomatic standards we had previously defined. With those ends accomplished, we will look at who and what defines the need for K-12 engineering material. We will examine what will fill those needs, and what standards if any are in place to use a guideline.

Having established our axiomatic base, we will look at tinkering. We will examine how it is being used, what standards it coincides with from our axioms, and who actively uses tinkering as a form of engineering education. We will ask what success, if any these tinkering instructors are having in regards to both instruction and interest in engineering related topics.

### IV. SUMMARY OF LITERATURE

To establish our argument we must first create our axioms, for our purpose our working definitions to use for comparison. For the purposes of research, we will start out with the following generic definitions:

*Tinkering- to repair, adjust, or work with something in an unskilled or experimental manner [5]*

*Engineering- the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people [6]*

Let us first examine engineering. As we can see from our standard definition, math and science are referenced. The definition works as a basic definition but how is engineering actually defined in regards to education? The National Academy of Engineering, which advises our nation on all matters involving engineering have both a working definition and standards in regards to engineering in K-12 education. The NAE defines engineering as “design under constraints.” [7] This definition is what the academy used in its two years of research into engineering standards in education. Notice it is different than the standard definition. This definition is rather broad, and while the academy acknowledges math and science in effective engineering design, it uses the rather broad definition as its basis.

The next question to arise with the standard definition of engineering is the feasibility of engineering by this standard definition to occur in K-12 education. We can again look to the NAE for a definitive answer to this question. The NAE is of the opinion that “although it is theoretically possible to develop standards for K–12 engineering education, it would be extremely difficult to ensure their usefulness and effective implementation.” [5] From this one statement we can derive two things: 1. There were no agreed upon standards at the time of this report for engineering education in grades K-12 and 2. It is a difficult process in terms of developing these standards, with the goal being the standards usefulness and effective implementation. These findings can be supported by the fact that a standard definition for the term engineering would appear to be elusive.

The NAE also has gone on to develop an argument for the need of engineering materials in the K-12 education system. It finds that current STEM standards do not include engineering, and that “engineering education can stimulate interest and improve learning in mathematics and science as well as improve understanding of engineering and technology. [7]”

Given this apparent need for engineering material in K-12 education, what will help fill that need?

What can be done to help create standards and stimulate the growth of engineering in the education field? Again the NAE has a few ideas. The NEA suggests the following:

**RECOMMENDATION 1.** Federal agencies, foundations, and professional engineering societies with an interest in improving precollege engineering education should fund a consensus process to develop a document describing the core ideas of engineering that are appropriate for K–12 students.

**RECOMMENDATION 2.** The U.S. Department of Education and National Science Foundation should jointly fund the development of guidelines for K–12 engineering instructional materials. Development should be overseen by an organization with expertise in K–12 education policy in concert with the engineering community

**RECOMMENDATION 3.** The following research questions should be part of a wide-ranging research agenda in K–12 engineering education funded by the National Science Foundation, other federal agencies, and the private sector:

- How do children come to understand (or misunderstand) core concepts and apply (or misapply) skills in engineering?
- What are the most effective ways of introducing and sequencing engineering concepts and skills for learners at the elementary, middle, and high school levels?
- What are the most important synergies in the learning and teaching of engineering and mathematics, science, technology, and other subjects?
- What are the most important considerations in designing materials, programs, assessments, and educator professional development that engages all learners, including those historically underrepresented in engineering?
- What are the best settings and strategies for enabling young people to understand engineering in schools, informal education institutions, and after-school programs?

**RECOMMENDATION 4.** Federal agencies with an interest in improving STEM education should support a large-scale survey to establish a comprehensive picture of K–12 engineering education nationally and at the state level.

Since we have found definitively, that standards for engineering materials in K-12 education do not exist, it makes it difficult to argue definitively one way or another if certain aspects of engineering materials follow any set standard for engineering education material. It also makes it difficult to argue that any particular form of mathematics is required for the material to be actual engineering preparation materials. The NEA cites calculus or pre-calculus at the high school only twice in all of its *Standards for K-12 Engineering Education?* report, and states that even at the high school level “although students can be expected to bring additional skills to the engineering design process (algebra, geometry, trigonometry and possibly elementary calculus), the major focus should be on determining whether or not students have developed advanced skills in determining the most appropriate operations to address various steps of the process—defining problems quantitatively, creating engineering drawings with scale factors, using tools to accurately measure materials, setting up a testing apparatus that allows for quantitative comparisons of different materials and structures, etc [7].” Based upon this statement, it would appear that the NEA puts a majority of “engineering” into things other than mathematical applications in grades K-12. So what does that leave us with then for preparatory materials for engineering? Let us reexamine tinkering.

Let us define tinkering in the same way we defined engineering, with a more relevant definition pertaining to the subject matter at hand, engineering education. Tinkering using the standard definition appears to imply the practitioner is unskilled. Therefore it would appear that a tinkerer would not be an engineer or practitioner of engineering. However, through constant tinkering and experimentation one could become “skilled” and develop a working knowledge base. If one can apply a scientific analysis approach to the act of tinkering, then one could become skilled having used a scientific process. This could very well mean that tinkering, if conducted in a certain way could be viewed as “the application of science” which is directly mentioned in part, in our standard definition

of engineering. Using only our standard definitions and a slight modification in the application of tinkering we have been able to link tinkering with engineering. Given these facts, how does the field of engineering education define tinkering?

Tinkering in the field of engineering education widely accepted rather new term. There has yet to be produced a concrete definition that can be referenced for comparison, in the same fashion we did for engineering. There are no standards for tinkering, and anyone can be a tinkerer. The term tinkering does not appear a single time in the NEA *Standards for K-12 Engineering Education?* findings. It would appear that someone needs to take definitive action and define the term. Using the logical progression of thought in the aforementioned section we have linked the terms engineering and tinkering. For discussion purposes in this paper, tinkering will hence forth be assumed to have a “scientific approach.” With this slight modification we will accept this as our standard definition in regards to an engineering education definition.

## V. DISCUSSION

Upon reexamination of our initial question, there is a need to determine whether tinkering (which we have now defined in terms of engineering and engineering education) fills a need for engineering material in K-12 education.

Having related tinkering back to engineering, we can attempt to apply the same standards to tinkering that are applied with engineering in K-12 education. We are back to the small issue in that no set standards exist in K-12 education for engineering. We can however look at the NEA report and their recommendations to get a good idea of what these standards should look like.

In the second recommendation made by the NEA, specifically mentions “organizations representing informal and after school education programs” as experts that need to directly oversee and guide the creation of these engineering education standards. There are an ever growing number of afterschool engineering programs. A quick look at the materials presented in the programs clearly demonstrates “tinkering with scientific approach.” The existence of these programs and the implementation of tinkering in them (with the indirect support of the NEA) is an indication that some in the field of engineering view tinkering as a viable piece of engineering education material for grades K-12.

An inspection of the third recommendation by the NEA will yield yet another opportunity for tinkering to help the field of engineering education. The recommendation specifically asks for:

- How do children come to understand (or misunderstand) core concepts and apply (or misapply) skills in engineering?
- What are the most effective ways of introducing and sequencing engineering concepts and skills for learners at the elementary, middle, and high school levels?
- What are the most important synergies in the learning and teaching of engineering and mathematics, science, technology, and other subjects?
- What are the most important considerations in designing materials, programs, assessments, and educator professional development that engages all learners, including those historically underrepresented in engineering?
- What are the best settings and strategies for enabling young people to understand engineering in schools, informal education institutions, and after-school programs?

In regards to the first question asked, it has been shown that children learn through play [8][9][10]. Some of the core concepts of engineering are critical thinking, and creative thinking skills [7]. One could argue tinkering can fulfill those needs. Our original definition of tinkering referred to tinkering as unskilled experimentation. Playing with Legos or Lincoln Logs is by definition a form of tinkering. When given some set criteria or specifications, you have tinkering with applied scientific analysis, which was our definition of tinkering that we have managed to relate back to engineering. You have managed to teach engineering concepts through tinkering in scientifically proven “tried and true” method.

The second question posed by the NEA also has an answer in tinkering. In much the same way

learning through experimentation and tinkering occurs and builds, engineering principles could be taught in the same way. In tinkering, individual components are often brought together and interact. These interactions through trial and error create the desired effect. Engineering principles should be taught in the same way, from the ground up with the most basic principles and allow the learners to pick up on the pieces and be allowed to implement them in an experimental, hands on fashion in much the same way tinkering does.

In regards to the fourth question asked by the NEA, tinkering could be a means to reaching students typically underrepresented in the field of engineering. If proper education with tinkering is conducted throughout the K-12 education process, different groups often underrepresented in engineering might have found an interest because of the positive exposure to engineering through tinkering.

The last question posed by the NEA in recommendation three also has a possible solution in tinkering. Learning occurs best through play and a seemingly informal setting (in the manner that tinkering occurs.) A great many after school programs are already using this tinkering strategy in there programs to effectively relate engineering to their students. Let us take a look at just a few groups of tinkerers who are already using this concept of tinkering as a means of teaching engineering principles.

Project Lead The Way is an example of a program currently active in our schools which is employing tinkering as a means of engineering education (and all the while without the use of any advanced mathematics.) The goal of project lead the way is to “develop the critical-reasoning and problem-solving skills that will help make them the most productive in the world[11].” It would appear that Project Lead The Way is then actively looking at the rather pressing issues brought to our attention by *Rising Above the Gathering Storm* and aimed at addressing them. Project Lead The Way aims to do so by “engaging students in activities-, projects-, and problem-based (APPB) learning, which provides hands-on classroom experiences. Students create, design, build, discover, collaborate and solve problems while applying what they learn in math and science. They are also exposed to STEM fields through professionals from local industries who supplement the real-world aspect of the curriculum through mentorships and workplace experiences[11].”

A close inspection of the means by which PLTW aims to fill the need for engineering materials would have you notice that the means chosen are in part a tinkering approach. Activities, projects, and the possibility to create, design, build and discover are all properties of the tinkering process. PLTW has managed to utilize tinkering with scientific analysis as a means for bringing engineering into the classroom. The real question is, does this method work?

Findings would suggest that PLTW is working. Engineering amongst previously underrepresented groups I steadily increasing, as well as overall retention of students in an engineering field upon completion of Project Lead The Way. Results have also shown marked improvement in engineering literacy and comprehension, as well as a better understanding of what an engineer does[11][12].

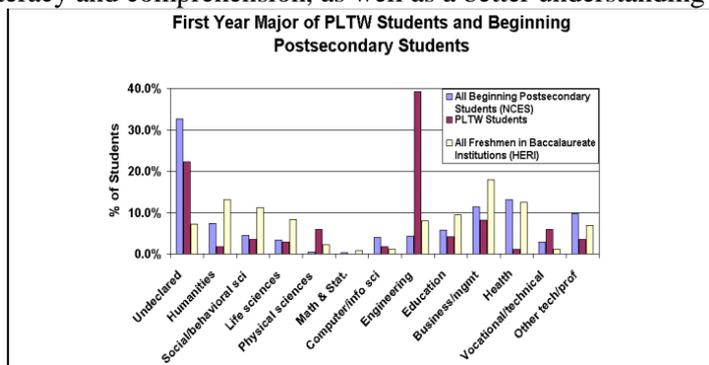


Figure 2: Graph depicting the Majors of PLTW students in further educational endeavors[12].

Let us look at another example of tinkering being used as a means of education. The television show *Design Squad* is another example of tinkering being used as a means to teaching engineering

principles in a fun manner.

In his article *Excite Kids About Engineering Design Squad and Engineer Your Life Resources*

*Make It Easy* by Jack Cheng looks at the *Design Squad* at great lengths and analyzes several key facets of the show. In the introduction of the article he describes a scenario in which students are actively learning through scientific analysis and experimentation and refers to that act as tinkering [13]. The article also discusses how design squad is a powerful tool in the introduction of students to the engineering process. The show makes very clear the elements of the design process, showing each one by name as the team's progress through them. This allows for educators to easily reference the steps in the design process with students, as well as relate them to how engineers approach real life problems and challenges.

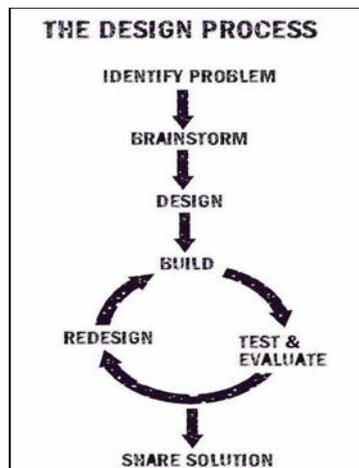


Figure 3: A graphic representation of the step by step process depicted in the television show *Design Squad* [14].

Another benefit of *Design Squad* is that it taps into the wide variety of problems and challenges that engineers' face. However, as Cheng points out, only two percent of America's high school graduates choose to study engineering, and largely based on the fact that they do not know what engineering is or what engineers do [13]. The show and website are designed to inform youth through information and experimentation what an engineer actually does, as well as attract historically underrepresented groups in the field of engineering such as women and African Americans, by showing how a wide variety of interests can be satisfied by a career in engineering[13].

*Design Squad* is yet another example of an application of tinkering done with scientific intent and a specific purpose. It demonstrates that tinkering, when done correctly, can function as a means to teach engineering and engineering principles to students in grades K-12, and all the while allow students to have fun and not notice they are learning along the way.

Tinkerers exist on other television shows as well. The vastly popular show *MythBusters* is a veritable "tinkerers dream" [15]. One of the shows cast, Grant Imahara is a self-proclaimed tinkerer and engineer, who weekly turns the spotlight on urban myths and legends and with the application of scientific analysis and tinkering, proves or disproves these myths. He claims that his engineering skills are critical to the job. The entirety of his design process and his tinkering approach are exhibited weekly on the show. Whether it be creating an Archimedes "death ray," or constructing a confederate long range rocket, his ability to tinker and use his engineering skills are integral to his success[15].

As we have seen, tinkerers are all around us and are already leading the charge toward the education of our youth about engineering and portraying engineering in a real world context. Whether it be in the form of Project Lead The Way, *Design Squad*, or *Mythbusters* tinkerers have already begun to develop a means to teaching engineering to a new generation, even if standards did not exist at the time.

## VI. CONCLUSION

As we have seen in *Rising Above the Gathering Storm* our nation has an ever increasing need to produce a new generation of scientists and engineers. Integration of engineering into K-12 education will be an integral part in this process, however there is some debate as to this should occur, and at what point you can consider something engineering. As we have seen tinkering appears to be a viable option to introducing engineering practices into the K-12 curriculum. Although no widely accepted standards exist, tinkering is already proving that it meets the suggested criteria put forth by the NEA. Tinkering in fact could very well answer some of the questions the NEA has posed for the engineering education community. In fact there are several different organizations already using tinkering as a means to educate this future generation of engineers (Project Lead The Way, *Design Squad*, *Mythbusters*) about both engineering principles and practices, as well as what it actually means to be an engineer.

The future of engineering education appears to have a bright future. It would seem that tinkering is now finding its own place in that world; a place where tinkering could very well take a definitive role in the education of our future generation of scientists and engineers.

## ACKNOWLEDGMENTS

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