
AC 2011-362: A LOOK AT STEM EDUCATION FROM THE TOP DOWN

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A Look at STEM Education from the Top Down

Abstract

This paper addresses STEM education issues, not in the traditional formative framework associated with K-12 education, but rather, in relation to what one might deem, the positive outcome framework associated with students majoring in STEM areas at the university level. The motivation for this approach is based on an argument that, while university students in STEM disciplines are considered as STEM education achievements, fundamental flaws in basic conceptual mathematical knowledge persist; flaws that if more aggressively addressed at the K-12 level could result in attracting more youth to pursue STEM interests. The argument is based on personal anecdotal evidence associated with the author's experiences. Hence, it does not have a rigorous foundation. Nonetheless, it is an argument that will hopefully resonate with many university-level educators, and, in turn, stimulate education researchers to re-evaluate the potential of current STEM initiatives to reverse the declining trend in STEM education in the U.S.A.

1. Introduction

The needs related to science, technology, engineering and mathematics (STEM) education in the USA are many. A well-recognized need is for more K-12 students to pursue STEM disciplines at the university level. It is the acknowledgement of this need that is central to the various STEM initiatives at the National Science Foundation (NSF), as well as other funding agencies. There are a wide variety of reasons responsible for the increased lack of interest in STEM subjects among younger (K-12) students. Based on the proposals that were funded in the NSF 2010 FIRE (Fostering Interdisciplinary Research in Education) program, it would appear that a major reason is that students are not sufficiently motivated by STEM topics. The five funded proposals include the following:

(FP-1): “*Applying Embodied Learning*” **Award #1042995** . “This project brings cognitive scientists together with physicists. The goal is to improve high school and college students' physics proficiency through specific types of lab experiences that allow the student to become part of the physical system being studied. Lab experiences where students have direct experience with physics quantities (e.g., feeling forces--as opposed to reading about force, seeing forces being exerted on someone else, or even measuring forces with instruments) may lead to the use of brain areas devoted to sensory and motor (sensorimotor) processing when students later think and reason about the physics concepts they experienced.”

(FP-2): “*Conceptualizing Non-Contact Forces*” **Award #1043026** . “The project will investigate the efficacy of real-time, interactive visuohaptic (visualization and force feedback) simulations for teaching STEM concepts. It focuses on the learning of non-contact forces, where conceptualization of force fields, traditionally represented visually by field lines, may be enhanced by the ability to feel the forces directly. The research team partners a haptic engineer and visualization expert with a science education researcher. A key pedagogical innovation of the approach is to enable middle and high school students to experience forces through their own

somatosensory system in real time, allowing them to discover phenomena that may seem surprising based on their current knowledge.

(FP-3): “*Early Fraction Learning*” **Award # 1043020**. “The goal of the proposed work is to advance our understanding of the ways in which thinking in the mathematics domain is related to the emergence of other cognitive building blocks in the early years. The project will examine whether children are better at reasoning about fractions when questions are framed in the context of social, rather than physical relationships, thereby avoiding the whole number bias that hinders understanding. The work is a collaboration between a cognitive scientist and a mathematics educator and the work will largely take place in preschools and daycare center.”

(FP-4): “*Designing Transformative Assessments*” **Award # 1043040**. “This project, Designing Transformative Assessments for Interdisciplinary Learning in Science (DeTAILS), aims to design and implement technology-enhanced formative assessments to help college students integrate scientific knowledge and solve complex problems across disciplines. Specifically, researchers will target fundamental biological processes in physiological contexts that are closely related to physics. The assessments will be administered to college students enrolled in introductory physics, biology, physiology, and science education courses.”

(FP-5): “*Computer Game Design*” **Award # 1042944**. “This interdisciplinary team pairs a developmental psychologist from a non-profit organization with educational researchers, computer scientists, and graduate students from the University of California-Santa Cruz (UCSC) to develop, test, and study computer game authoring tools with 140 middle school girls and minorities in four local schools. A UCSC associate professor of computer science with expertise in transforming game design, as well as mentoring women in computer science, mentors the PI through one-on-one sessions, structured professional development, and research. . . . The five-phase research study uses CT as the framework to develop, test, and refine the game authoring tools. During these phases, qualitative and quantitative methods will capture and analyze research data to reveal what kinds of computer games girls and minorities like to create and whether game authoring builds computational thinking.”

All of these funded proposals relate to new and novel means of motivating students’ interest in STEM topics. Funded projects (FP-1) and (FP-2) implicitly postulate that this motivation might be enhanced by more direct sensory experiences related to concepts in physics. Funded project (FP-3) seeks to discover whether students can gain a better understanding of fractions (hopefully resulting in increased motivation in math) can be achieved by considering this concept within a social context. Funded project (FP-4) seeks to motivate students by designing formative assessments that integrate their knowledge across STEM disciplines. Funded project (FP-5) proposes the use of computer game authoring to (hopefully) build computational thinking.

In their own right, the funded proposals are, indeed, novel and creative ideas. However, given that U.S. students’ understanding of STEM topics continues to drop relative to that of students in many, many countries around the world, one might ask if those countries are doing better because of their use of such novel and creative ideas in the classroom. It is reasonable to argue

that the answer to this question is clearly: no. If one accepts this answer, then while such ideas might contribute to improved motivation, one must still acknowledge that there are other larger reasons for the continuing decline of STEM education in the USA.

Having taught university-level undergraduate and graduate courses in a wide variety of STEM topics for over 30 years, this author has observed an equally disturbing decline in the relative performance of U.S. students in relation to students from other countries. This observation is often reflected in the consistent and continued ‘dumbing down’ of course concepts, acknowledged by many academics who have taught in STEM disciplines for any length of time. In view of this continued decline of competency among U.S. university graduates, it is not surprising that more and more companies are looking to other countries to hire personnel with the level of STEM competency they need [1].

A STEM educator might ask: *Why should research be conducted in relation to those students who have achieved to goal of K-12 STEM education? Isn't it far more important to fund research that will enhance the ability and entice students in K-12 education to achieve this goal?*

The question implicitly presumes that students in STEM areas at the university level have a higher level of mastery of K-12 mathematical concepts than their counterparts. It also presumes that STEM courses at the university level are taught in a way that takes advantage of and further advances this mastery. Yet, it is conceivable, and it will be argued in this proposal, that this is not entirely the case; that, in fact, often students in STEM majors have a very weak grasp of basic mathematical concepts. It will be argued that a firm understanding of such concepts is lacking even among upper level undergraduates and graduate students in STEM disciplines. If one accepts that there is a glaring weakness in conceptual understanding among a measurable subset of upper-division university students majoring in STEM disciplines, then this author would pose the following questions in response to the above question.

RESPONSE QUESTIONS: *If a measurable proportion of upper level undergraduate and graduate students in STEM disciplines are, indeed, lacking in understanding of some of the most basic concepts in mathematics that, in turn, continues to fuel the ‘dumbing down’ of university level STEM curricula,, then isn't it possible that STEM education at the K-12 levels has somehow failed? Furthermore, could it be that many of their peers who have deemed themselves too lacking in mathematical ability to pursue STEM majors, in fact, have a strong potential to understand mathematical concepts, but lack the opportunity to realize this potential throughout the K-12 STEM education curricula as currently constructed?*

These response questions are rhetorical. Of course, if indeed, students who graduate from STEM university programs having glaring weaknesses in understanding of basic mathematical concepts, then, by definition, there is a fundamental flaw, at least in the guiding philosophy of STEM education. And, of course, if STEM curricula are structured in a way that emphasizes procedural knowledge over a firm grasp of basic concepts, then, to be sure, there will be students whose desire for a deeper understanding of basic concepts will not be sufficiently nurtured to entice them to pursue STEM areas.

The continued ‘dumbing down’ of concepts at the university level reflects flaws in the very foundation of STEM education. An increased knowledge of the nature of these flaws and how they manifest in relation to STEM disciplines at the university level could lead to potentially transformative approaches to STEM education at all levels. The weaker the level of understanding of basic mathematical concepts is among those being educated to be teachers in STEM areas of K-12 curricula, the more likely it will be that future generations of students in those curricula will be presented with procedural knowledge with a progressively weaker conceptual foundation. Students who are more inclined toward such knowledge will be favored, while those who thirst for a deeper, more holistic understanding will be left behind; those very students who are most needed for the long term benefit of any 21ST century society.

2. The Problem to be Addressed

The problem to be addressed in this paper is to consider anecdotal evidence for the significance of major issues associated with hypotheses that are believed to correlate directly to a weak grasp of basic mathematical concepts among upper level undergraduates in engineering and graduate students in both engineering and other STEM disciplines. The evidence to be presented is based on this author’s own documented experiences. A major goal of this work is to motivate a more rigorous examination of these issues in a controlled setting.

2.1 The Importance of the Problem to STEM Education

It is commonly assumed that students who progress in STEM areas throughout their college years are representative of the goal of STEM education in the K-12 years. Arguably, the single most logical reflection of the success of STEM education is the students who graduate from STEM disciplines at the university level. If the main goal of STEM education is to prepare and entice students to embark on STEM areas of study at the university level, then while there is still some merit to this assumption, it is waning in relation to both the number of students entering university-level STEM disciplines, and to the performance of students from other countries. It may also be that the structure of the K-12 STEM education is geared more toward students who have certain inclinations that continue to be fostered in the deteriorating U.S. university setting. Students who are less inclined to be attracted to STEM areas throughout their K-12 years would then be even less motivated to delve into STEM areas at the university level, if that level maintained the structure of their prior experiences. There are many students whose interest in STEM areas has remained dormant or has been squelched throughout their formative years, but that begins to awaken in their late teen years; especially if they are in a university setting. The majority will choose majors that do not entail STEM requirements, in part, because they feel they are not capable in those areas. Those few who do endeavor to explore STEM courses will all too often find themselves feeling as inferior as they felt in their high school years, as they attend classes where they are surrounded by peers who seem to be far more mathematically talented than themselves. While it may well be that those surrounding them are far more comfortable with the manner in which the material is presented, it is possible that their comfort is more a result of the familiarity with the procedural manner in which the material is presented than with their understanding of any underlying concepts.

There are many reasons for the decline of higher education in the USA, and it is outside of the scope of this proposed effort to address that phenomenon. Rather, the scope of this work is to identify potential weaknesses in STEM education that persist among university level students in STEM disciplines, and to motivate education researchers to examine those weaknesses in relation to STEM education at all levels. The students related to this work include upper level undergraduate and graduate students in STEM disciplines. These are students who, by all standard measures, are exactly the desired outcomes of STEM education. However, if these target outcomes are fundamentally flawed, this would suggest that there are fundamental flaws in the K-12 levels. It is believed that there may well be such flaws; flaws that favor students with certain tendencies and alienate students of equal, if not greater caliber of understanding, but whose tendencies are out of step with the manner in which the material is presented; flaws ('crimes') that are aided and abetted by educators who have been trained to propagate them.

The mere speculation of such flaws may well be viewed as heretical by some those who educate K-12 teachers, as well as by some university professors. For, to accept their possibility would necessitate consideration of a major revamp of education, both of students and, more importantly, of educators. However, if indeed such flaws do exist, it is imperative that they be duly acknowledged. For, if they are not, they could severely diminish the value of the myriad of approaches to improving STEM education that have been and continue to be pursued. The following section will argue that such flaws are likely to exist.

3. The Specific Research Hypotheses

In order for the reader to gain a better sense of where the hypotheses to be proposed in this section were derived from, it is appropriate to provide a brief summary of this author's teaching background. Throughout his Ph.D. in mechanical engineering at the University of Wisconsin-Madison, he held teaching assistantships in the departments of mechanical engineering, electrical engineering, and mathematics. His primary duties were highly interactive, and included lecturing, supervising and guiding students in laboratory settings, and guiding discussion sessions. Courses he was either solely or jointly responsible for included pre-calculus algebra, vibrations, acoustics, electrical communications, and instrumentation. During his tenure as a faculty in mechanical engineering at Purdue University, he taught a variety of courses in the systems, instrumentation and controls division. He also developed and taught two cross-listed graduate courses. One concerned Fourier transform theory, and the second one finite dimensional Hilbert spaces. During his joint appointment in the departments of aerospace engineering/engineering mechanics and statistics at Iowa State University he has taught courses in dynamics, feedback controls, Kalman filtering, time series, probability and statistics for engineers, and probability theory for graduate-level researchers. He also co-developed and taught a course in applications of Hilbert spaces for statistics and engineering applications, and a two-semester course sequence in functionality and aesthetics. This sequence was the first ever cross-listed course between the colleges of design and engineering. Finally, he has acted as an advisor for the aerospace senior design courses and has served as a committee member on theses of students in STEM areas, as well as areas such as political science, economics, education, journalism, and creative writing.

Consequently, this author has a long history of teaching courses in a number of STEM (and non-STEM) disciplines. The justification for the hypotheses to be presented in this section will be supported by material related to his teaching experiences in only his most recent two years. Because his primary research to date has not focused on education, he did not bother to retain documentation related to prior years. Nonetheless, the material to be presented reflects his experiences over the course of many years.

3.1 Case Studies- In this section, results of a number of case studies related to the courses taught during the past two years are presented. Because each one typically entails support for more than one of the hypotheses to be proposed in the next subsection, it was felt that by presenting these studies prior to the hypotheses, the reader might more naturally see how the hypotheses were arrived at.

Case 1: Sets & Subsets- Let S be a set, or collection of two objects; specifically, $S = \{ (0,1), (1,1) \}$, where the object (x,y) denotes the location of a point in the x - y plane. Define the subsets $A = \{ (0,1) \}$ and $B = \{ (1,1) \}$. Describe the set $C = A \cap B$, where the symbol \cap denotes 'intersection'; that is, the objects that are contained in both set A and set B .

Of a total of 17 STEM-oriented students in a *graduate level* course in probability and statistics, ten students gave the correct answer; namely the empty set, or, in a words, nothing. Seven students gave the answer $\{1\}$; their logic being that each object has a second component whose value is one. Even though the topic of sets is not discussed in calculus courses, it is a topic that almost certainly has been discussed to some degree in their experiences in prior STEM courses. This study points to a number of possibilities. One is that students do not understand the difference between an object and an attribute of that object. Another may relate to the use of mathematical notation. For, had the problem been framed using two physical object and using baskets to contain them, it is possible that the very framework, itself, would have seemed so simple as to make the problem statement almost mindless. It should also be mentioned that this problem has also been a central one in relation to this author's courses in statistics for engineers at the undergraduate level. By exposing those students to their lack of understanding of the nature of sets, objects, and their attributes, one might expect the problem to be resolved. It was not. Throughout the many semesters he has taught these courses, a measurable number of students never seem to 'get it'. Furthermore, some of them become indignant when it keeps being brought to their attention that it of fundamental importance to the most basic concepts in probability theory.

Case 2: Complex Numbers- Consider a complex number $c = a + ib$ that is represented in Cartesian (i.e. x - y) coordinates. For simplicity, suppose that both a and b are greater than zero. Viewing this number as a vector in the complex plane, compute its magnitude and direction.

This problem was posed in a class of the 11th week of a *senior level* course in feedback control systems for engineers. Out of 80 students, 56 gave the correct answer:

$$|c| = \sqrt{a^2 + b^2} \quad \& \quad \theta = \tan^{-1}(b/a).$$

Twenty one students gave the answer for the magnitude as $|c| = \sqrt{a^2 - b^2}$, and three students had no idea how to proceed. This problem was given *after* complex numbers had been discussed in relation to the roots of a polynomial for many weeks prior to this part of the course. Even after it

was shown that the correct magnitude results directly from Pythagorean's theorem of right-triangles, a number of students could not understand why the imaginary number, i , should not be included in the use of this theorem. They didn't seem to be bothered that their answer could result in a negative magnitude. While complex numbers do not play a major role in most introductory calculus and pre-calculus courses, graphs in the x - y plane do. Many students failed to see the connection to that topic. Because this topic was couched in a course that was in the students' major area, this author did not get any real sense of indignation on their part. In contrast, because the statistics for engineers course is a required single 'dead-end' course outside of their major area, those students might well have had greater reason to rebel against (re-?) learning a concept they might never use again.

Case 3: It is believed that this case relates as much to the use of symbols as it does to the concept of a set, and to the concept of integration as addition. It is, again, related to a statistics course for engineers. And so, it is a course whose content is contextually foreign to them. The problem is:

Let X denote the act of noting whether or not any frog to be tested in a study undergoes a sex change. Then the sample space for X is $S_X = \{0 \text{ (no)}, 1 \text{ (yes)}\}$. Let the parameter $p = \Pr[X = 1]$. Use the formula $E(X) = \int_{S_X} x \cdot f(x) dx$ to prove that the theoretical mean of X , [denoted as $E(X) = \mu_X$], is equal to the parameter p .

This problem in its generic form was included in the first exam. The form provided here was given in the *second* (10-week) exam. It had been discussed using progressively more mathematical notation since the first day of the course. Specifically, it had been noted since day-1 that a *random variable* is an *action*, that when performed can result in more than one possible number, and that the *sample space* is simply the set of the possible numbers that could result. [Note: There was no mention of the more mathematically rigorous elements of random variables, such as one might encounter in a course on measure and integration theory.] Finally, it had been repeatedly emphasized in lectures and homework problems that in the case where the sample space contains only a discrete number of values, then formal integration reverts to simple addition; that is,

$$E(X) = \sum_{S_X} x \cdot \Pr[X = x]. \quad (1)$$

The connection between a formal integral and a summation such as (1) is a core concept in calculus. Conceptually, integration means adding 'things' up. Those 'things' can be areas, point masses, or a combination of the two. [This author has yet to encounter a single upper-level student in engineering who has a firm grasp of this concept.] After poor performance on the first (5-week) exam, the above problem was presented in class in relation to the following basic statics problem:

Consider a beam of length one, with two point forces acting on it- a force of value $1-p$ acting at the location zero, and second force of value p acting at the location one. Compute the moment about the location zero.

Every student immediately knew that it was p . As is shown below, at the 10th week, after repeated coverage of basic probability theory, many of the students were not able to relate this setting to a setting involving two point masses of probability. Out of a total of 53 students, 28 gave the correct answer:

$$E(X) = \sum_s x \cdot \Pr[X = x] = 0 \cdot (1-p) + 1 \cdot p = p.$$

Examples of some of the more common incorrect answers included the following:

$$\frac{1}{p} \sum_{k=1}^p x_k = \frac{1}{p} [\mu_x - \mu_x |_1^p] = p \quad ; \quad \frac{1}{n} \sum_{n=1}^c X_k = p \quad ; \quad \int_{S_x} x f_X(p) dx = xp dx = 1 = p = \mu_x$$

$$\int_0^1 x f_X(x) = \frac{x^2}{2} \Big|_0^1 = 1/2 - 0 = 1/2 = \mu_x \quad ; \quad \int_{S_x} x f_X(x) dx = \frac{1}{n} \sum_{k=1}^n (x_k) = \mu_x = p.$$

The above answers comprise a mix of confusion, ranging from the notion of an integral as a sum, to the sample mean as distinct from the theoretical mean, to nonsensical expressions related to basic integration. A variety of elements unrelated to the problem are also introduced. That this problem posed such difficulties to so many students at the 10th week of the class is, in no small part, related to the fact that from the very beginning of the course there were a number of students who rejected the value of any theory that did not involve numbers (i.e. data). By the 10th week the class had become polarized, in the sense that there were students that finally had embraced an appreciation for concepts, and there were almost as many who had completely rejected the same. Symbols also played a major role, and ranged from confusion that persisted throughout the course, as to the meaning of the compact ‘ Σ ’ notation for *summation*, to a failure to distinguish an action denoted by an upper case X , from a number represented by a lower case x that results by carrying out the action X . Hence, it is also possible that many students were simply trying to recall a formula that might be the correct one.

Case 4: This case illustrates the influence of context on self-perceived knowledge. The context was a course entitled *functionality and aesthetics* that was comprised of 14 seniors: 7 engineers and 7 interior design students. Part of the intent of the course was that each group would provide mentoring to the other. This did not happen. While the reasons for this are not entirely clear, what was clear was that neither group had a level of conceptual understanding of its discipline sufficient to explain it to the other group at even the most basic level. Attempts to better understand the reasons included giving the students the well known 30-question version of the *math anxiety rating scale* (MARS) exam. The use of this exam was suggested by the design professor who co-taught the course, and who had just finished her Ph.D. in curriculum and instruction in the area of assessment. Since at the time, this author was also teaching an upper level course in statistics for engineers, and his cohort was teaching an upper level design class, it was decided to also administer the exam to those classes, as well. The results are given in the table below, and were presented in [2].

Table 1. Average scores for each noted group of students for the 3 areas of the MARS-30 survey. The rows represent type of anxiety (1=low, to 5=high). Group 1 includes all students in the DSGN/ENG. course. Groups 1(d) and 1(e) include the design and engineering factions of Group

1, respectively. Group 2(e) includes engineers enrolled in a statistics course taught by this author, and Group 3(d) includes design students enrolled in an upper division design course taught by this author's colleague in the Design College.

	Group 1	Group 1(d)	Group 1(e)	Group 2(e)	Group 3(d)
S1(numerical)	1.97	2.24	1.64	2.75	2.18
S2(testing)	2.62	3.24	1.96	2.52	2.97
S3(abstract)	2.05	2.87	1.28	1.81	2.49

First, we restrict our attention to the case study course results (Group 1). As might be expected, neither the design nor the engineering students appear to have major issues related to numerical elements of mathematics (S1). The level of anxiety with respect to abstract mathematics (S3) is over twice as high in the design student group compared to the engineering group. This is also to be expected; as would be the difference in the level of test anxiety (S2). And so, the results related solely to Group 1 do not reveal any new math-related issues. A comparison of Group 1(d) and Group 3(d) results suggests that the latter group has slightly less test and abstraction anxiety. While the number of students (7) in Group 1(d) is too small to make any strong claims, it is reasonable to speculate that this difference is statistically significant. It stands to reason that when placed in a class setting with engineering students, design students may experience a greater level of abstraction anxiety. Perhaps the most revealing issue relating to STEM education in the table is the level of anxiety of Group 2(e). Their average level of anxiety related to numerical math was higher than all other groups. And while their level of abstraction anxiety is less than that of the design groups, it is 50% higher than the level of Group 1(e). Again, due to the small size of the latter group, the statistical significance of this difference was not investigated. However, it is believed that it warrants further investigations. Specifically, what it suggests is that one's level of math anxiety in relation to abstraction may be notably influenced by the course content and classroom environment. In relation to Group 1, math concepts were minimal; whereas in relation to Group 2(e) they were central. In an environment where abstraction is in the forefront, it is likely that exposure of limited abstraction capability/training will result in anxiety.

Case 5. This case study relates to the use of mathematical language and symbols, and how students both in and outside of a STEM discipline respond to them. Specifically, in the interdisciplinary course including 7 engineers and 7 interior design students, the concept of conditional probability needed to be covered in relation to predicting whether or not certain types of travelers would like to have in-flight internet service. As an experiment, this author decided to simply give the students the full data set, and then ask them to estimate the probability that a business traveler would desire internet service. Without any hesitation, the students immediately discarded any data that did not include business travelers. They then used the proportion of business travelers who said they would like internet service as the estimate of the probability in question. In the very next class this author attempted to show them the beauty of what they had actually done, in relation to sets and conditional probability. Practically every student failed to see the connection. Furthermore, the majority had no interest in seeing any connection. It was at that point that this author decided to avoid the use of mathematical jargon and symbols for the remainder of the course. By doing so, the non-STEM interior design students were actually quite capable of carrying out tasks related to probability and statistics more readily than students

taking this author's course in statistics for engineers. It was quite clear that many STEM students view mathematical language and symbols with trepidation, if not disdain.

3.3 The Hypotheses- It is believed that the cases presented in the last subsection, while anecdotal, provide an argument for consideration of the following hypotheses, in relation to upper level undergraduate and graduate students in STEM disciplines:

(H1): A significant number of upper level undergraduate and graduate students not only lack basic mathematical conceptual knowledge, but are either unable and/or resistant to learn it.

(H2): The language and symbols used in mathematics can cause confusion that significantly stifles the desire to recognize and/or learn underlying concepts.

(H3): The level of self-perceived mathematical knowledge is contextual, and

(H4): A polarized classroom environment is more likely when conceptual knowledge is emphasized.

4. Discussion

The purpose of this work was not so much to suggest changes to STEM education at the university level, as it was to look at STEM education from the top down. That is to say, it was intended to identify potential flaws in understanding that persist among students who, by all counts, would be considered success stories. Anecdotal evidence for such flaws was presented above. Even though it is anecdotal, there can be little argument that there are fundamental flaws in STEM education in the U.S.A. at all levels, including K-16 levels and even the graduate levels of university education. It is imperative that these flaws be identified and duly remediated in order for students from U.S. to compete in a 21st century global job market, and to contribute to a resurgence of the U.S.A. as a dominant force in STEM areas of research and development.

4.1. Supporting Views for Understanding of Basic Concepts- In addition to the more pragmatic outcomes mentioned above, there are other fundamental reasons for stemming the demise of conceptual knowledge in favor of procedural knowledge. Some views related to the topic of disciplinary specialization are mentioned here. Such specialization is intimately related to a deep understanding of basic mathematical concepts, as the latter can play a major role in providing a more holistic understanding of a wide variety of apparently disconnected disciplines. For one, Davis [3] acknowledges several problems with disciplinary specialization. When disciplines become more and more specialized, they tend to isolate themselves with the proliferation of their own findings and specialized language. Specialists tend to find it difficult to introduce their field to beginners. Learning and conveying the discipline language is only one problem, as communicating concepts and theories are equally as difficult and problematic. He also notes that disciplinary specialization tends to be myopic, in that its scholars are inclined to give their methods greater priority, or to an extreme, believe that their way is the only way of looking at the world. Finally, he argues that disciplinary specialization tends to ignore or minimize broader issues and holistic perspectives, and that in a 21st century world a holistic perspective is critical to the advancement of knowledge.

Another view of this issue comes from the famous mathematician, Alfred North Whitehead: *“Let us now ask how, in our system of education, we are to guard against this mental dry rot. We enunciate two educational commandments: Do not teach too many subjects, and again: What you teach, teach thoroughly.”*[4]

Derrida [5] discusses ‘biotechnocrats’, who value technical expertise over a broader, wiser, and more holistic approach to knowledge and life. Even Albert Einstein expressed continual concern with the growing trend towards overburdening young students with specialized knowledge. To Einstein, highly specialized and technical education, if not countered with diversity and depth, would preclude a more well-rounded and harmonious enlightenment, as reflected in the following quote [6]:

“I want to oppose the idea that the school has to teach directly that special knowledge and those accomplishments which one has to use later directly in life. The demands of life are much too manifold to let such a specialized training in school appear possible. The development of general ability for independent thinking and judgment should always be placed foremost, not the acquisition of special knowledge. It is essential that the student acquire an understanding of and a lively feeling for values. He must acquire a vivid sense of the beautiful and of the morally good. Otherwise he—with his specialized knowledge—more closely resembles a well-trained dog than a harmoniously developed person.”

4.2 STEM in Relation to Multi- and Inter-disciplinary Education- Within the most current vein of STEM initiatives, it should be noted that there is an increasing recognition that the number and quality of students studying toward and completing baccalaureate degrees in STEM disciplines must be expanded to a much more multidisciplinary framework. In a recent bill presented by Rep. Susan Kosmas [7], the official summary recommends expansion of STEM grant uses in creating *multidisciplinary* or *interdisciplinary* STEM courses or programs, and in expanding undergraduate STEM research opportunities to include interdisciplinary research and research in industry, at federal labs, and at international research institutions or research sites. Without a strong common conceptual base in mathematics, the ability of such programs to succeed will invariably be significantly hampered. The NSF funded programs discussed in the introduction do recognize the need for more multi- and inter-disciplinary frameworks in relation to STEM education. What they seem to ignore is the fact that many students who are considered as STEM success stories lack a firm understanding of even the most basic mathematical concepts. It is likely that such programs will, indeed, contribute in a positive way to a better understanding of STEM topics on the part of young students who are poor performers per standard measures. However, none of the funded proposals address evaluation of the potential impact on high achievers. In a relatively recent study [8] it was noted that even the top achievers from the U.S.A. were low compared to top achievers in many other countries.

4.3 Challenges in Relation to Conceptual Knowledge- The challenges to embarking on an effort to bolster conceptual knowledge are legion. At the most basic level there is the balance between learning the 3 R’s, and focus on mathematical concepts. For example, a child needs to know how to subtract, but is there value in knowing that the notion of subtraction is, mathematically, a substitute for the concept of an additive inverse? Most people would say that this concept is totally irrelevant to an understanding of basic mathematics. Such people fail to understand that such a concept can serve to stimulate a young mind to appreciate concepts such as groups of objects and operations that one can define on it. Children have an enormous potential for

imagination. While rote memorization and procedural knowledge are necessary elements of basic mathematics, they are woefully lacking in their ability to stimulate that imagination and make learning more exciting.

Another challenge relates to those who teach mathematics. Very often they, themselves, do not appreciate the creative potential of basic concepts. And those who have such an appreciation are often constrained to focusing on procedural knowledge in order to ensure that their students pass examinations that emphasize the same.

This challenge grows throughout the higher grades, including university level courses. Mathematics departments at many universities now teach calculus for engineers, with a focus on procedural knowledge. This author has had to bear the consequences of this limited focus, as reflected in lack of student understanding of basic concepts such as those described in the cases included in section 3.1. His repeated efforts to coordinate efforts with math educators have been ignored, if not rebuffed; as if to say “You do your job, and let me do my job.” The fact is, as educators, we are all in this together. Until and unless professors, department chairs, and administrators across campus begin to treat education in a more unified framework, the goal of truly enhanced and integrated conceptual understanding of mathematics at the university level will not succeed.

4.4 On the Anecdotal Nature of this Work- This work is based on a proposal that this author submitted to the NSF 2010 FIRE program. The proposal was rejected, in part because, as accurately noted by one of the reviewers:

“The proposal does not draw from mathematics education literature, but rather builds upon the author's personal experiences and issues he or she has observed while teaching mathematics to undergraduates.”

As was noted in the proposal, a search of the literature resulted in finding no investigations of deficiencies in the knowledge base of graduates of university-level STEM programs. The proposal was this author's attempt to embark upon the first stage of such a study. Because this author strongly believes that university-level deficiencies in STEM education's ‘success stories’ could provide valuable insight into reasons for the continued decline of STEM education in relation to the international arena, this author deemed it appropriate to present his anecdotal evidence for the proposed hypotheses at a conference of engineering educators. It is his hope that this work will ‘resonate’ with some of those educators, motivating them to see sufficient merit in this work, so as to pursue related research related to the proposed hypotheses, and other hypotheses as deemed relevant to this area of STEM education research.

References

- [1] Gogolap, Pallavi, “Corporate profits are up. Stock prices are up. So why isn't anyone hiring?”, Associated Press, December 28,2010.

- [2] Sherman, P. and Brunner, L. “A Case for Adaptive Identification and Control of Interior Design and Engineering using Formative Assessment” presented at the 2009 *Annual ASEE Global Colloquium on Engineering Education*, Budapest, Hungary, October 12– 15, 2009.
- [3] Davis, J.R. (1995). *Interdisciplinary Courses and Team Teaching*. Phoenix, AZ: American Council on Education and The Oryx Press.
- [4] Whitehead, A. N. *The Aims of Education and Other Essays*, Macmillan Co., 1929, as reprinted in *Education in the Age of Science*, edited by B. Blanshard, NY, Basic Books, 1959.
- [5] Derrida, J. (1980). Structure, sign, and play in the discourses of the human sciences. In *Writing and difference*. (A. Bass, Trans.), University of Chicago Press.
- [6] Einstein, A. (1982). *Ideas and opinions*. (C. Seelig, Ed.). NY, Three Rivers Press.
- [7] H.R.4955 - Transforming Undergraduate STEM Education Act, introduced by Representative Suzanne Kosmas, D-FL, March 25, 2010.
- [8] *The Third & Fourth International Mathematics & Science Studies (TIMSS)*, published by The National Center for Education Statistics, 1999 & 2007.