Moving Beyond Paideia – Transforming the Educational Pipeline into one that Focuses on "Learning for Earning," as well as "Learning for Learning"

Abstract

This paper analyzes the traditional role our educational system has played in attempting to prepare an undergraduate student for an engineering career. Specifically addressed is a career in electronic product design and production engineering. Recognition is made that the gap between a student's academic preparation and our industry's real world need has continued to widen in our rapidly changing high tech world [1]. The school's customer, the student, is not aware of this gap while in the educational pipeline. The deficiency of both marketable technical and interpersonal "soft" skills after graduation is discussed. The paper offers two new models:

1. The United States currently is ranked 24th in science and 38th in math among 71 countries. Model 1 argues that to be most effective in a globally competitive, cost sensitive, and ever-changing electronic product environment, students need to be exposed to electronics and electronic product production in creative and fun ways when they enter the educational pipeline (age 5 or earlier). This exposure continues and widens as the student proceeds through the secondary segment of the pipeline (high school). The addition of this technical education expands Mortimer Adler's *Paideia Proposal* at the primary and secondary levels for ALL students. If the student chooses engineering at the post-secondary undergraduate level, the student leaves the pipeline. A real world learning environment becomes the student's classroom, rather than exclusively teaching in an antiseptic college classroom. A contract electronic production business is used as a real world classroom for the student's entire four year engineering degree program. The student plays an active role in every facet of the business operation over those four years. This permits the concurrent development of the necessary real world skills to accompany traditional textbook theory. Even though the business classroom is electronic product design and production in nature, the production processes involved permit a more effective way of teaching skills across the ABET accreditation science and math requirements. These requirements include calculus by using the motion control dynamics of circuit board assembly automation, the physics of soldering, solder joint grain structure and other elements of material science, electronic assembly cleaning chemistry, additive manufacturing processes such as 3-D printing, and even the effect of free market economics on their future jobs. The complexities of developing and maintaining the assembly processes associated with robotic automation, as well as the applied statistical methods needed for meta-process control (sometimes called "Factory 4.0") and root cause failure analyses are used as examples. In addition, it is essential that "softer" skills such as working under real world business pressure, critical thinking, judgment, root cause analysis, team dynamics and conflict resolution be taught as part of the educational process. Using the real world classroom, the student will experience and effectively learn these skills as well. The Center for Electronics Manufacturing and Assembly (CEMA) at The Rochester Institute of Technology is used as a case study. This center reflects some of the new educational model's principles such as real world active learning.

2. The second new model provides a radical alternative to the traditional organizational structure of an electronic product design and production business. It can only be enabled with a workforce that has been educated in accordance with the new engineering education model. This business model eliminates the overhead costs of the department-based hierarchal pyramid structure, one that has evolved out of the Henry Ford assembly line.

Introduction

In this paper, the following terms for the most part are used in the following ways: *Manufacturing* – the fabrication of both electronic and mechanical components. *Assembly* – the process of connecting or joining components, including electrical test. *Production* – the process of creating a product by the manufacturing and assembling of components.

Careers in commercial and military electronic product production are unique. It is necessary to understand the theory across much of the physics spectrum – thermal, mechanical, chemical, electrical, material science, combined with significant real world experience – to be successful in producing a quality high tech electronic product in an efficient, cost competitive way. The term "product" in this context refers to requiring an assembly process to create the finished goods. It is this process that invokes many branches of science. In addition, the assembly technology for electronic products has changed from largely manual processes to complex automated processes. This was caused by three primary factors:

1. The component industry has continually pushed their designs into smaller and smaller packages. This is in response, in part, to product designs that are handheld and/or weight sensitive. Often the device interconnects are underneath the component – called a BTC (Bottom Terminated Component). In addition, it is not feasible to hand solder a 03015 metric (0.012 x 0.006 Imperial) chip resistor.
2. Pervasive use of RF (radio frequency) and very low working voltages in products have made designing circuit boards with short electrical distances between components a big advantage in the product's performance. These circuit board "real estate" restrictions have eliminated manual assembly as a practical option.
3. The global competitive pressure in high labor rate regions has prompted a reduction in labor cost through a reduction in labor *content*. This has included the automation of material retrieval and transport, as well as the automated insertion of leaded components on the same surface mount technology (SMT) placement machine platform.

Not only the vast changes, but also the acceleration and speed of those changes, have challenged academia in this traditional industrial engineering discipline. In 1970, Alvin Toffler foresaw a society that would have trouble coping with the speed of this unsettling technological change [2]. What has been experienced in electronic product assembly is an example of that rapid change. Unfortunately, most post-secondary schools are always behind the curve in trying to prepare students properly for the ever changing "real world." For example, our industry is about to incorporate artificial intelligence (A.I.), virtual reality (VR), augmented reality (AR), and nano assembly in the *design* and *building of* electronic products [3]. Most schools cannot provide their students with the real world experiences necessary to develop an understanding and maintain the changing skills needed for this technology. The logistics of the traditional education method does not permit it. We have not been successful in our strategy to "educate" in one world – the isolated educational pipeline – and then to send the "educated" into a real world requiring many additional skill sets to respond to our dynamic technology. This strategy has created an ever-widening gap between academic preparation and industry need. The added complexities of this dynamic industry have taken what was largely thought of as a vocational or trade occupation and transformed it into one that requires engineering level personnel. What is required to hit this technological moving target is a self-updating educational system – one that automatically changes to meet the evolving technology used in product design and assembly. The current

learning system that typically requires a long process just to make a curriculum change does not work. A method to create this self-correcting environment is to use a business as the student's classroom. Free market economics requires quickly implemented design and process changes to enable a business to compete successfully. Students using a contract manufacturing business as their classroom for a full four-year undergraduate program leading to a B.S. degree in Applied Electronic Product Engineering Sciences is a paradigm-shifting alternative. The student would learn the additional and changing skill sets using a curriculum that is forced to change as the competitive needs of the business change. With the school and business co-located, and the school's faculty also leading business product teams that consist of half staff and half students on the contract production floor, the faculty will add new content to the students' classes as they are adopted by the business. The model addresses the aforementioned ever-widening gap between traditional education preparation and the ever-changing industry need. It provides the student with passage through a new educational pipeline in primary and secondary segments and real world learning outside the pipeline for post-secondary through graduate studies. To summarize the new model addresses the two fundamental deficiencies of the traditional model: 1. There is a lack of student exposure to the technology in the primary and secondary school segments of the pipeline (Fig. 1). To combat this, creative tools are developed to engender interest and a basic understanding of technology at a very young age. These tools will introduce students to the hardware associated with high tech "educational" and social media toys, phones, tablets and games that have become very familiar to them. In addition, basic concepts of how electricity, software and coding enable these "toys" will be taught. This strategy will be expanded throughout the primary and secondary grades to continue to relate everyday electronic products to the science the products embody.
2. During the post-secondary and graduate phases, educating the student in an antiseptic, static, exclusively academic environment, and then sending the student to the real world to work creates an ever-widening preparation gap. To address this, a school is wrapped around an EMS (Electronic Manufacturing Services) contract business. The business is used as a significant part of the student's classroom for their entire undergraduate and graduate education, leading to a B.S. in Applied Electronic Product Engineering Sciences, and perhaps M.S. and Ph.D. Degrees.

The Education Pipeline

Regardless of the country where one grew up, a person is the product of that country's educational system. A common element of that system is the fact that the student is isolated from the real world throughout the education process. There are exceptions with systems that offer student co-ops, apprenticeships, occasional field trips and, even in isolated instances, public/private partnerships. In these cases, private companies or the government may contract a university (e.g., Fraunhofer Institute in Germany) to perform tasks in and for real world interests. However, the vast majority of one's education, from a student's entry into the educational system to his emergence from it, is done in isolation from the real world. One could call this the *educational pipeline*. The pipeline shepherds students along from more or less a common entry point – preschool or kindergarten, typically somewhere between the ages of 3 to 5 – to one of several exit points (Fig. 1). What happens inside the pipeline has changed considerably from the beginning of formal education until today.

Education: A Brief History

Our species has the unique ability to create a permanent record of the knowledge it acquires, leaving this knowledge for the benefit of those that follow. This repository of what has been

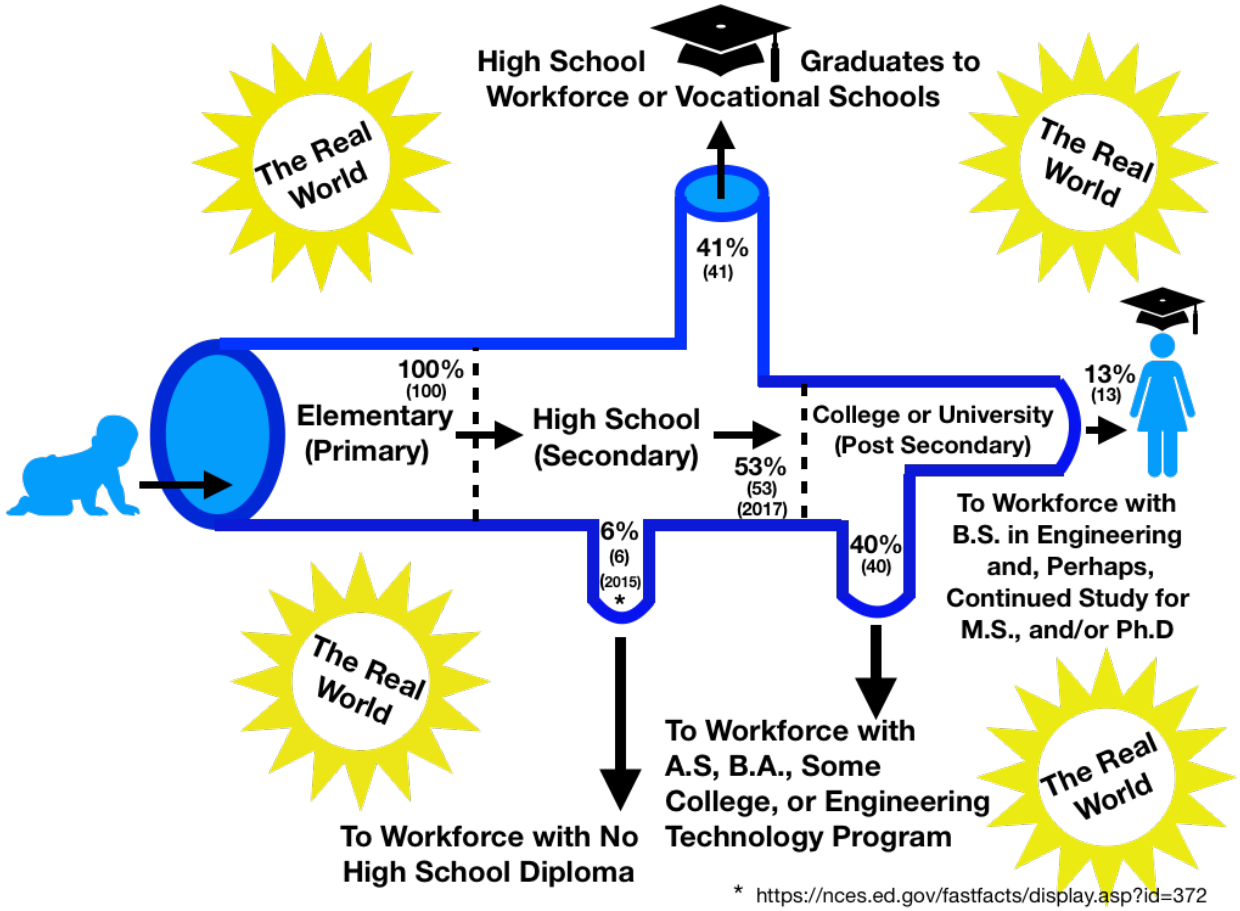

Figure 1. The Traditional Education Pipeline

learned by others permits future generations not to have to "reinvent the wheel." Isaac Newton recognized the value of being able to utilize this library of learning when he famously said, "If I have seen further it is by standing on the shoulders of giants [4]." The objective of primitive (pre-civilization) education was insuring basic human needs.

The process was not formal or organized and may be better described as "training." Anyone who did not look or act like you and came from a different tribe was a threat. Children were taught this, as well as hunting and planting. In the beginning, the sole purpose of education was survival. It was a full time job fending off a puma attack, gathering enough food to prevent starvation, and not freezing to death. However, this was not "organized" education – simply tribal training from the elders to their children [5]. Over 6,000 years ago, early civilizations in Egypt, China and the Middle East began to form and be occupied with activities other than individual and tribal survival. Writing was invented by the Sumerians over 3000 years ago and permitted the creation of permanent records. This achievement is credited as a key element in the formation of organized, formal education systems. This education was largely religious and cultural in nature [5, p. 34]. During the 17th and 18th century *Age of Enlightenment* in Western Europe, advances in science and logic started to be used to explain observations and demonstrate causal relationships. Education followed suit. Science, called "natural philosophy," began to play a significant role in a student's education.

Education in The United States
The onset of civilized society and subsequent events such as the invention of the printing press, the Industrial Revolution, the Enlightenment, and the American Revolution of the 18th century, made education a critical success factor in permitting individuals to govern themselves – for the first time being able to throw off the yoke of kings and tyrannical governments. On January 6, 1816, Thomas Jefferson wrote to Charles Yancey, "If a nation expects to be ignorant and free, in a state of civilization, it expects what never was and never will be." Toward this goal, Mr. Jefferson believed it was essential that the State provide free and equal access to primary education, eventually, for all. This would reinforce and enable a child to achieve whatever he or she defined as "happiness," regardless of the random conditions into which they were born.

The Progressive Educational Era
The progressive era in U.S. education is generally defined as beginning in the period between the 1890s and 1930s. Its leader is considered to be John Dewey. One of the primary objectives of school became educating individuals who would enter society upon graduation and be equipped to improve the human condition for the "greater good" through social engineering – not only being educated to find individual personal happiness. This meant that K-12 subject matter in schools would change and adapt to the changing needs of society. This paralleled the progressive political climate that began to look at the Federal Constitution as a fluid document that should be interpreted to meet the changing needs of the country.

What is "Paideia?"
The word "Paideia" comes from the Greek, "pais paidos:" *the upbringing of a child*. In Latin, it is associated with the word "Humanitas" or "Humanities," denoting the general learning that should form the basis of every individual's education. In 1982 Mortimer J. Adler of the Paideia group wrote "The Paideia Proposal – An Educational Manifesto [6]." It was inspired by a deep concern of some educators that the progressive educational policies adopted by the K-12 public school academic community were causing serious harm to the students they were charged to educate. Adler's concern was rooted in the progressive educational strategy of veering away from a single classical track of instruction to which every student in the primary and secondary educational system should experience.

Dr. Mortimer Adler's 1982 *Paideia Proposa*l suggested that K-12 education should consist of a single core curriculum based on certain invariant principles. Adler believed these "learning for learning" truths could be accessed and captured by the student through proper instruction and by reading the classics. He also believed "electives and specialization … are wholly inappropriate at the level of basic schooling." In other words, to permit a branching into subjects that are intended to promote "learning for earning" during the K-12 grades dilutes the education curriculum. Further, this dilution creates a distraction from teaching the core competencies essential to the student's optimum development.

An expansion of educational topics was becoming prevalent in colleges and universities as a popular way to pick up some easy credits toward a degree. This expansion then spread into the elementary and secondary public school system. The justification for this softening of teaching the traditional 3Rs in the primary and secondary grades and the customary teaching of humanities in colleges, was to develop new curricula to conform to the individual's abilities and, yes, enjoyment. Some complain that this has led to a high school graduate's inability to sign a contract because cursive writing is no longer taught in elementary school. In colleges, this

explosion of non-traditional classes was an effort to permit a student to learn what their talents were and how they could be used to benefit humanity - Bartending 101? This was accompanied by a corresponding dilution or contraction of traditional class offerings. To some this was troublesome at best and counter-educational at worst. It caused a backlash in some educational circles like the Paideia group to return to an invariant core curriculum.

Concerning education, Adler believed that there are certain truths and values that are absolute and invariant. This directly contradicted the progressive educator John Dewey who espoused a pragmatist progressive philosophy. Out of the Adler group's education philosophy emerged "The Great Books" – literary classics that should be read as an essential part of every individual's education. The second edition consists of 60 volumes, comprising 517 works of 130 authors. Included are not only classics by Shakespeare, Aeschylus, Chaucer, and many others, but also in mathematics and science, such as Euclid, Pascal, Descartes, Newton, Einstein, etc. In his Paideia Proposal, Dr. Adler specifically contends that the public school primary and secondary segments of the educational pipeline be exclusively reserved for "learning for learning." This learning should be based on certain absolute and invariant principles. And so, primary and secondary schooling (K-12) should be single track with everyone required to take the same classes that embodied those absolute principles. "Electives and specialization are entirely proper at the level of advanced schooling – in our colleges, universities, and technical schools. They are wholly inappropriate at the level of basic schooling (K-12) [6, p.21]."

One thing that Dewey and Adler did agree on was the importance of active, as opposed to passive, learning. Active learning "involves the use of the mind, not just the memory. It is a process of discovery, in which the student is the main agent, not the teacher … [6. pp. 50-51]." Adler submits that many teachers practice passive learning, acting merely as indoctrinators – overseers of memorization – but they are not truly teachers. There is no better example of active learning than educating in the real world (Fig. 3).

Murray Gell-Mann, the renowned particle physicist who discovered and named the Quark, said it another way. Upon receiving his doctorate in physics, he reflected on why he was so successful in school while many of his smarter friends were not. The concluded that he had a superior ability to "memorize, regurgitate and forget [7]." This is true through most of the current educational pipeline. Many examples of problem solving in engineering and math classes that are taken in the "pipeline" require memorizing the material in the textbook. Then, the student must be able to regurgitate these facts in the blue exam booklet while solving a problem on a test. (Oh, if it's a homework problem, you can go to the back of the book to see the correct answer). It's not until after graduation, when one arrives in the real world, that it becomes evident that 90% of the real world problems do not have a closed-form solution. There are more unknowns than equations. What is required to arrive at the best solution? Judgment. *Judgmen*t and its sister *critical thinking* are only learned in a real world environment.

Classifying What We Encounter

Classifying the quality of organized thought or output is usually done based on the utility of that output. It can be thought of as analogous to entropy in thermodynamics. The more structured a system is, the lower its entropy and, often, the more value the system can provide.

A rock with seemingly random symbols carved in it shows a level of intelligence at work versus random generation. It strongly suggests a non-random process was employed in its creation.

However, its seemingly random nature causes it to appear to have little value and is said to have relatively high entropy (disorder in the symbols). If the symbols can be decoded, and they turn out to provide instructions on how to prevent cancer – well, the population rejoices and the entropy plummets. The entropy falls not so much because of the value of the subject matter, but because it is discovered that the symbols are organized – they mean something. Of course, even if not providing a pathway to preventing cancer, if the symbols turn out to be part of an alien book entitled "How to Serve Man," one may react with similar elation – unless it is discovered, as it was in the 1962 episode of Rod Serling's *Twilight Zone*, that the book is a cookbook [8]! However, as distasteful as this discovery would be for the terrestrial population, the book could have considerable value to the aliens. It contributes to maintaining the low entropy while turning an old idiom: "The proof of the *human* is in the tasting!"

The DIKW Pyramid – A way to classify communicated output or observations

The DIKW pyramid (Data – Information – Knowledge – Wisdom) is a classification system that ranks the level of organization and structure of input received through one's senses, usually linguistic or symbolic in nature [9]. There can be an analogy made with entropy: As stated above, the more structured and organized, the lower the entropy. For example, a solid, crystalline material has lower entropy than a liquid whose shape is defined by its container. In the linguistic/ symbolic world, the elements of the DIKW hierarchy (Figure 2) may be defined as follows:

- **Data**: Symbols or numbers that are unorganized or unprocessed. Like low grade or waste heat in thermodynamics, "data" is of high entropy (disorder), without much potential use by itself. One exception is using the heat that is generated as a byproduct of the work done by an internal combustion engine to heat the passenger compartment of a car.

- **Information**: When data is organized in a way that makes it useful. For example, relating the actual PCB temperature as it travels through a reflow oven to the oven's zone settings and conveyor speed. Another example would be organizing the symbols (in this case letters from the English alphabet, in a way that conveys a fact (when read by someone who understands the English language). e.g., *these pretzels are making me thirsty.*

- **Knowledge**: When information is organized and codified and permits inferences to be made outside the specific information at hand. For example, an engineer may use reflow profile information (zone settings and conveyor speed vs. actual measured board temperatures) for a given circuit board to create a profile for a new board. Said another way, "Knowledge is a fluid mix of framed experience, values, contextual information, expert insight and grounded intuition that provides an environment and framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations it often becomes embedded not only in documents and repositories but also in organizational routines, processes, practices and norms [10], [11]."

- **Wisdom**: "… the ability to increase effectiveness. Wisdom adds value, which requires the mental function that we call judgment … [12]." This is a key skill that we should expect our students to acquire. It is where our educational effort should be directed when preparing students for a career in high tech electronic product production. With this as an educational strategic goal, the question becomes what tactically is the best educational plan to accomplish it.

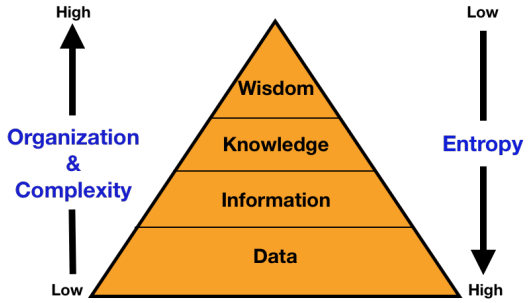

Figure 2. The DIKW Pyramid

How do we Teach *Wisdom*?
One short step up the DIKW Pyramid from the "data" or "random" symbols that are carved in the rock in the above example is the memorization of facts. *Fin17fpldr atinocw6 ecjreterhsam7* is classified as "data." It is an example of unorganized symbols. *Thomas Jefferson wrote the Declaration of Independence in 1776* is an example of the same symbols but organized into a statement that has some meaning. However, what value does this statement have by itself? Not much. Yet, students have been graded on being able to recall this fact, not necessarily to understand its significance. On the DIKW scale, memorizing the fact would be placed on the "Information" level – above "Data," but below "Knowledge." This is because the letters are organized in a way that communicates an intelligent statement (if one understands the English language). This falls significantly short from what education's goal in high tech electronic product assembly should be: Teaching "Wisdom."

Nature does not codify itself. We do. Nature is continuous with no boundaries or divisions between, for example, electronics and mechanics. We create these divisions – statics, dynamics, electronics, thermodynamics, etc. They are all based in the same physics. The atoms in a copper wire provide an easy path for an electric charge to propagate from atom to atom. Electrical work is done on a charged particle by an electric field. Opening your front door does mechanical work. To the universe both are "work" – the path integral of a force over a distance. Each breath we take changes the state of the system we define by drawing a box around it. How this change effects the universe is often difficult to predict except for one effect that is absolutely certain: the entropy of the universe (state of disorder) rises – the coiled watch spring inexorably continues to wind down. The question is why do we continue to teach in a "division of physics" way?

What is the most effective path toward *Wisdom* as students move through the Pipeline?
A New Engineering Educational Model (Figure 3)

The Primary segment – Can we realistically expect schools to teach the Navier-Stokes equation to a student who is between 3 and 13 years old? Of course not. But it is one thing to "teach" the equation to a student and then expect her to solve a test problem with it, and quite a different thing to expose the child to what the effect Navier-Stokes has in the real world. Pouring a glass of water vs. pouring a glass of molasses vs. pouring glass (yes, glass is an amorphous/non-crystalline material and can be considered to be a fluid of a very high viscosity!)
Most children start utilizing their opposable thumbs at a very early age. "Mommy, can I use the tablet computer? How about the mobile phone with all the cool apps on it?" How difficult would it be for the first grade teacher to show his class what's inside the tablet or phone and, in a very basic creative way, explain what the primary components and assemblies do? This would include the circuit boards – the "highway system" that permits the electricity to go to the right places.

The Secondary Segment – High school offers additional learning windows to expand on the science and engineering that is at the core of the real world electronic "toys and gadgets" students "play" with and use. The teacher could continue to concurrently "drill down" into these devices while showing the relationship between the physics and the mathematics they are learning at the same time in the classroom. Perhaps, a field trip to a plastic molding company would help to show the class why the phone case they drop all the time doesn't break, but the LCD display does and how the case is actually manufactured. The new educational model requires that just like every undergraduate should have read Dickens' "A Tale of Two Cities," we submit that every student while in the primary and secondary segments of the educational pipeline should be exposed to a basic level of real time, real world technical content.

The Post-Secondary Segment – This is where a departure from the pipeline is needed, or at least a re-engineering of the pipeline to include the real world (Fig. 3). For electronic product assembly, using a for-profit EMS (Electronic Manufacturing Services) business as the students' classroom will provide a vehicle to teach real world skills such as judgment, critical thinking and team dynamics – in other words, *Wisdom*. A B.S. degree in Applied Electronic Product Engineering Sciences, attained in this real-world educational environment would prepare a student to hit the ground running upon graduation. The need of the business to compete will require the continual adoption of leading-edge production skills. These new skills, in turn, will automatically prompt a curriculum change in the school since the product leader on the assembly floor also teaches in the school. The changes will be incorporated in the classroom either in an existing or as a new class [13].

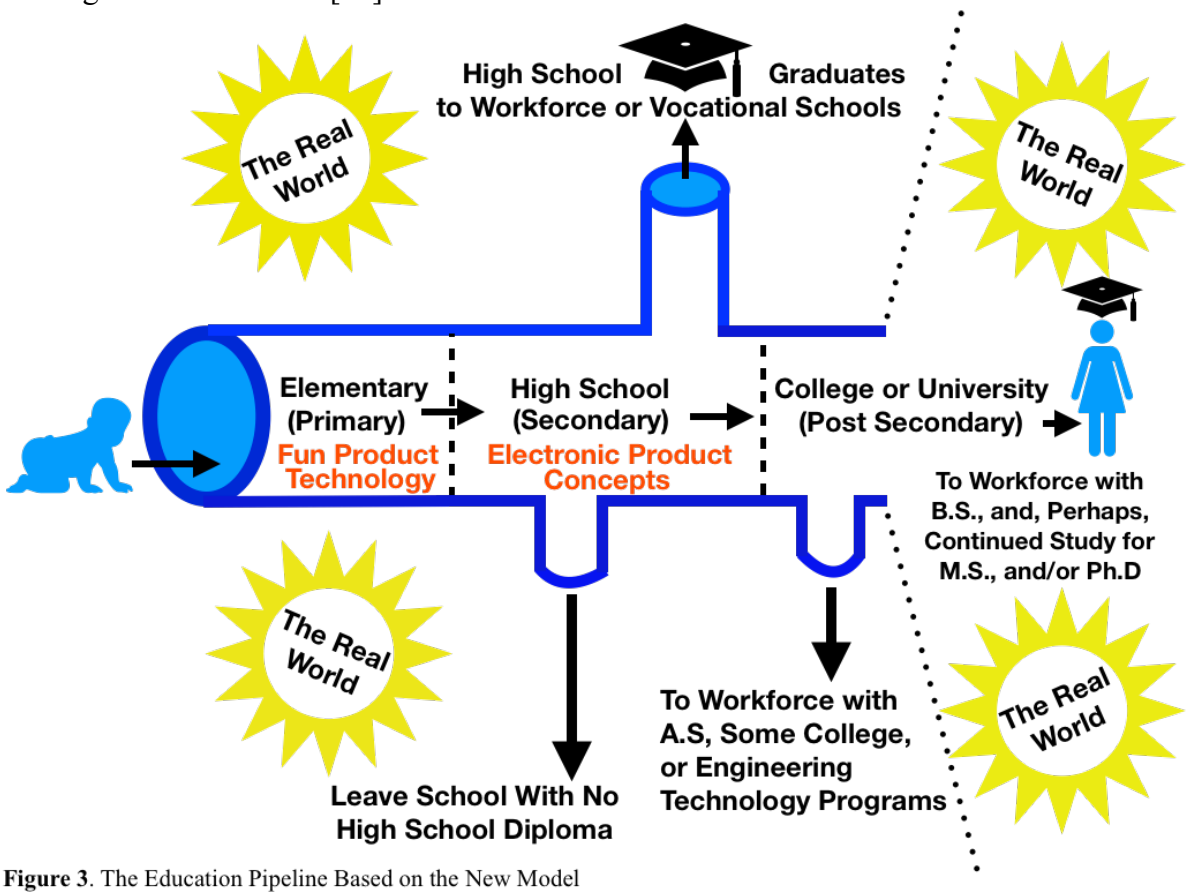

Figure 3. The Education Pipeline Based on the New Model

The Graduate Segment – Technical masters and doctorate theses are pure science, utilitarian, or some combination of both. In any case, in this segment of the education process, both teaching narrowly focused advanced subjects, as well as leaving the realm of teaching existing material to enter work of original discovery and study are pursued. For the Electronic Product Production field, practical topics are usually chosen, e.g., the study of new doping additives in lead-free solder alloys. Here the academic world and real world come together naturally as topics that typically refer to real world needs. Empirical tools create a bridge from the theoretical to the practical.

A New Production Organizational Business Model – The Second New Model
Today's global competitive landscape requires revisiting how production companies are structured in high labor rate regions and the role that education plays in that structure.

A Radical Change in the Organizational Business Structure - We are progeny of an organizational model that evolved from the Henry Ford division of labor production line, and the reactive, "Inspect the quality into the product" philosophy. "Put an inspector behind every assembly operator and you're sure to get a quality product." When U.S. production was the only game in town, the hierarchal, department-based, overhead-laden model, could work [14]. Today, in most cases, our fixation on raw labor rate differences is misplaced. The need to absorb the exorbitant overhead and indirect costs imbedded in this traditional organizational model can result in double and triple the raw labor rate [15].

Focusing on What Is Most Important to the Customer – Their Products.
The customer whose product is being produced for them is not concerned with how their contract assembler is organized. They care only about the quality and on-time delivery of the products the assembler is building. The new organizational model aligns the assembler's priority with the customer's interest. The specialization of skills on the production floor, caused in good part by Henry Ford's division of labor model for the mass production of automobiles in the early 20th Century, contributed to the balkanization and reinforcement of engineering division, as well.

Eliminating the *Silos* or *Fiefdoms* (and Their Costs) from the Corporate Landscape
Colleges also began to organize around what seemed to be a natural division of physics into its constituent parts – electronics, mechanics, chemical, etc. While engineering became specialized in the organizational structure of a technical business, schools reflected this specialization as well by creating majors and even specifying different types of engineering degrees – e.g., mechanical, electrical, industrial. Companies hired based on these degrees. "We need to hire 4 electrical engineers, 6 mechanical engineers and 5 industrial engineers." Departments were created to manage these areas of engineering specialization – grouping engineers of similar training – and the organization pyramid began to form. Each department has group leaders, section heads and department managers, which serve a management function. These functions are indirect, overhead, or G&A costs, and are paid for by loading up the direct labor rate. This, in turn, increases the price that the company sells its labor (labor sell rate). In addition, specialists and/or personnel with experience in buying material, finance, test, quality assurance, etc., are grouped together into their own departments (Fig. 4). Frequently, this focus of grouping personnel based on common skills results in adversarial relationships between departments. Managers and

personnel often blame other departments for problems on the production floor – Silo vs. silo (Fig. 5). The manager of your department typically does your performance review, so you have a self-interest in your manager succeeding in the silo wars. All this is non value-added activity that impedes production and adds cost, i.e., the project suffers.

Before Henry Ford

Before the division of labor took hold in the early 20th century, a team of craftsmen did product assembly. Each individual of this team was highly trained and, in most cases, could build the entire product by themselves, if need be. Not only was he well versed in how the product went together, but he also had a thorough understanding of the underlying science and engineering on which the product was based. As demand and volume increased, the assembly line was introduced to better permit the mass production of products. Manual assembly was done primarily by unskilled assembly labor much more efficiently and cheaply. The work in-process moved by the assembler who did one thing over and over again without regard, or need to know, how his or her job related to the finished product. What has changed in product assembly is that the need for manual assembly has been decreased dramatically by automating the manual processes. The assembly line remains. However, machines have replaced workstations previously occupied by human operators. Think of a circuit board moving down the assembly line – now, in many cases entirely built by machine.

Humans to Machines, and Back to Humans

Ironically, a new production model that returns to the pre-assembly line team of craftspeople better serves this automated assembly model. In the new model all departments are eliminated. There are only two groups in the organization – product teams that consist of multi-skilled engineers and a leadership group (Fig. 6). Each engineer on the product team is well versed in all aspects of the design, assembly and business processes, including the underlying physics and mathematics on which they are based. This is the *Super Engineer*. There is a problem, however. Our schools produce engineers who are specialized and certainly have no in-depth knowledge of material procurement, quality assurance, economics, marketing, project planning, marketing and cost management. This is contrary to the need in the new model for the product team "craftspeople."

The Leadership Group

The leadership Group serves as an enabling function for the self-directed product teams. They are responsible for providing the resources that a product team needs to be successful. They also serve as a check and balance on product team decision-making, and act as a third party to deal with internal conflicts that the product team can't resolve on their own. They effectively work for the product teams. One of the critical success factors for this production model is equipping each engineer with a full understanding of all aspects of the design, production and business of an electronic product. This requires a new approach to high tech electronic product education at all levels in the educational pipeline.

A New Educational Model to Serve the New Product-Focused Business Assembly Model: The Development of the Super Engineer

Cost is reduced significantly when the traditional hierarchical organizational structure (Figs. 4 and 5) is replaced by the new, two-group organizational model (Fig. 6). This occurs because of the ability to eliminate layers of management, overhead and indirect costs [15], [16].

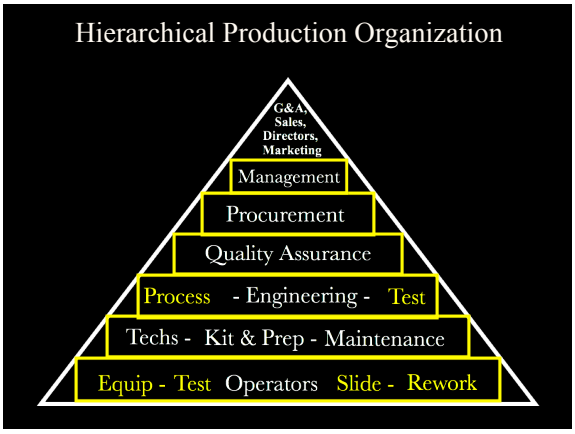

Figure 4. Existing Corporate Division of Labor Model: Silos and Fiefdoms

Figure 5. Existing Corporate Model: Direct and Indirect Labor

Figure 6. The New Corporate Organization Model – Only Two Groups: Product Teams and Leadership

The new production business model is based on creating a self-directed product team with engineers who have been cross-trained in a 4-year real world classroom. This will lead to a B.S. in Applied Electronic Product Engineering Sciences, giving the student the necessary theory AND experience that will lead to a proficiency in all necessary electronic product related and interpersonal skills.

Another shortcoming of the traditional post-secondary school system is the lack of relating one class to another. A student goes from structural analysis class with one professor to material science class with another professor. There is little discussion on how these classes relate to one another. Knitting together classes like chemistry and heat transfer is largely left to the student after graduation when they are thrust into the real world and have "a-ha" moments that reinforce the science continuum that exists in the real world. This issue is addressed in the new model by the students' work on product teams in the contract production business, combined with the fact that the product team leader on the assembly floor is also an instructor or professor in the school. The team is self-directed and consists of about half staff and half student (Fig. 6). This permits an engineering education that is characterized by a real time correspondence between classroom instruction and the world design and production issues that the student encounters on the production floor, an environment that provides a "physics continuum." As just one example:

exhaust air or nitrogen flow in a reflow oven is used to help teach many of the principles of fluid dynamics, heat transfer and thermodynamics.

Time for the additional course material

There is a significant amount of additional class material in the new educational model. This is in addition to the concentrated and continual student participation for 4-years on product teams in the real world business that the school is wrapped around. Where does the additional time come from? The traditional academic school year in the U.S. is 180 days. The business year is 250 days. Because of students' role in the business and the objective of educating the student in the real business world, the new educational model has a 250-day academic year.

A Vocational Versus an Engineering Education

In the U.S., the 1990 Perkins Act defines vocational education as "organized educational programs offering a sequence of courses which are directly related to the preparation of individuals in paid or unpaid employment in current or emerging occupations requiring other than a baccalaureate or advanced degree."

Postsecondary Vocational Education: "Vocational education at the non-baccalaureate postsecondary level primarily focuses on providing occupationally specific preparation. Postsecondary-level occupational programs generally parallel the program areas identified at the secondary level:

- Agriculture;
- Business and office;
- Marketing and distribution;
- Health;
- Home economics;
- Technical education (including protective services, computers and data processing, engineering and science technologies, and communication technologies); and
- Trade and industry [17].

The education of all engineers on a product team in the new organizational model could not be further from this definition of vocational education. Here are three reasons:

1. All product team members have undergone four years of an extremely diverse, intensive, and extended engineering curriculum.
2. Every product team engineer is expected to be able to perform in the team environment and be tasked with any aspect of product design or production needed by the team. This includes the operation and optimization of the production assembly line – the product engineer replacing the assembly and test operators, set-up, kit and prep, Q.A., procurement, equipment repair and maintenance personal and all product business related tasks such as program management, scheduling and financial management.
3. The curriculum is comprised of all the disciplines required for traditional engineering accreditation, including all the mathematics, plus additional material. The difference is that the classes are taught using the business as a key element of the students' classroom.

Moving Toward the New Educational Model

A Case Study - The kind of fundamental changes suggested above do not come easily. Implementing them is a difficult process. It is a "big ship to turn" to try and build a bridge from academia to the real world. However, as described below, there have been significant advances

in the direction of supplementing the traditional "learning for learning" education with "learning for earning," and developing this set of marketable skills by teaching the student in a real world environment. SMT education is challenging. Traditional classroom instruction is only effective in teaching high level concepts and terminology. The industry is not short of acronyms and terms. Learning them is critical to a student's ability to demonstrate a solid knowledge of the industry – leading to success in job interviews after graduation for electronic product assembly positions. However, classroom instruction alone cannot adequately address concepts of miniaturization, automation and process control. Many programs like industrial engineering will teach concepts of statistics and process control but not in the context of SMT. The electronics production industry combines many engineering concepts including materials science, design, fabrication, programming, statistical process controls, etc. Depending on the student's degree and research interests, they may be employed by a supplier (material, equipment, etc.), an EMS company, an OEM or an OPD (Original Product Developer). Each of these employers has a unique expectation prior to hiring a college graduate. To prepare students adequately one should also consider the gross revenue of the company with whom they first gain employment. For example, if a production engineer's position is listed by a Tier 1 company with hundreds of millions of dollars in revenue per year, that company may have a much narrower scope of job task expectations than if the same job was hired in a Tier 3 or 4 company. Since the early 2000's, engineers in the SMT field are expected to do more job tasks with the same title, and young graduates need to be prepared for that environment. Employers expect them to be ready, willing and able to work as a technician, designer and production engineer in a single work shift. Most college students have no knowledge of SMT, and an introductory course typically begins as a vocabulary lesson, teaching acronyms and the "lingo" of our industry. However, vocabulary is not compelling and not useful considering much of this can be learned on the job within the first few months. There are reasons for learning terminology, primarily preparing students unfamiliar with the topic for interviews. Ideally, a course in SMT should also have a fully equipped SMT laboratory where the students would be taught practical, real world skills of paste and adhesive printing, component placement, reflow soldering, and inspection techniques for challenging component types. Maintaining a fully functional SMT lab can challenge the students to consider process windows or limits to a stable manufacturing process (Fig. 7). Topics taught in lab include challenges associated with various classes of products and market segments (automotive, medical, military, hand-held, etc.).

Figure 7: Center for Electronics Manufacturing and Assembly (CEMA) at RIT

Beyond equipment operation and controls, concepts in design for manufacturing (DfM), design for reliability (DfR) and quality control should also be introduced for ensuring that these graduates appreciate the difficulty in not only manufacturing the product but ensuring the produce survives box build, shipping, installation and field conditions. Preparing students for warranty vs. customer expectation reliability is also a critical concept that needs to be addressed and taught.

Design and material interactions affect the eventual quality and reliability of all products. Teaching concepts that differentiate quality and reliability are critical. Many students consider inspection an unnecessary process step, assuming the process can be optimized to illuminate defects. Unfortunately, we have not reached a steady state in regard to technology innovations. Constant miniaturization will require inspection due to the likelihood of defects. This requirement can be significantly improved using automated inspection tools (AOI).

Teaching topics in analytical analysis and failure mode analysis, physics of failure and root cause can also be incredibly useful for emerging engineers in the field of SMT manufacturing. Universities also have the unique opportunity, depending on the research topics, to add novel new techniques that may be under development. Packaging miniaturization, semiconductor manufacturing and packaging and photonics integration are just some of the topics being investigated at RIT.

RIT Educational Topics;

- Quality Engineering
- Design of Experiments (DOE)
- Statistical Process Controls
- Controls for Manufacturing Automation
- PCB Fabrication
- SMT Assembly
- Analytical Testing and Analysis of PCBAs
- DfM, DfR, DfX
- Robotics

As we move into more advanced forms of advanced manufacturing which include topics in Industry 4.0 and the Internet of Things (IoT), it is our next generation of engineers, who may have taken classes in analytical mathematics and robotics that can enable these new technologies. It seems every company and supplier have their own definition of Industry 4.0. Our industry needs standardization before we can automate the factory for data tracking and optimization, and eventually automation.

As a final project reinforcing the importance of a “learning for earning” real world educational environment, RIT students are assigned a teardown project, where each student finds an electronic device and analyzes the component complexity and design. The project culminates in a presentation where the student must consider the production volume, materials required for manufacturing, and capital equipment in order to effectively complete the SMT process. As might be expected, the students typically select vastly different products – from cable set-top boxes to cell phones. The result is an appreciation for the variety and complexity of the

electronic product industry – no two assemblies are alike, and our students learn that first hand prior to going into industry.

In summary, this case study describes a bold rethinking in industrial engineering education that recognize the gap that has formed between academic preparation and industry need in high tech electronic product production. But even more important has been the significant progress made to close that gap by implementing many creative changes to an industrial engineering student's post-secondary curriculum.

Measuring the Success of Post-Secondary Production Engineering Education

When we design an experiment we typically try to statistically establish the causal relationship (if any) between independent and dependent variables – sometimes the data can be quantified, other times they cannot.

Measuring the success (the dependent variables) of a new way to approach the post-secondary education (the independent variables) of a student who wants to have a career in electronic product production first involves understanding the employers' expectations. These expectations are built upon the production-related job tasks that the various engineers in either an EMS company or an OPD (Original Product Developer) requires for successful product assembly. In addition, that analysis should include comparisons between business tier levels measured in annual revenue. As stated earlier, the tier has an impact on the responsibilities a given production engineer has within the organization and, hence, what management's expectation is of the production engineer. RIT has been engaging various EMS and OEM companies that hire Engineers into SMT roles to provide an academic, independent assessment of the job tasks that are needed to be taught in a four year production degree program.

Skills gap and skills shortage are consistent elements of the STEM workforce assessment rhetoric in the recent years [18], [19], [20]. Nevertheless, skills gap narratives often paint a sweeping picture of gap in generic skills rather than field-specific technical skills (micro). This results in specific skills needs of different industries getting overshadowed or ignored in skills gap exploration. Despite these concerns, skills gap studies within manufacturing sector tend to concentrate on positions difficult to fill (supply issue) rather than on specific technical competencies that are missing in the available pool of applicants. There are hardly any studies that document the specific technical skills employers have difficulty in sourcing or the changing requirements for entry into the industry [21, 22].

Most importantly, industries that are involved in technology-aided manufacturing face an additional level of challenge. The changing nature of production work and the automation of processes demand cross-disciplinary teams that work in sync at every stage of the manufacturing process. This requires engineers with depth of knowledge in their discipline and also breadth of awareness about other fields where their discipline knowledge could be gainfully applied [23, 24]. However, higher education has not demonstrated the flexibility in curricula that enable the creation of such 'T-shaped' engineers[20]. Lack of such 'T-shaped' engineers with cross-disciplinary knowledge and skills and the impending retirement of baby boomers will result in 2,000,000 manufacturing jobs going unfilled by 2025 [25].

General Conclusions

1. For some rapidly changing professions such as high tech electronic product production, the traditional educational model is no longer effective in producing a world class workforce.
2. It is not realistic to expect that the current strategy of educating in one world (academia) and then sending the graduates to the real world will produce an industrial workforce with the necessary skill sets.

Conclusions: A New Educational Model

1. What is required is an extension of Mortimer Adler's *Paideia Proposal* in the primary and secondary segments of the educational pipeline, adding an introduction to the construction and operation of the electronic "toys" that have become an intrinsic part of the young student's life.
2. In the post-secondary segment of the pipeline, a correspondence must be made between the engineering course material being studied and how that material relates to the positions the students will hold after graduation. Having the students use a real world contract production business as their classroom, co-located with the school, will close the current, ever-widening gap between academic preparation and industry need. This is done by providing "learning for earning" (leading edge marketable skills), as well as the traditional "learning for learning." As important, the student can be effectively taught "wisdom" or "judgment" and other "soft" skills that cannot be taught in an antiseptic classroom.
3. The electronic product production industry is very capital intensive with new and improved equipment being introduced continuously. The EMS business will utilize leading edge design and production equipment that the equipment suppliers will continually refresh. This will permit the student to develop confidence in the equipment over their four year education period and will serve as a marketing tool for the equipment providers.
4. This model will also provide the college a real time, self-updating curriculum. The real world will dictate the ever-changing course work that will be most relevant to the student by being most beneficial to the business.
5. Potential future employers will have their products produced in the contract production (EMS) business by participating students as part of their engineering education. These will be desirable employees upon graduation. Legal contracts will be available between the company and the student, guaranteeing the student a job upon graduation.
6. This new education model produces a win-win-win arrangement among the equipment suppliers, the high tech electronic product industry and the student.
7. As an interim response to the high tech electronic product production industry's need for properly prepared engineers, a gap analysis should be done to understand the specific skills needed by industry versus the current skills taught at the post-secondary educational level.

Conclusions: A New Business Organizational Model

1. The organizational business model that has evolved out of Henry Ford's division of labor model must change. This hierarchal structure is cost-burdened as a result of massive overhead and indirect activity and should be replaced. It simply cannot compete effectively on today's low labor rate global playing field.
2. Using engineering personnel who have been educated in accordance with the new educational model will permit a radical organizational restructuring from the present hierarchal division of labor model (Figures 4 and 5) to a model with only two groups (Figure 6).

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