Concurrent Education – A New Post-Secondary Educational Model that Provides "Learning for Learning" as well as "Learning for Earning" in Rapidly Evolving Industries such as High Tech Electronic Product Design and Assembly

Abstract

This paper presents a new engineering education model that employs the principles of Concurrent Education [1]. The four-year post-secondary program will result in a B.S. in Applied Engineering and Production Sciences. All traditional engineering major areas of specialization (e.g., M.E., E.E., I.E., etc.) are eliminated. The paper makes the case that, in all these areas, the *engineering* is essentially the same. The difference is the artificial focus on particular segments of the continuous physics or science spectrum. Unlike the traditional post-secondary engineering education model, this new model wraps an engineering college around a contract engineering business, or full service EMS company (electronic manufacturing services). This new post-secondary education architecture will provide the student with a real-world learning environment for a full four-year undergraduate engineering program. The students learn the traditional engineering theory and practical skills by participating in every aspect of the EMS business – hence, the phrase *concurrent education*. The professors in the school also lead project teams consisting of students and staff on the EMS production floor. The students will be compensated for their work in the EMS. The teaching staff will be employed by the business as well as the school. The paper presents the planned curriculum for the students' freshman year. The school utilizes the real world EMS classroom to provide an active learning environment. As the students progress through the program, typical textbook-taught engineering subjects such as, dynamics, motion control, analog and digital electronics, heat transfer, thermodynamics, material science, calculus, etc., will be taught by utilizing the EMS production equipment, product designs and manufacturing/assembly processes to teach the theory, coordinated with written supplements to the traditional engineering textbooks. The paper also presents the win-win-win relationship developed for the three entities that have an interest in the new educational model's construction: 1. The Capital Equipment Automation Industry: Automated electronic product production is extremely capital intensive. Companies providing their equipment to the 501(c)(3) business means the students will be learning on it. In addition, the EMS will showcase the equipment operating in a real world environment. The equipment manufacturers will be able to show potential customers their automation equipment in this setting. 2. The Companies That Have Their Products Assembled and Perhaps Designed by the EMS: There is no better education for future employees (the students) than their participation on the product team that is building those products. Formal employment contracts between the company and the students upon graduation will be available. 3. The Students (i.e., the school's customers): Being educated in a competitive, real world environment means the students will be exposed to leading edge design and production technology (e.g., advanced automation, artificial intelligence, meta process control, etc.) with their course work continually updated as the EMS business processes advance to stay competitive. The paper identifies and explores this self-updating nature of the curriculum to meet the needs of the business as a method to ensure the student is always receiving a leading edge education. The students will always bring this acquired state-of-the-art wisdom to their future real world employers, fulfilling Wordsworth's words that *the child is father to the man*.

Key words: manufacturing competitiveness, engineering education excellence, engineering curriculum, offshore manufacturing, artificial intelligence, Concurrent Education, EMS Business

Introduction

In this paper the following terms are used in the following ways:
Manufacturing – the fabrication of both electrical, electronic and mechanical components.
Assembly – the process of connecting or joining components into subassemblies and a final assembly, including electrical test.
Production – the process of creating a product by *manufacturing* and *assembling* components.
Design – creating both the unique electrical and mechanical functional features of a product.
OPD – Original Product Designer, or Developer – A company that produces and brands their own products with or without the participation of contract services.
EMS – Electronic Manufacturing Services Provider – a full service contract manufacturer who can provide all elements of electronic product design and production for an OPD.

Electronic products and systems are ubiquitous. From an electric pencil sharpener to the fire control system on a Trident nuclear powered submarine, these products utilize electrical components packaged in a mechanical assembly. During product or system operation, there is input from a human, robot or another product or system, causing a desirable output from the product or system to a human, robot or another product or system. The input data, both analog and/or digital, are processed, and the resultant output is some form of work – electrical, mechanical or both (the path integral of a force over a distance) – e.g., a useful pencil point is created, or a missile is fired at a target. These products and the production processes needed to create them contain all the traditional science and physics theory our traditional post-secondary educational system have been teaching – the physics hasn't changed. However, the application of the physics and the processes employing the physics has changed with the ever accelerating technological advances. The traditional method academia has used in providing students with the skills needed to develop and produce the thousands of products needed by individual consumers, companies and governments is in serious need of rethought and revision. This paper does not address pure research as an occupation. Even so, a student grounded in science and physics at an undergraduate level, taught practically and actively in a concurrent fashion, has an advantage in their future research pursuits.

An engineer must be well versed in many high-tech electronic product design and production techniques to thrive in the real world. For example, advanced robotics using artificial intelligence and virtual/augmented reality are tools that have and will be used extensively in electronic product design and production. These are tools that have been looking for a home in academia. Simply offering a course in these leading edge tools without the student actively participating in their application is not an effective teaching method. Teaching in a real world competitive business setting with student involvement will provide the necessary skills needed to complement the theory. This concurrent education method is significantly more effective in teaching these quickly evolving technological tools than the traditional teaching method.

There are many ways to design a particular electronic product. For a given design, what are the resulting attributes that maximize the "goodness" of a product's design? Here are just a few:

1. Does the product do what it is advertised to do?
2. What is the product's cost (price) / benefit?
3. Does it perform reliably? How robust is the product to the variability of the conditions in which is used?

4. Is the product's price point competitive with similar products? What is the total cost, including the cost of yield loss, needed to produce the design in production?
5. Is the operation of the product "user friendly?"
6. Is the production, operation and disposal of the product "eco-friendly?"

Electrical products do not miraculously appear through some sort of spontaneous generation – they go through a design process. In some cases, the initial phase of this process is now being done by computer: Provide the product performance specifications, operating conditions and other salient product requirements such as size, weight, interface, etc., to a computer program, and the computer will create the product design. When a design is shown to be satisfactory through some combination of analysis and testing (through simulation modeling, electrical, RF and mechanical testing of prototypes), then the production process is validated. This should include developing and validating the supply chain. Finally, a formal statistical study of the elements of the production process is done to determine the Cpk – a prediction of production yield based on a sample run. Using the traditional education model, are students learning the skills needed to successfully perform these tasks? Can graduates produce products with attributes described above? Even if we are attempting to teach these skills, how effective are our methods?

A Simplified General Process for Launching a New Product

1. Form a project team.
2. Write a product specification.
3. Test the product's value from a marketing perspective by performing a QFD (Quality Functional Deployment) analysis.
4. Modify the product spec. accordingly.
5. Construct a project plan identifying required tasks, dependencies, task durations and resources. Calculate the project duration and the critical path using a PERT chart.
6. Conduct the electrical and software design (block diagrams, schematics, logic flow).
7. Breadboard the electrical / software design.
8. Modify the electrical / software design accordingly.
9. Layout and test the electronics on a printing wiring board (circuit board) prototype.
10. Perform the mechanical / packaging design. In parallel, assess the producibility (manufacturing and assembly) of the product through a DF MATERRS^{SM} analysis (Design for Manufacturing, Assembly, Test, Environment, Rework, Repair and Serviceability).
11. Build prototypes.
12. Perform the appropriate environmental testing (Thermal, Shock, Vibration, Reliability).
13. Modify the design.
14. Develop operations sheets for production. For high volume, utilize a continuous flow assembly strategy – line balance.
15. Establish an acceptable material supply chain.
16. Measure the process variation and validate the production process by calculating the process capability, Cpk. It should be a minimum of 1.33 to ensure a capable process with a short term 4-sigma level defect rate (which translates to 3.2 defects per million opportunities or 3.2 DPMO).
17. Begin production with process and meta-process control monitoring (Factory 4.0)

The Current Value of a B.S. degree in Engineering The debate on what value should be assigned to a post-secondary engineering degree for a student who is emerging from the traditional educational pipeline into the real world continues to be provocative. As with most issues of this type, a danger is arriving at an unconditional conclusion based upon generalizations. The more prudent approach is to narrowly define the conditions that are under analysis. For example, "value" is the operative word which requires attention. Are we speaking of "value" in the sense of imbuing principles in the student that develop an understanding of the world and allow her to achieve individual fulfillment through both personal achievement and making a contribution to a particular field of study? Are we referring to the "value" of an education that provides the student with real world, marketable skills in a specific industry or business? Are we evaluating a particular type of post-secondary degree: associate's, bachelor's, master's, or doctorate? Does the achieving of a degree represent a proficiency in competing as an individual or contributing in a team environment? Has the student learned problem solving, critical thinking, team dynamics, conflict resolution, process development and other general "soft" skills? How many of the skills required in the previous paragraph are taught? Even if some are, is the teaching done in an antiseptic classroom or a real world environment? Are they taught concurrently, in sync with teaching the theory, or without regard to the time frame?

There is Something Seriously Wrong Here!

1. The U.S. world ranking among 71 industrialized countries in science is 24th, in math 38th [2].
2. The U.S. achieves these results while requiring an out-of-state student at a public college to pay an average of $154,528 for a 4-year B.S. degree in Mechanical Engineering
3. Student debt is out of control. At over $1trillion, student loans are now the second largest form of consumer debt.
4. Apple Inc., IBM and Google no longer require an applicant for employment have an engineering degree. In fact, they no longer even require that you went to college [3]!

The History of Education in Less Than 600 Words – How did we get here?

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 [4, 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.

The History of 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 children to achieve whatever they 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.

Adler versus Dewey

Dr. Mortimer Adler's 1982 *Paideia Proposa*l – *An Educational Manifesto* [5] 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.

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 … [5. 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 engineering learning than educating in the real world where the theory is on full display.

The Traditional Educational Strategy – The Education Pipeline

Our educational process can be looked at as a pipeline (Fig. 1). Our post-secondary (college) part of the pipeline for engineering education has largely adopted Adler's K-12 "learning for learning" philosophy. 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*. Inside the pipeline students are shepherded 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)

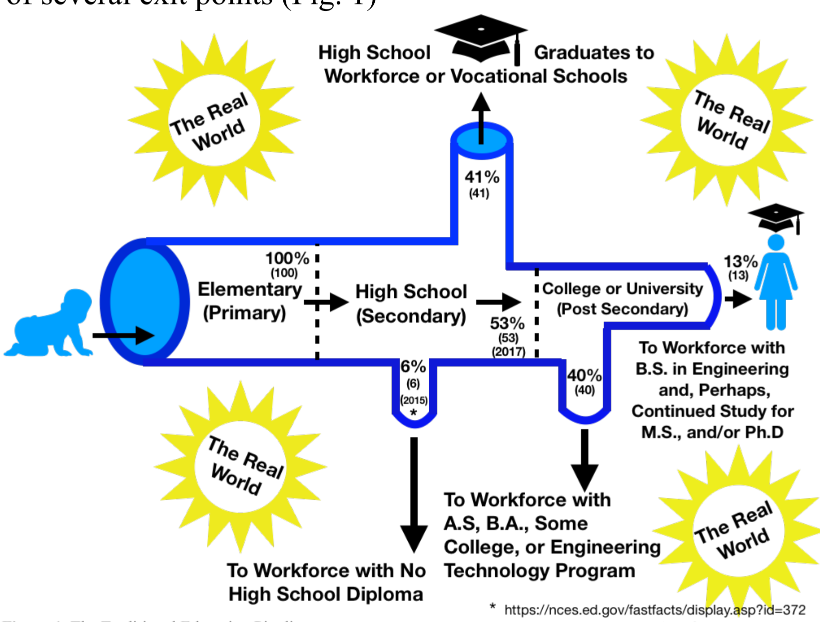


Figure 1. The Traditional Education Pipeline

What happens inside the pipeline has changed considerably from the beginning of formal education until today.

Our Traditional Education System's Strategy to Produce Engineers

Dr. Murray Gell-Mann was a particle physicist who named and helped discover the sub-atomic particle the "Quark." In his 1994 book called *The Quark and the Jaguar*, Dr. Gell-Mann reflected on why he had been so successful in his academic studies, culminating in a doctorate from M.I.T. He wasn't as smart as some of his student friends and yet seemed to breeze through his undergraduate and graduate work as his more intelligent friends struggled. Then, the light bulb went on when he realized that his superior ability to "memorize, regurgitate and forget" was at the core of his academic accomplishments [6]. 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 most of the real-world problems an engineer encounters do not have a closed-form solution.

Our academic strategy from the beginning of its development has been to educate in one community and then send the "educated" out into the real world to work – keeping a "wall of separation" between the two as evidenced by the lack of real world experience, in general, of the college teaching faculty. As the technology has accelerated, this wall has created an ever growing gap between education preparation and real world need. The "dual world" model does not work as evidenced by the statistics given above. The academic community has lost touch with the ever changing engineering skill requirements of the real world. It is not enough to teach the student to solve the odd-numbered problems at the end of the chapter – and, as mentioned above, you can find the answers to the problems at the end of the book. No, most of the problems a student will encounter in the real world do not have closed form solutions – there are more unknowns than equations. Question: What is needed to come to the best solution for an open form, statistically based problem? Answer: Good judgment and her sister critical thinking. Question: What is required to develop good judgment and critical thinking skills? Answer: Real world experience. Question: How can a student develop good judgment and critical thinking skills? Answer: Be educated in a real world environment.

Product Assembly Then, Product Assembly Now

The assembly technology for electronic products has changed from largely manual processes to complex automated processes. (Fig. 2) 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 BTCs (Bottom Terminated Components) and are not hand solderable to a circuit board. In addition, it is not feasible to hand solder 03015 metric (0.012 x 0.006 imperial) chip resistors. (Fig. 2b)

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 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* [7]. This has included the automation of material retrieval and transport, as well as the automated insertion of leaded components on the same SMT component placement machine platform.

Figure 2a – The Way Electronic Components Looked Then …

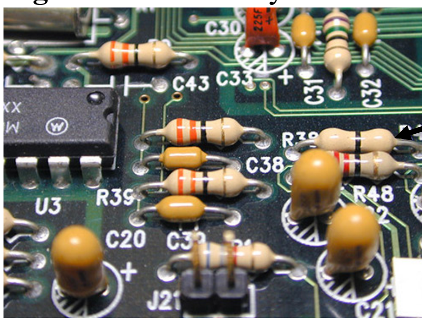


Figure 2b.
... and the Way They Look Now on a Jefferson Nickel ...

Figure 2c.
... Requiring Moving from Labor Intensive Manual Insertion and Hand Soldering ...

Component Insertion and Placement Robot

Solder Reflow Oven

Figure 2d.
...to Automation (Automated Circuit Board Assembly Line at Rochester Institute of Technology)

Not only the vast technology 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 [8]. 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 [9]. Most schools cannot provide their students with the real world experiences necessary to develop an understanding of the changing skills needed for these new design and production tools. 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 education pipeline, and then send the "educated" into a real world that requires many additional skills 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 thought of as a vocational or trade occupation and transformed it into one that requires engineering level personnel.

A New Engineering Educational Model – What is the most effective path toward *Wisdom* as students move through the Pipeline? - Closing the Gap Between Academic Preparation and Industry Need

We believe our education goal of creating a world class engineering workforce requires developing student *wisdom*, not just memorizing and learning closed-form problem solving. To do this active learning for a student's entire education is required to develop judgment and critical thinking skills by using a concurrent, real world, skill-based strategy that complements "learning for learning" with "learning for earning."

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 your smart phone? You know, the one with all the cool apps on it?" How difficult would it be for the first grade teacher to show the 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 Graduate Segment – Skipping the post-secondary, college segment for the moment, technical masters and doctorate theses are either 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 assembly 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 are studied. Empirical tools create a bridge from the theoretical to the practical.

The Post-Secondary Segment – This is where a total 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 an EMS 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* [10] [11]. Receiving a B.S. in Applied Engineering and Production Sciences attained in this real world educational environment would prepare a student to hit the ground running upon graduation. However, that environment must be continually updated to respond to the real world technology that is in a constant state of change.

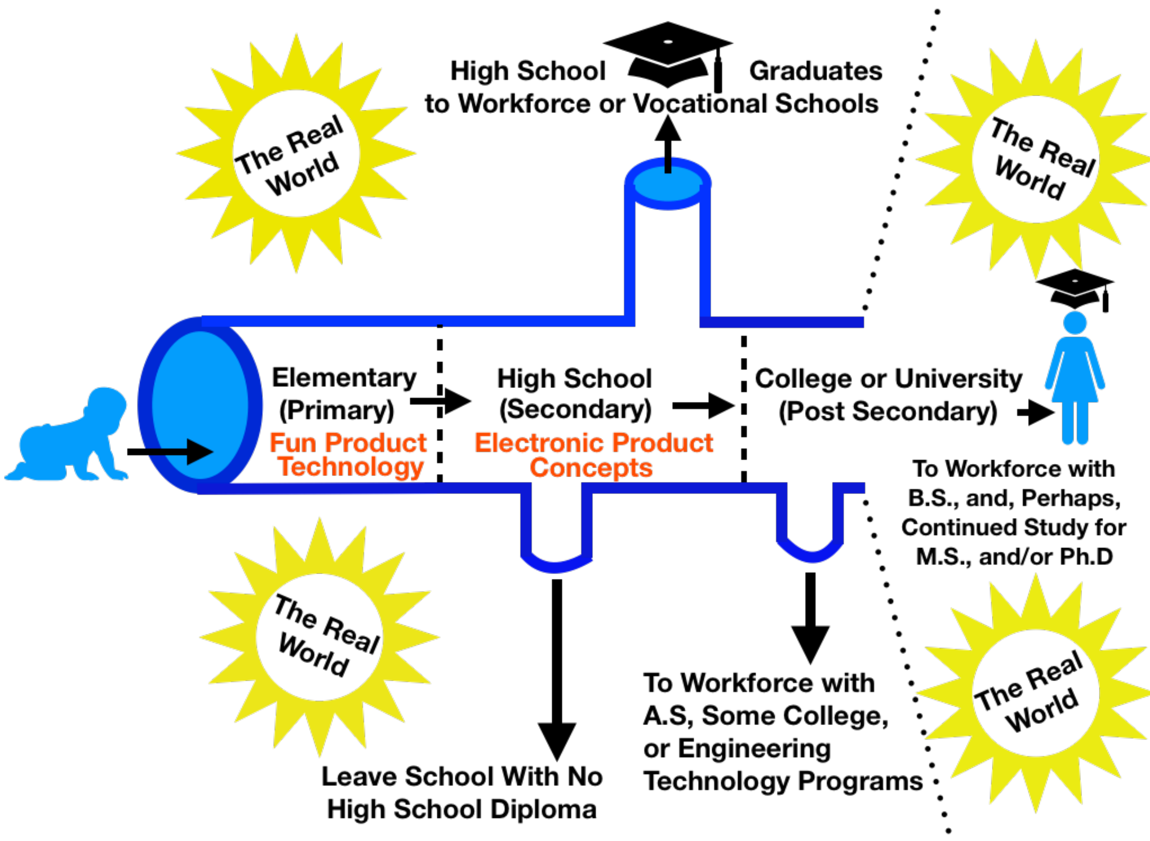


Figure 3. The Education Pipeline Based on the New Model

The New Post-Secondary Engineering Education Model is Self-Updating

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 electronic 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 that must compete for survival as the student's classroom. Free market economics requires change 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 Product Design and Production Engineering Sciences is a paradigm-shifting alternative. The student would learn the additional and changing skill sets in 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 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 it is adopted for 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: primary through postgraduate. 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 are normally 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 a the ever-widening preparation gap. To address this, a school is wrapped around an EMS (Electronic Manufacturing Services) business. The business is used as a significant part of the student's classroom for their entire undergraduate and post-graduate education, leading to a B.S. in Applied Engineering and Production Sciences, and perhaps M.S. and Ph.D. Degrees.

The New Post-Secondary Engineering Education Model Merges Academia and Industry into a Win-Win-Win relationship

There are three primary entities with an interest in the new educational model's construction:

1. <u>The Capital Equipment Automation Industry</u>: Automated electronic product production is extremely capital intensive. Providing their equipment to the 501(c)(3) business means the students will be learning on it. In addition, the EMS will showcase the equipment operating in a real world environment. The equipment manufacturers will be able to show potential customers their automation equipment in this setting.
2. <u>The Companies That Have Their Products Assembled and Perhaps Designed by the EMS</u>: There is no better education for future employees (the students) than their participation on the product team that is building those products. Formal employment contracts between the company and the students upon graduation will be available.
3. <u>The Students (i.e., the school's customers)</u>: Being educated in a competitive, real world environment means the students will be exposed to leading edge design and production technology (e.g., advanced automation, artificial intelligence, meta process control) with their course work continually updated as the EMS business processes advance to stay competitive.

A New Production Organizational Business Model – A 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.

Hierarchal Organizations
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?

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.

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 [7]. 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 [13].

Eliminating the *Silos* or *Fiefdoms* (and Their Costs) from the Corporate Landscape
As the division of labor began to become more and more pervasive, 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, who 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 at which 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 himself, 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.

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.

Humans to Machines, and Back to Humans – The JEM Center Organizational Model
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*. (Fig. 7). 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 Education 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 [13], [14].

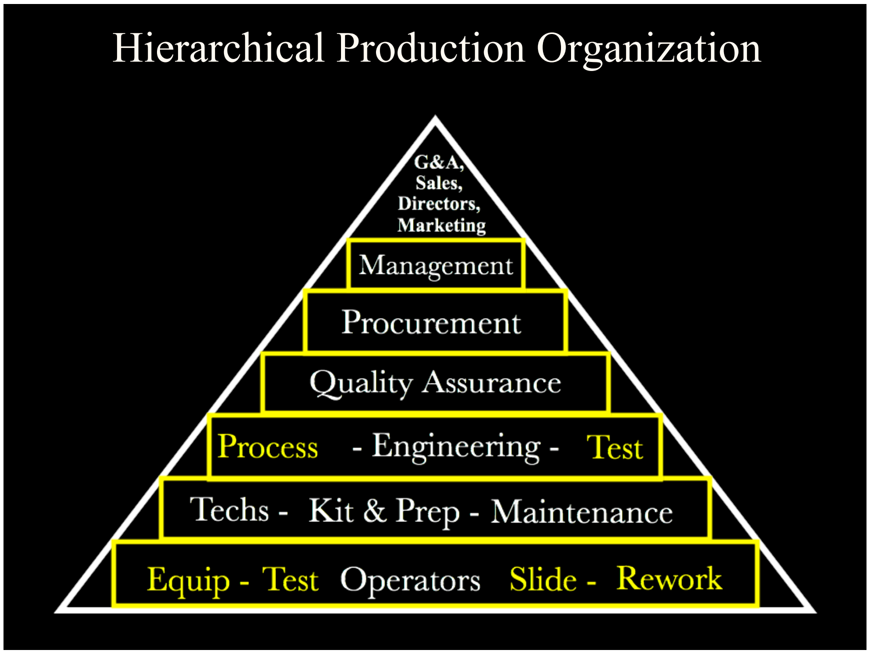


Figure 4. Existing Corporate Division of Labor Model: Direct and Indirect Labor

Figure 5. Existing Corporate Model: Silos and Fiefdoms

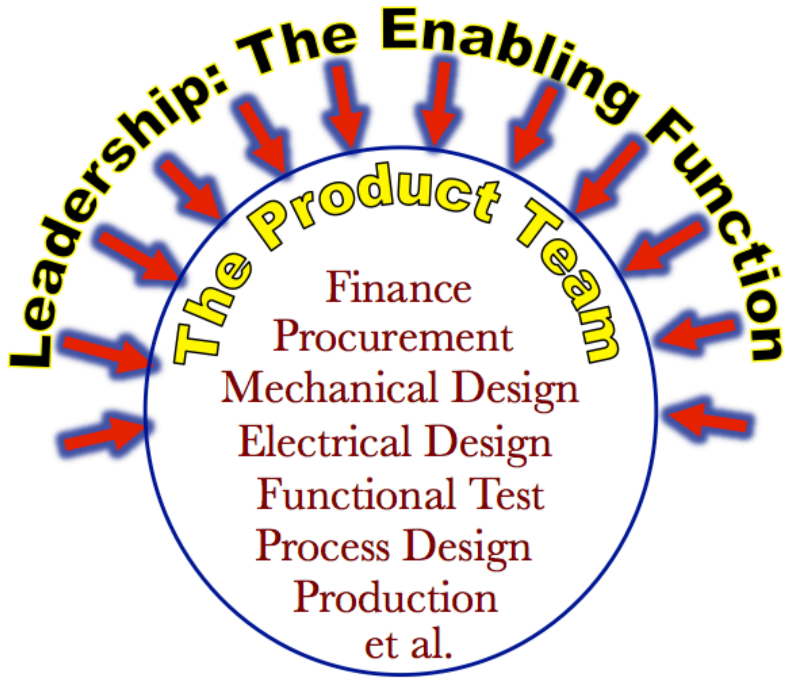


Figure 6. The New Corporate Organization Model - Only Two Groups: Product Teams and Leadership

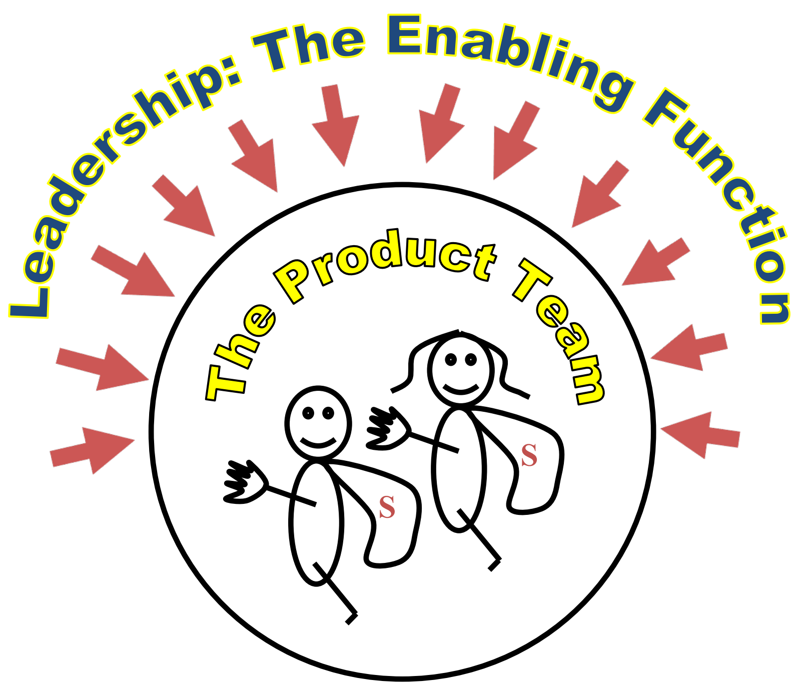


Figure 7. The Cross -Trained "Super Engineer" – Fewer People, Better Educated. More Skills, Self-Managed

The Future Jefferson Electronic Manufacturing (JEM*) Center

* License is taken with the acronym "JEM." Using the definitions of "manufacturing" and "production" in the first paragraph of the "Introduction" section above, it should be "JEP," The Jefferson Electronic Production Center ("JEP" Center). However, "JEM" sounds better than "JEP."

How the JEM Center Business Model Allows Industry to be More Competitive

A new industry production business model is based on dismantling the traditional hierarchal business structure and replacing it with self-directed product teams, staffed with engineers who have been cross-trained in the 4-year real world classroom at the JEM Center. A B.S. degree in Applied Engineering and Production Sciences, signifies that the graduate has the necessary theory AND experience needed to achieve a proficiency in all engineering, product production and interpersonal skills.

The Future Jefferson Institute of Technology (JIT)

As discussed above, this is a new college that uses the new JEM Center as its classroom. The student will participate in all aspects of the JEM business as part of project teams – half-staff, half-student. The project team in the JEM Center is led by the same professor / instructor in JIT. JIT is in the process of being launched. Included in this paper are class listings for year 1 and the JIT newsletter containing launch status.

Jefferson Institute of Technology
Classes / Lesson Plans - Year 1, Trimester 1

1.1.1 Introduction to the Jefferson Electronic Manufacturing (JEM) Center Includes,
  - 1.1.1.1 Introduction to Civics
  - 1.1.1.2. Organizational & Personal Ethics in an Engineering and the Production Team Environment

1.1.2 Anatomy of an Electronic Product and an Introduction to the Assembly Processes

1.1.3 Basic Economic Theory and its Application in the Electronic Product Production Business

1.1.4 Calculus 1.0 and its Application in High Tech Electronic Product Design and Assembly (e.g., Introduction to Motion Control – distance, velocity, acceleration; PID as a Tool in Oven Control) – Use Component Insertion and Placement Equipment in JEP

1.1.5 Basic Production Mathematics – Units, Significant Figures, Estimating, Continuous flow Assembly, Line Balancing, Theory of Variation

1.1.6 The Formation of Technological Thought in the Western World

1.1.7 Fundamentals of Chemistry and Material Science and Their Relation to Electronic Product Assembly

1.1.8 Applied Chemistry in Electronic Product Manufacturing

Note: All classes will be tied to student work on project teams in the JEM Center using the science, physics, math and required "soft skills" embodied in the state-of-the-art production lines and other areas of JEM design and production activity. This will bring the course material to life. Supplemental textbooks are being written to assist in this linkage. Course lesson plans have not been included in this paper.

Jefferson Institute of Technology
Classes / Lesson Plans
Year 1, Trimester 2

1.2.1 Electronic Product Production: A Combination of Design, Manufacturing and Assembly and Test

1.2.1.1 Designing the product – Creating a product specification: Quality Functional Deployment (QFD) and basic electronic design theory

1.2.1.2 Producing the Product
- 1.2.1.2.1 Kitting the parts
    - 1.2.1.2.1.1 Manufacturing (Fabricating) Parts
        - 1.2.1.2.1.1.1 Make
    - 1.2.1.2.1.2 Ordering Parts
        - 1.2.1.2.1.2.1 Buy
- 1.2.1.2.2 Assembling the parts
    - 1.2.1.2.2.1 Assembly in Product Production – Process Development
    - 1.2.1.2.2.2 Assembly in Product Production – Lean Assembly
        - 1.2.1.2.2.2.1 Lean Assembly
        - 1.2.1.2.2.2.2 Value Stream Mapping (VSM)
    - 1.2.1.2.2.3 Assembly in Product Production – Product Flow
        - 1.2.1.2.2.3.1 Batch Assembly
        - 1.2.1.2.2.3.2 Continuous Flow Assembly

1.2.1.3 Testing the Product

1.2.2.1 Assembly in Product Production: Process Development

1.2.2.2 Assembly in Product Production (Lab)

1.2.3 Working in Teams

1.2.4 Reading, Writing, Speaking, Listening

1.2.5 Working in Teams – Introduction to the JEM Center Team

1.2.6 Calculus 1.5

1.2.7 Physics 1 Simple Mechanical Machines – The Lever / The Pulley / The Inclined Plane & Wedge / The Screw / Gears / Wheels and Axles / Machine Elements and Basic Mechanisms / Hydrostatic and Hydraulic Machines / Internal Combustion Engines / Power Trains

Jefferson Institute of Technology
Classes / Lesson Plans
Year 1, Trimester 3

1.3.1 Computers in Product Production

1.3.2 Manufacturing in Product Production: Material Forming (Subtractive)

1.3.3 Manufacturing in Product Production: Material Forming Lab – 3-D Printing Introduction (Additive)

1.3.4 Digital Electronics (*Being Digital*)

1.3.5 Calculus 2.0

1.3.6 Physics II (Electronics / Modern / Nano Technology)
- Water Analogy: Resistors, Capacitors, Inductors, Coils (Induction)
- Electric Work / Electrical Power
- The Physics of Heat: Thermal expansion, Temperature scales. What is heat? What is Temperature?

1.3.7.1 Electronic Product Production Process Development

1.3.7.2 Introduction to Process Troubleshooting
- Critical Thinking Introduction
    - Root Cause Analysis
    - Defect Analysis
    - The SPC Connection
    - Airless Tires – Pluses / Minuses

1.3.8 Analog Electro-Mechanical Machines: Relays / Solenoids / Transformers

How Does Your *Dynamics* Class Relate to Your *Engineering Economics* Class?

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 (JEM center), combined with the fact that the product team leader on the assembly floor is also an instructor or professor in the school (JIT). The team is self-directed and consists of about half staff and half students (Fig. 6). This permits an engineering education that is characterized by a real time correspondence between classroom instruction and the 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.

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 [15].

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 personnel 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.

Measuring the Success of the New Post-Secondary Engineering Education Model
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) for students who want to have careers in engineering requires a close symbiotic relationship between the school and the graduate's employer.

Whether the JIT graduate is employed through a contract with the JEM client for which they are producing and perhaps designing products as a student attending the Institute, or employed by companies that simply hire JIT engineering graduates, close tracking of the graduated student's employment performance will be done with the help of the employer. This will permit adjustments to be made at the school to continually optimize the school's ability to provide industry with world class engineers

Frequently Asked Questions and Comments

Q1. How do you reconcile the time needed for the additional course material and student JEM activity? 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 four years on product teams in the real word business that the school is wrapped around. How can all the additional classes and intense student JEM participation be accomplished in the traditional undergraduate engineering 4-year period? Where does the additional time come from?

A1. The traditional academic school year in the U.S. is 180 days. In Japan it is 240 days. In South Korea it is 250 days. The typical business year is 250 days. Because of the students' role in the JEM business and the objective of educating the student in the real business world, the new JIT educational model has a 240-day academic year: Three 16-week trimesters per year for four years.

Q2. How will a balance be attained between a student's work on project teams in the JEM Center and their course work in JIT?

A2. The classwork and JEM participation is closely coordinated as part of the lesson plans for JIT. For example, when taking the heat transfer class, the student will be working on the full convection solder reflow oven. There is a supplemental heat transfer text that has been written to accompany the traditional heat transfer textbook by Frank Kreith, et al. with theory and problems directly associated with the physics utilized in the JEM reflow oven. Additionally, the PID (Proportional / Integral / Differentiation) software algorithm used to keep the oven zones within a few degrees of their set points e.g., maintaining the reflow profile (zone-to-zone temperature setpoints) will be used in the machine control software educational unit.

Q3. This is a complex and complicated project. Can you provide an assessment and implementation plan and the data that justifies the approach you are taking?

A3. The kind of fundamental changes suggested above do not come easily. Acceptance and implementation are difficult to achieve. Data for the justification of the approach is found in this paper. The basic assessment and effectiveness metrics are described in the section above entitled "Measuring the Success of the New Post-Secondary Engineering Education Model"

The current status of JIT as of the writing of this paper is included below.

Q4. One has to wonder if the new educational model keeps students locked into a narrow field that limits future employment opportunities.

A4. Actually, we believe the instruction across all traditional engineering disciplines will provide the student with a more robust series of engineering skill sets. As the degree title implies, a *B.S. in Applied Engineering and Production Sciences*, the intent is to provide the student with knowledge and an ability to work in all engineering settings across the science and physics continuum. This along with the development of skills such as critical thinking, judgment, team dynamics, conflict resolution, etc. should make the student a valuable addition to any technically based company as well as prepare them for graduate school if this is what they desire. Please see the paper above for details.

Q5. What about accreditation?

A5. The plan is to have the JIT engineering degree program accredited by ABET.

General Conclusions

1. For some rapidly changing engineering professions, 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 Education Model

1. In the post-secondary segment of the educational 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.
2. The electronic product production industry is very capital intensive, with new and improved equipment being introduced continuously. The JEM 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.
3. This model will also provide JIT 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.
4. Potential future employers will have their products produced in the JEM 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.
5. This new education model produces a win-win-win arrangement among the equipment suppliers, the high tech electronic product industry and the student.

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 education 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 (Fig 6).

Figure 8. The Jefferson Institute of Technology Newsletter

Volume 6
No. 4

The JIT Newsletter

The Quarterly Summary of the Development and Launch of The Jefferson Institute of Technology

December 2019

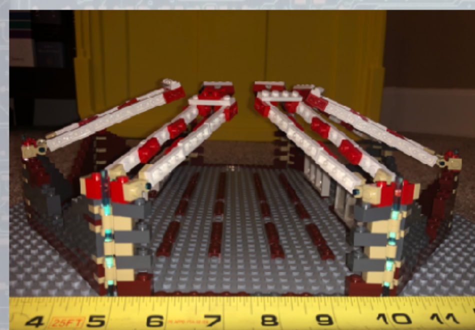
JIT FACTS

Did You Know …

1. JIT will be co-located with the JEM Center, the Jefferson Electronic Manufacturing Center: a contract manufacturing (EMS) business.
2. **The JEM Center will provide the student with a real-world classroom to supplement the traditional undergraduate engineering education.**
3. Over 4 years, JIT students will participate in every aspect of the JEM Center operation - AND, be paid for their contributions.
4. **Successful completion of the 4-year JIT program will result in a B.S. in Applied Product Design and Production Sciences.**
5. Each product assembly process step continues to be scrutinized & assigned to a traditional applicable engineering class, e.g., printing solder paste to chemistry, fluid dynamics, etc. The JIT class is then supplemented with process - related content.
6. **The JIT academic year will consist of three, 16-week trimesters.**
7. Students will graduate with APICS (Material & Supply Chain Management) and ASQ (Including 6-Sigma Black Belt) certifications. They also will have taken the Fundamentals in Engineering (FE) Exam that can lead to a P.E license.

THE JEFFERSON INSTITUTE · MANUFACTURING EXCELLENCE THROUGH CONCURRENT EDUCATION · JEFFERSON PROJECT

2019, Q4 Accomplishments and 2020, Q1 Objectives



1. (Photo above) An early representation of JEM with 4 independent, flexible product assembly lines. Ceiling is hung (like Madison Square Garden In NYC). This provides structural integrity while maximizing operational floor space. JIT classrooms / labs / residence apartments for students and faculty are in the process of being added to model.
2. A significant change to the structure of the school has been made. Instead of the school (JIT) being "not-for-profit" & the associated, real world business classroom (JEM) being "for-profit," both will be "not-for-profit."
3. Capital formation underway ($30-$40 M). Seeking "Angels!"
4. Paper on the state of high tech education was presented for ASEE conference (American Society of Engineering Educators) at Cooper Union in NYC. Paper is on website. Abstract for follow-up for paper, specifically on JIT/JEM, at Montreal conference in June was accepted.
5. We were invited to do a webinar by SME. Thanks to James Moore of Cardio Command for facilitating. You can view it from our website.

JIT FACTS

Did You Know …

8. **Real world Issues encountered by the student in the JEM Center operation will be addressed in real time. These issues, many without closed-form solutions, will permit the student to develop a crucial skill: good judgment - invaluable to their future employers.**
9. Corporate sponsors will provide leading edge automation equipment and supplies. Students will always be learning in a state-of-the art environment.
10. **Basic student tuition is $5k/ trimester. Corporate student sponsorships, scholarships & the paid work in the JEM Center can reduce this cost.**
11. Curriculum development is partially based on Mortimer Adler's *Paideia Proposal and The Great Books*, but with a blending of *Learning for Learning, AND Learning for Earning.*
12. **The School's development borrows from the Jeffersonian strategy he used for The University of Virginia.**
13. Formal contracts between students and JEM's clients will guarantee students a job upon graduation, and guarantee the client companies employees with a world class education - those educated by building the company's products.

Detailed project information can be found on our website: http://thejeffersonproject.org
If you are interested in participating, there are many opportunities, e.g., faculty positions, corporate sponsorships, textbook development and review, and more.
Contact Tom Borkes at jeffer2@earthlink.net or (407) 342-3228 for more information.

You have received this newsletter because of your interest in the Jefferson Project. If you no longer wish to receive project updates, send an email to jeffer2@earthlink.net and request to be removed from our distribution list.

References

[1] T. Borkes, "Concurrent Education: A Learning Approach to Serve Electronic Product Manufacturing," in *Proceedings of SMTA International, 1994,* San Jose, CA

[2] Pew Research Center Story, February 15, 2017, Data from the *Program for International Student Assessment* (PISA) of the *Organization for Economic Co-Operation and Development* (OECD)

[3] C. Purtill, *Apple, IBM, and Google don't care anymore if you went to college* from Quartz, August 23, 2018. [Online]. Available: https://qz.com/work/1367191/apple-ibm-and-google-dont-require-a-college-degree/

[4] E. H. Wilds and K. V. Lottich, *The Foundations of Modern Education*, 4th ed. New York: Holt, Rhinehart and Winston, 1970.

[5] M. Adler, *The Paideia Proposal – An Educational Manifesto*. New York: Simon & Schuster, 1982.

[6] M. Gell-Mann, *The Quark and the Jaguar*. New York: W.H. Freeman, 1994, p. 75.

[7] T. Borkes and L. Groves, "Reducing Labor Content as a Strategy to Improve Competitiveness," *Proceedings of SMTA International, 2015, Chicago, IL*, pp. 9-10.

[8] A. Toffler, *Future Shock*, New York: Random House, 1970.

[9] S. Hadlington, "Molecular robot opens the way to nano-assembly lines," *Chemistry World*, January 2016. [Online]. Available: https://www.chemistryworld.com/news/molecular-robot-opens-the-way-to-nano-assembly-lines/9302.article

[10] J. Rowley, "The Wisdom Hierarchy: Representations of the DIKW Hierarchy," *Journal of Information and Communication Science*, vol. 33, pp. 163–180, April 2007.

[11] D. P. Wallace, *Knowledge Management: Historical and Cross-Disciplinary Themes.* Westport, CT: Libraries Unlimited, 2007, pp. 1–14.

[12] T. Borkes, "A New Manufacturing Model for Successfully Competing in High Labor Rate Markets - How to Minimize Labor and Material Cost, the Controllable Contributions to High-Technology Electronic Product's Cost, and Assess a Manufacturing Region's Business Climate," in *Proceedings of the Pan Pacific Microelectronics Symposium, February 2013, Maui, Hawaii*.

[13] T. Borkes, "'… Like Holding the Wolf by the Ears …' The Key to Regaining Electronic Production Market Share: Breaking Free of the Division of Labor Manufacturing Model in High Labor Cost Global Regions," in *Proceedings of SMTA International, 2008, Orlando, Florida*.

[14] T. Borkes, "Electronic Product Assembly in High Labor Rate Markets – A Case Study in Exploiting the Counterweight to Low Labor Rate Competition: Automation," in *Proceedings of the Pan Pacific Microelectronics Symposium, 2014, Big Island, Hawaii*. p. 8.

[15] National Center for Educational Statistics. [Online]. Available: https://nces.ed.gov/pubs/web/95024-2.asp