Using the Principles of Concurrent Education to Teach a Post-Secondary Engineering Program

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ABSTRACT

Concurrent Education will use real world physics-based theory and leading edge production-based processes that are taught in conjunction with traditional engineering undergraduate course material. This concurrent and coordinated presentation of theoretical and real world subject matter will form a significant part of the student's *classroom* for a full 4-year engineering undergraduate program. This is essential for several reasons: 1. the rapid rate of change in *learning for earning* competitive skill requirements in an industry such as high tech electronic product design and production. These changing skill requirements simply outrun the ability of academia to keep up, 2. an environment of totally new and evolving real world design and process tools such as artificial intelligence, digital twinning, big data real time statistical analysis, extreme automation, and robotics, has caused the gap between academic preparation and the student graduate's industry skill level need to continue to grow, 3. companies that do not embrace these techniques quickly descend to a level of competitive disadvantage, 4. one strategy for a company to acquire these desirable new skill sets is to hire entry level personnel who have been exposed to them as part of their academic experience in a real world setting. This is a *deliverable* of concurrent education. Unfortunately, by continuing to educate as we have for decades using the traditional model of educating in one community and then sending graduates to the real world with primarily *Learning for Learning* skills, has been largely a failure on the global competitive landscape, 5. this paper identifies twelve key weaknesses in our traditional post-secondary engineering education process that has exasperated the mission of creating a world class competitive engineering work force.

The paper makes the case that a radically new approach is needed to confront the issues we encounter in today's globally competitive, rapidly changing environment. The Jefferson Project will wrap a new post-secondary school around a co-located EMS (Electronic Manufacturing Services) business. Successful completion of a 4-year undergraduate program will result in the student receiving a B.S. in Applied Engineering Product Design and Production Sciences. This paper uses several examples from the school curriculum to illustrate how students will use the EMS as a significant part of their *classroom,* using concurrent education to teach the traditional undergraduate engineering course content more effectively. The first example is the school's core undergraduate classes in *Vector Mechanics for Engineers: Statics and Dynamics*. The second example is a class in the school and EMS that include teaching the process for reflowing solder paste. This is shown to be an effective way for students to be educated in such concepts as thixotropic material, surface tension, free surface energy, oxidation, flux surface preparation, adhesive and cohesive bonds, wetting, and the dynamics of tombstoning. The EMS will be a full-service contract design and manufacturing business (Electronics Manufacturing Services). A key aspect of this highly automated, high technology business is that all the physics, technology, mathematics, and engineering that is taught in a traditional undergraduate engineering program are present – from material science to thermodynamics to analog and digital electronics to calculus and differential equations. In addition, students will acquire hard and soft skills such as team dynamics and critical thinking as they work on program teams that are half-student / half-staff, doing real world work for paying EMS clients, all the while being subject to real world competitive pressure. The science underlying the behavior of the universe hasn't changed! It has always existed, seamlessly knitting together observable (and non-observable) physical phenomena as part of the natural continuum we encounter. As noted below in item 7 of the section entitled *12 post-secondary educational weaknesses…*, academia has attempted to teach engineering by chopping up and codifying different regions of the natural continuum into *classes* with different instructors. The student goes from a class in material science to a thermodynamics class without any significant recognition that the science found in both is part of the same physics continuum, often with overlapping principles that should be stressed. The operational program teams in the EMS Center are led by program leaders who are also the students' professors in the school. This provides continuity for *all* engineering classes that are taught in this active learning environment. Supplemental textbooks are written and provided as a bridge between the standard textbook for an engineering class and the material as presented at the school. This paper provides a course description for the *Vector Mechanics for Engineers: Statics and Dynamics* classes to be taught in the second and third trimester of a student's freshman year. Correspondence is made between the subject matter as presented in a traditional antiseptic classroom and this subject matter, plus additional material that will be taught at the EMS Center. This paper demonstrates how a traditional *learning for learning* engineering education can be effectively supplemented with the latest *learning for earning* skills, using the sophisticated

real world design, automation, and processes in the EMS Center. Engineering theory is brought to life and kept up to date using component placement robotics and additional real-world leading-edge equipment and process techniques. Additional papers have been published on this subject [1], [2].

Key words: Concurrent Education, High Tech Engineering, Undergraduate Skill Gap, Learning for Earning

INTRODUCTION

The state of high tech engineering education in the United States is in crisis. It is a crisis that just won't be resolved by yelling "STEM, STEM, STEM!" Although this may make us feel better, it amounts to nothing more than nibbling around the edges of the issues as summarized in the section below: *The Twelve Weaknesses in Our Current Post-Secondary Engineering Education System*. The root causes of this education failure are found in the structure and objective of the post-secondary high tech teaching strategy. The structure of the traditional model that has been used for decades, i.e., teaching in one world, academia, and then sending the *taught* to the real world to work – simply doesn't work. Almost exclusively, the objective of the educators has been to teach *learning for learning* without regard to the requirements and conditions the students will encounter when thrust into the post-graduation real world. After all, in most cases this is what the educators are most effective teaching. Dr. Murray Gell-Mann of subatomic particle fame said it best. When asked what he credited his superior academic record over most of his classmates, even though he knew he was not as *smart* as many of them, he said: I realized my ability to get good grades was my ability to memorize, regurgitate and forget [12]. One last point: In a world of fierce global competition, the traditional model has used global wage rate disparities as an excuse for the exodus of high tech jobs from the U.S. This is mostly pretense as even in low labor rate regions of the world automation has diminished the influence of the labor cost contribution to a product's total cost. The exception is an automation process with high yield loss that requires significant labor intensive rework. This is discussed below in the section entitled *The Twelve Weaknesses in Our Current Post-Secondary Engineering Education System, 10. Faux Automation*.

This paper makes the case for using a new strategic model in high tech product design and production education: a post-secondary educational model that concurrently teaches the traditional *learning for learning* along with providing the student with *learning for earning* real world skill sets. It is an extension of Mortimer Adler's *Paideia Proposal* [3]. The basic tactical element for accomplishing this strategic objective is to co-locate a school with a business and use the business as an important element of the student's classroom during the entire 4-year undergraduate program.

THE TWELVE WEAKNESSES IN OUR POST-SECONDARY ENGINEERING EDUCATIONAL SYSTEM

There are twelve specific conditions that contribute to the inability of academia to provide industry (their meta-customers) with educated engineering students (their direct customers) that result in a world class, leading-edge workforce – a workforce that can successfully compete on the global landscape. Some of these reasons are controllable and some are not. The ones that are not controllable are structural in nature. They require a major reassessment of how we think about, and how and why we educate engineering students in our schools of higher education [4]. This, in turn, leads to a reassessment and overhauling of the goals that academia should embrace in engineering education. The remaining reasons are controllable and help form the tactical elements needed to meet the new strategic goals – goals that are built on changing the structure and relationship between academia and industry.

Condition 1: Outdated material - The necessary skill sets engineering undergraduates need to develop in the academic world are constantly changing. These are introduced in the industrial real world at a rapidly accelerating rate. Academia in its own isolated, stand-alone world, even with the best intentions of a college, cannot respond to this rate of change [5]. These skill requirements may turn over twice during the period of a typical 4-year engineering undergraduate program. This is illustrated by companies such as Apple and Microsoft who no longer require a college degree in engineering for entry level engineering job consideration [6]. They are more interested in the real world skill sets an applicant can bring with them to their companies (developed from the applicant's real world experience). Implicit in that statement from high tech companies seems to be the lack of value they see in an applicant's B.S. degree in engineering. i.e., the skill sets they would like to see or require don't normally come along with the degree.

Condition 2: High tech electronic product assembly continues to be thought of by many as it was in the decades of the 40s, 50s, and 60s, requiring only a trade school education - The widely held perception is that electronic product assembly consists of assembling leaded, through-hole components (Figure 2) either by hand soldering or wave soldering. The hand soldering typically occurs at single station build locations by single operators (Figures 2, 3, 4, 5) or by wave soldering. In the wave soldering process, normally components were inserted by a progressive slide line of women who are hand inserting components in a circuit board. When completed the *loaded* board is sent across a wave of liquid solder. (Figures 6, 7, 8, 9). The higher-level final box assembly and test is usually done manually as well. The corresponding process development and management used was and is still considered to require, at best, only an "engineering technology" degree rather than a "B.S. in engineering" degree – engineering math knowledge is not required. The reality is that hand assembly, even at low labor rates, where practical for leaded through-hole components is not feasible for components that are utilized today (Figures 10, 11, 12). In addition, product designs require analytic tools that have evolved into sophisticated computer techniques such as Finite Element and Finite Difference Analyses – clearly requiring an engineering level of understanding. Component manufacturing has introduced additive technologies, including 3-D printing, to its toolbox. Product assembly tools such as virtual and augmented reality, meta-process control (*Big Data Real Time Statistical Analysis*), extreme robotics, computer programming, et al., also require engineering and math skill sets.

Condition 3: The Naïve Student - The normal check and balance between the "supplier and customer" is not present. There is no easier mark to come along than a student (the customer) who can be easily persuaded to buy the value proposition that academia (the supplier) is currently selling: for upwards of $200,000 or more in cash and student loans you will receive a high paying job in industry (the real world) [7]. So, there has been little demand from the students or, for that matter the "meta-customer," i.e., the industry companies who employ the degree-holding students. Accrediting organizations who could provide a check on academia are normally academic-centric, without a clear understanding of real world needs. Since practically all schools have embraced the traditional academic model, industry has had to live with the quality of the entry level applicants – at least, until now.

Condition 4: Higher education academic standards have fallen - Notwithstanding endowments, colleges succeed economically, by persuading high school seniors that they should attend their institution for their post-secondary education. This objective, and student retention once they are matriculated, are important goals. There is a tension set up between meeting this goal and maintaining academic standards. However, the schools are faced with a dilemma: there has and continues to be a snowballing accumulation of skill deficiencies as students have been pushed along, shepherded frequently under the pretense of empathy, compassion, and social justice from their entrance into the academic pipeline to their arrival at the post-secondary stage – witness the reduction in difficulty and dilution in scoring expectation of the SAT test. In addition, colleges are faced with the general trend of reduced enrollment as this headline reveals: *U.S. colleges Enrollment dropped again in the fall of 2021, despite the arrival of vaccines* [8]. This trend that began before the pandemic and industry's indifference to a candidate's academic credentials suggest primarily correlation, not causation, to COVID-19.

Condition 5: Those that can do, do. Those that can't do, teach, Part 1 - Undergraduate engineering academia is littered with instructors who may be well accomplished at solving the odd-numbered problems at the end of the textbook chapter, but don't really have the "learning for earning" skill sets and experience that is of crucial importance to their unaware customers – the students.

Condition 6: Those that can do, do. Those that can't do, teach, Part 2 - Unfortunately, in many cases our post-secondary school system has become a dumping ground for teachers who have little or no experience with solving real world problems – most having more *unknowns than equations*, i.e., those requiring good engineering judgment to determine a method most likely to lead to the problem's best *solution*. This lack of practical knowledge is part of what can be described as lacking engineering wisdom [9]. It is certainly not representative of all academia, but it is a population large enough to adversely affect the student population's ability to compete for real world jobs. Of course, the naïve student who is in the process of graduating high school is incapable of discerning this negative attribute in a college they are considering [10]. Further, a company in a highly competitive global environment should not have to make the investment in time and money needed to train a recent graduate in applied engineering basics or the latest technology … and then have her leave after a year or two for a *better job*.

Condition 7: There is little *knitting* or connectivity among classes given at different times with different instructors - The result is the inability of students to clearly see the relationships that exist over the entire physics spectrum and math discipline – math being the language of the physics. These relationships that are in many cases difficult concepts to grasp should be taught holistically. Instead, they have been taught by academia, if taught at all, as isolated classes by different professors – perhaps, calculus on Monday and the laws of motion on Thursday.

Condition 8: Balkanization of engineering degrees - At a higher level, this applies to the balkanization of engineering degrees in industry e.g., Mechanical, Electrical, Industrial. These are artificial groupings of employees of similar abilities that developed out of the Henry Ford division of labor assembly model – grouping engineers based on their specific area of work. It soon evolved into an organization chart hierarchy that then needed layers of indirect management consisting of directorates, departments, and groups – all burdening labor cost with questionable value. As stated in no. 6 above, physics, science, engineering … the universe for that matter is a continuous spectrum. The only difference between a mechanical engineer and an electrical engineer is the part of the continuum they work. The engineering is basically the same. To be most efficient and competitive a company should employ engineers who have been taught across the entire engineering spectrum and have been part of self-managed project teams [11]. Some schools have chosen to recognize the advantage of teaching a wider variety of the sciences by offering degrees in *Engineering Science* – usually accompanied by noting a specialization in "mechanical or electrical." Although this type of "umbrella" degree moves in the right direction, it still only weakly recognizes the power of an evenly weighted cross-trained program that teaches over a wider swath of the physics spectrum – students are still taught in different science discipline classes by different instructors with little regard to no. 7 above.

Condition 9: Soft skill instruction - In addition, the students' curriculum at the undergraduate level is missing the seldom addressed "soft skills" such as team dynamics, critical thinking and open-ended problem solving. Using concurrent education, these are demonstrated and taught in the project team EMS environment where the students are active members.

Condition 10: Faux automation - Many operations say they automate – but do they really? Without engineers who understand the statistics involved in volume production and without the ability to optimize the automation, we spend large sums of money for the capital equipment needed to automate product assembly. However, if there is significant yield loss associated with processes that are not capable in the true statistical sense, the cost "advantage" afforded by automation is lost in the cost required for manual rework and scrap. This is especially true if the product is *pushed* through (Batch Processing) the assembly line rather than *pulled* through (Continuous Flow Manufacturing)

Condition 11: A student's academic success being largely dependent on the ability to "memorize, regurgitate and forget" - This "skill set" is what Dr. Murray Gell-Mann, who coined the term "Quark" for the subatomic particle he helped discover, credited for his superior academic achievements [12].

Condition 12: Colleges using primarily passive versus active learning techniques - When teaching in an antiseptic classroom there really is no other choice besides passive learning. Wrapping the school around a co-located real world business is an alternate to this traditional educational model. A real world, globally competing business would provide a perfect vehicle for active learning over the student's full 4-year engineering program. The student's participation in the business as well as the technical processes would be integrated concurrently to a single expanded theoretical curriculum. This would require the student to actively participate in every aspect of an EMS (Electronics Manufacturing Services) business's operation and lead to a 4-year B.S. degree in Applied Engineering Design and Production Sciences program.

CHOOSSING THE BEST BUSINESS TO USE AS THE STUDENTS' ACTIVE CLASSROOM

In evaluating different segments of our high tech industry as potential active learning centers for engineering undergraduates, the following criteria were considered:

1. Are the physics and engineering theory to be taught at the school reflected in the products and services that are sold to the business' customers?
2. Many of the school's engineering class titles will be similar or identical to those of traditional academia. Can the business that is chosen effectively integrate the existing textbook science with the added business' real world examples to form a curriculum leading to a B.S. in Applied Engineering Product Design and Production Sciences?
3. Do the real world products and services that the business produces lead to providing the student with valuable practical and marketable skills?
4. Will the business allow using third party contractors for their product design (i.e., private labeling)? Is the business willing to contract out the assembly of their products including material purchasing? Assembly only including fixture design? Electrical Test? Full service EMS (Electronic Manufacturing Services)?
5. Does the company already utilize third party contract services to produce their products?
6. Will the business support project teams of up to 16 members: half-student and half-staff for their product design and production?

A study of these considerations resulted in a model that wraps a new post-secondary school around a new real world, full service EMS (Electronic Manufacturing Services) provider. The analysis indicated that this business structure provided the greatest flexibility while meeting all of the evaluation criteria.

TERMINOLOGY

In this paper the following terms are used in the following ways:

Manufacturing – the *fabrication* of both electronic and mechanical components.
Assembly – the process of connecting or joining components into subassemblies and a final assembly, including electrical test.
SMT – Surface Mounted Technology
SMD – Surface Mounted Device
PIH – Pin-in-Hole
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.
PCB – Printed Circuit Board
PCA – Printed Circuit Assembly

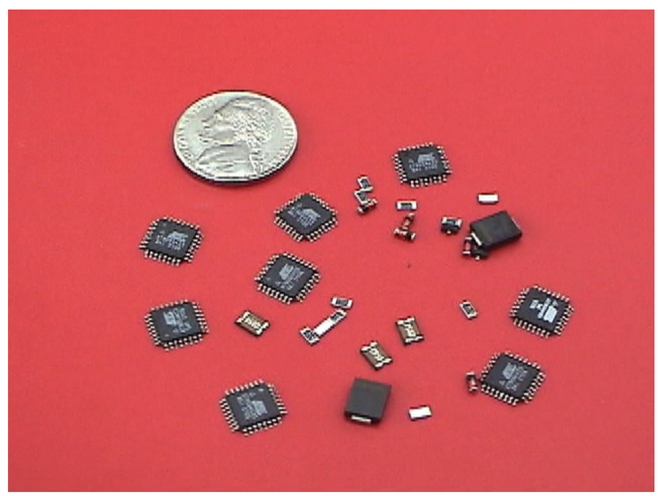


Figure 1. Assorted SMDs

Figure 1 shows some of the surface mount devices that the EMS will accommodate**.**

The EMS process objective of the first example used in this paper for concurrent education is to access the individual components and locate them on the circuit board, either inserted or placed in solder paste that has been printed on

the circuit board. This example is coordinated with the students' second and third trimester of their freshman year at the JIT in the following classes:
Vector Mechanics for Engineers: Statics – The analysis of rigid bodies that are at rest and constrained while under the action of forces, and
Vector Mechanics for Engineers: Dynamics – The analysis of rigid bodies that are in motion while under the action of forces.
It primarily employs the Component Placement / Insertion Robot in the EMS Center (see Figure 13) to teach many of the physics-based principles normally taught at the undergraduate level of a 4-year B.S. engineering program.

The second EMS Center real world activity used to teach undergraduate engineering principles in a school's class is the reflowing of solder paste and the development and real time monitoring of statistically capable assembly processes. It is used to complement traditional instruction in material science, thermodynamics, heat transfer and other areas of the physics continuum.

WHAT THE COMPLETION OF THESE COURSES WILL PROVIDE THE STUDENT: THE TEACHING OBJECTIVES

Successful completion of these classes will result in the student understanding and acquiring useful real world engineering skill sets. Note: All items below are directly correlated to the design and assembly processes developed by associated student / staff-based project teams as part of the class using the active learning classroom that the EMS Center provides. Also, provided for some items are notes that expand the traditional understanding of these terms.

1. Mass
2. Force: The action between two masses on one another. Forces are needed to access and place (or insert) a discrete component (electrical or mechanical) using a "pick and place robot"
3. Moments
4. Motion
5. Inertia
6. Speed
7. Velocity
8. Acceleration
9. Units of measure
10. Energy
11. Work – Pushing on a wall? or moving an electronic component? $W = \int F \cdot ds$ (work is a path function)
12. Scalar and Vector quantities
13. Equilibrium
14. Free Body Diagrams
15. Coordinate Systems - as a reference: The uncoupled independent nature of orthogonal axes e.g., Shooting a gun and dropping a weight simultaneously – which hits the ground first?
16. Calculus: Differential Equations – The formation of Newton's Three Laws of Motion
17. Newton's First Law – Masses at rest or at constant velocity
18. Newton's Second Law - Full expression including viscous damping and spring constant
19. Newton's Third Law - Launching a satellite from earth into geosynchronous orbit. – Aren't all masses on the earth rotating with the earth at a speed of 60 meters/sec. at the equator or about 1000 mi/hr., and revolving around the sun at a speed of 30 kilometers per sec or 67,000 miles/hr.? Our solar system rotates about its center of the Milky Way galaxy at 220 km/sec or 490,000 mi/hr.
20. Do Newton's Laws always apply? How about for velocities close to the speed of light?
21. Kinematics: Cartesian devices and mechanism
22. Kinematics: Introduction to non-cartesian devices and their control
23. Accuracy vs Precision. What is the difference? How are they achieved? Which one is most important?
24. Viscosity
25. Computer Programming: Giving the robot the appearance of intelligence
26. Optical Systems
27. Motors, Stepper Motors, Linear Motors
28. Big Data Process Monitoring
29. Meta Process Control
30. Mechanical tolerancing
31. The systems involved – mechanical, optical, computer
32. Vibration – structure-borne, environmental-borne, machine-borne
33. Movement of the robot's head
34. Material science
35. Heat transfer
36. Thermodynamics
37. Thixotropic material
38. Surface tension
39. Oxidation / Flux surface preparation / Wetting
40. Adhesive / Cohesive bonds
41. Dynamics of tombstoning
42. Process Capability

In addition, the JIT classes will teach the students (by their participation on the JEM project teams) many of the soft skills such as team dynamics, conflict resolution and critical thinking that are crucial to a real world project's success. Further, as the student works as part of a project team, they participate in administrative functions such as program management/planning tools such as PERT and Gant charting.

There is an automatic self-updating aspect to the JEM Center. It must compete for contract and EMS business. Consequently, the JEM Center has a direct self-interest in employing emerging, leading-edge technology in their effort to gain a competitive advantage. This benefits the students participating on JEM project teams as part of their JIT *classroom* as well as their future real world employers.

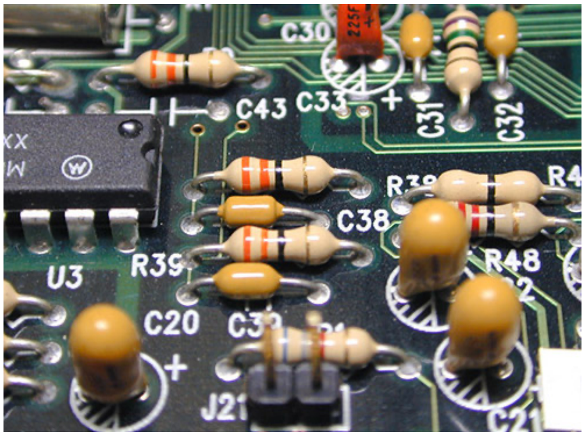


Figure 2. Components of the 1940s, 1950s, and 1960s

Figure 3. Hand place/ Insert/ Solder Components that have been Kitted and Delivered to Single Operator Stations

Figure 4. Single Station Build – Manual Labor

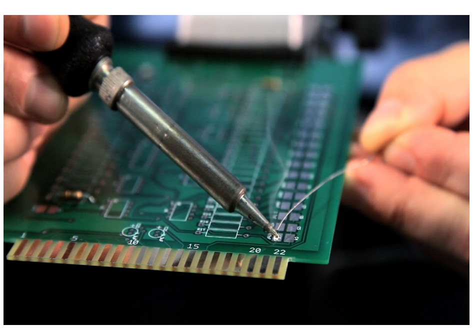


Figure 5. Hand Soldering – Manual Labor

Figure 6. Progressive Slide Line – Manual Labor

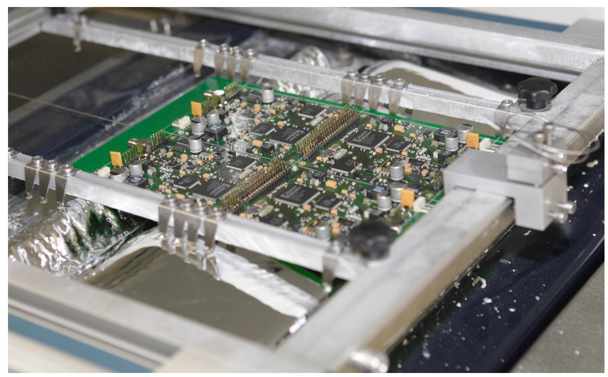


Figure 7. Wave Soldering – Fixtured Boards on a Conveyor Traveling Over Solder Wave

Figure 8. Wave Soldering – The Solder Wave

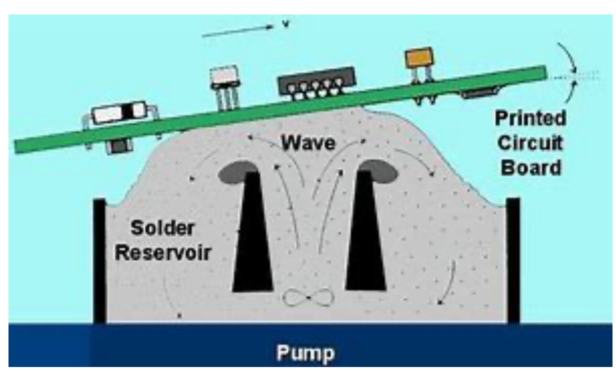


Figure 9. Wave Soldering Diagram

Old Style Component: Through-Hole Axial Leaded

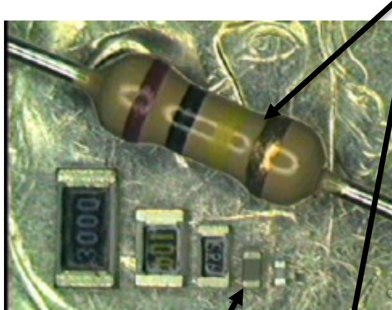
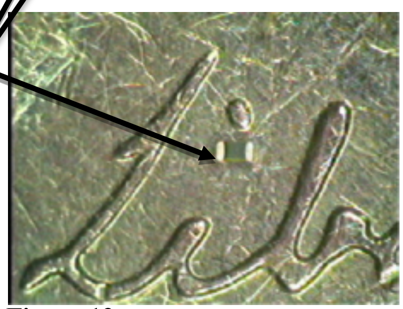


Figure 10.

Figure 11.



Newer Style Micro Surface Mounted Devices ... All on a Jefferson Nickel. Many are Not Compatible With Manual Assembly...Requires Moving Assembly from Labor Intensive **Figure 12.** Manual Placement and Hand Soldering to Totally Automated Assembly

JEM Center Active Classroom

Figure 13 is an example of an automated circuit board assembly line. Similar elements in this line will form the EMS Center that is collocated with the school.

Examples of Teaching Elements in the EMS Center

1. **Anatomy of a Component Placement / Insertion Robot Subsystem:**

The assembly process objective is to access each component with vacuum from a preprogrammed pickup point and place them at a preprogrammed location on a circuit board. An upward looking camera that establish the component's spatial position and a downward looking camera that provides PCB targets are used where needed. Board-to-board accuracy is established using fiducial marks that are part of the PCB artwork.

- **Robotic Head movement:**
  - **a. Accuracy vs. precision**
  - **b. Programming to get from point a to point b.**
  - **c. Scalar vs vector quantities – speed versus velocity, linear motion, curvilinear motion**
  - **d. Mass, acceleration, velocity, distance momentum, force, inertia – Differential equations defining relationships**
  - **e. Encoders, glass scales**

- **Component Carrier Movement and Operation:**
  - **a. Tape and Reel**
  - **b. Vibratory Stick**
  - **c. Matrix Tray**

2. **Solder Reflow Oven Subsystem:**

The assembly objective is to achieve a metallurgical solder bond between the component and PCB

- **a. Free surface energy – Surface tension**
- **b. Wetting (adhesive vs cohesive forces)**
- **c. Tombstoning**
- **d. PID temperature control algorithm**
- **e. Convective / Radiative and Conduction Heat Transfer**

3. **Additional physics principles taught using the JEM active learning classroom while assembling products:**
   - **a. Statics**
   - **b. Dynamics**
   - **c. Free body diagrams**

Figure 13. Automated Circuit Board Assembly Line at the Rochester Institute of Technology – From Manual Assembly Labor to Automated Robotic Assembly

Figure 14 poses the question "why are raindrops spherical?" In the EMS Center *classroom* of the school this question leads to exploring the subjects of surface tension, adhesive forces, cohesive forces, free surface energy, wetting angle, liquid wetting to solid surfaces, fluxing systems, and solder wetting for PIH and SMD assemblies, using the results of real world processes and illustrated in Figs 15 – 28.

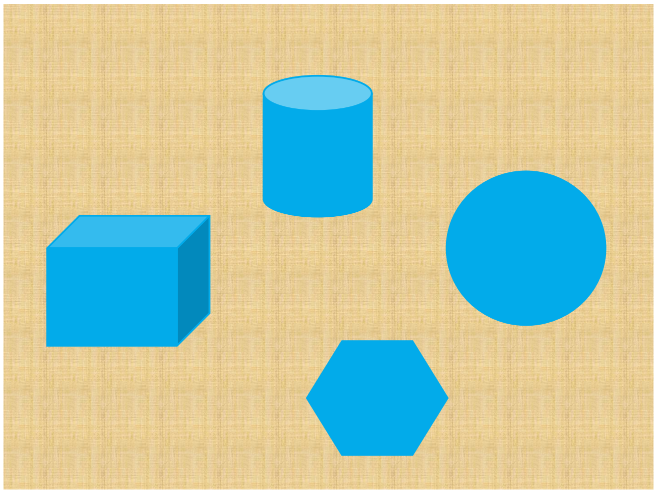


Figure 14. Raining Bricks?

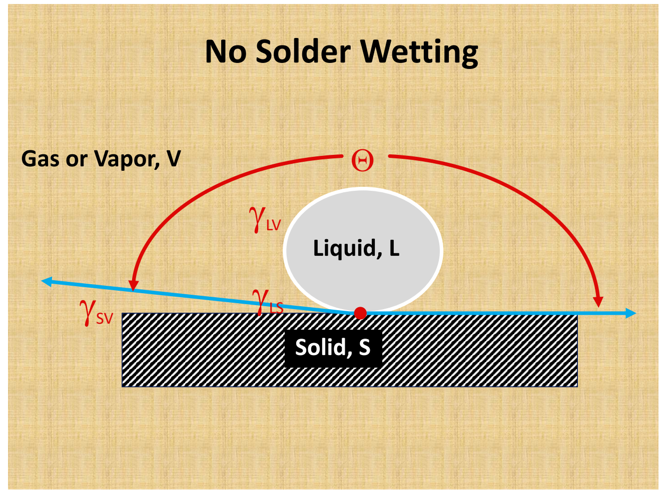


Fig 17. Liquid on a Solid Surface - Large Wetting Angle

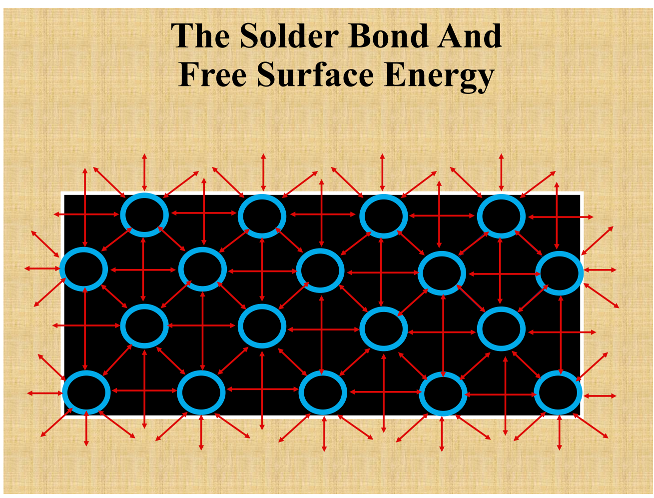


Figure 15. Free surface energy

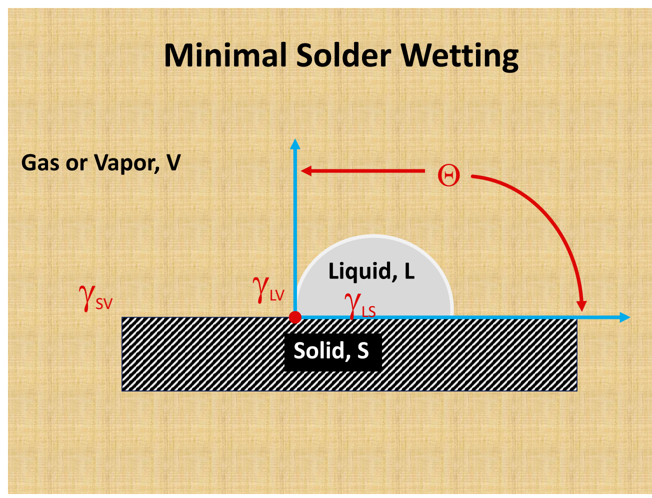


Fig 18. Liquid on a Solid Surface - Large Wetting Angle

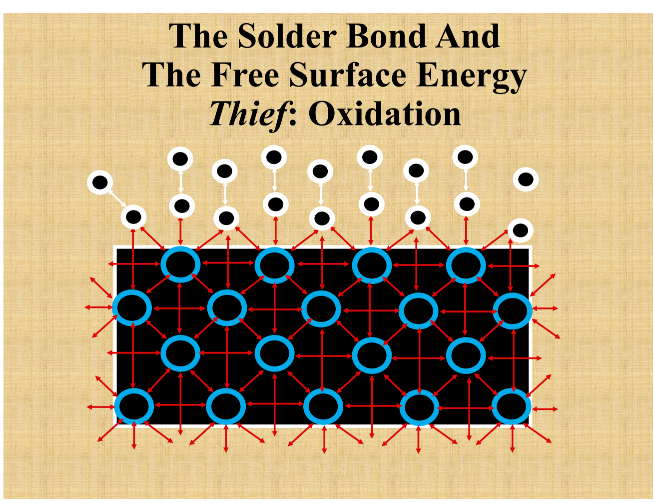


Figure 16. Oxidation – Flux is used to Restore Free Surface Energy

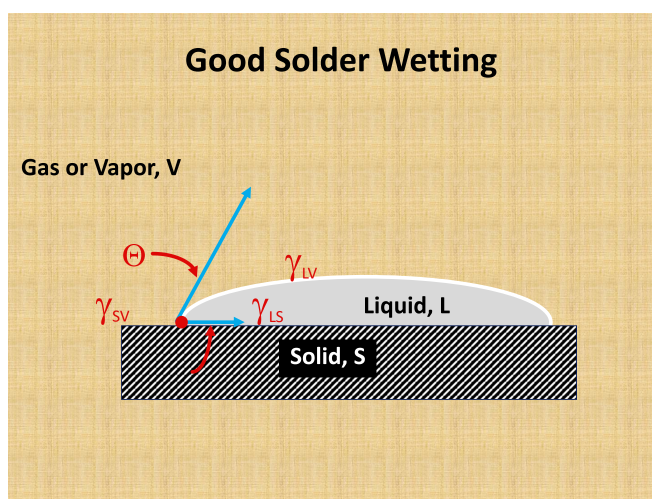


Fig 19. Liquid on a Solid Surface – Good Wetting Angle

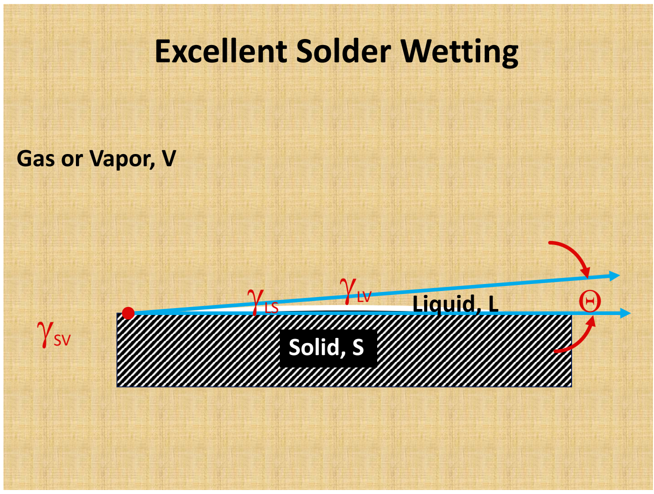


Figure 20. Liquid on a Solid Surface – Low Wetting Angle

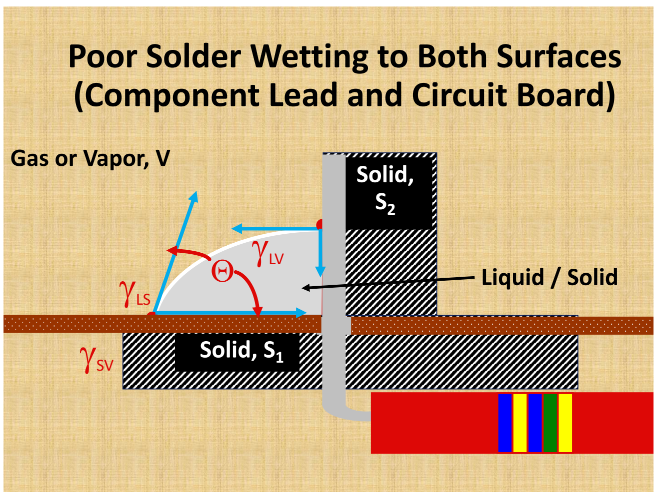


Figure 21. Liquid in Contact with Two Solid Surfaces - Poor Wetting Angles

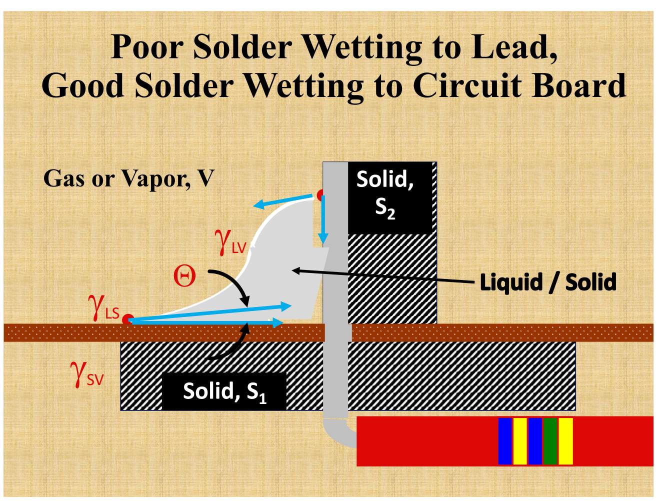


Figure 22. Liquid in Contact with Two Solid Surfaces – Good Wetting Angle to PCB, Poor Wetting Angle to Component Lead

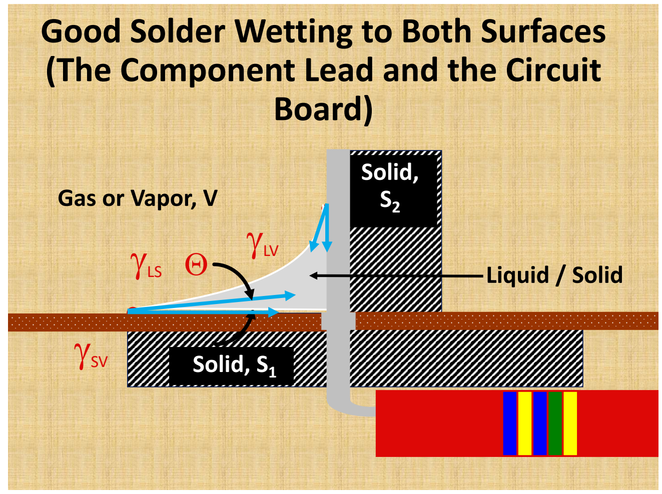


Figure 23. Liquid in Contact with Two Solid Surfaces – Good Wetting Angles

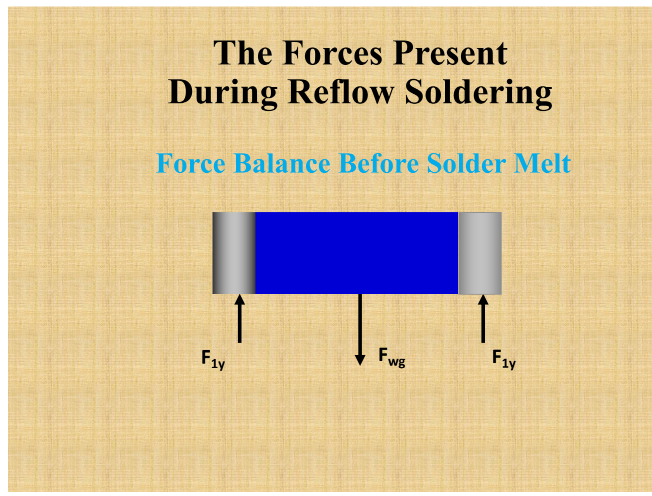


Figure 24. Solder Wetting on Surface Mount Devices

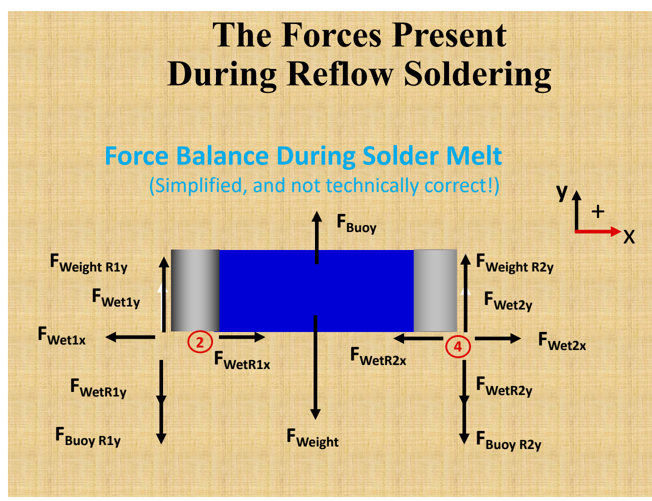


Figure 25. Solder Wetting on Surface Mount Devices

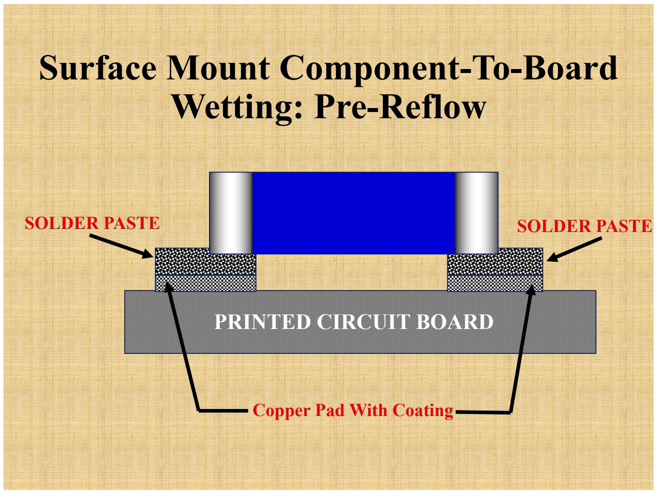


Figure 26. Surface Mount Devices Placed in Solder Paste Before Reflow

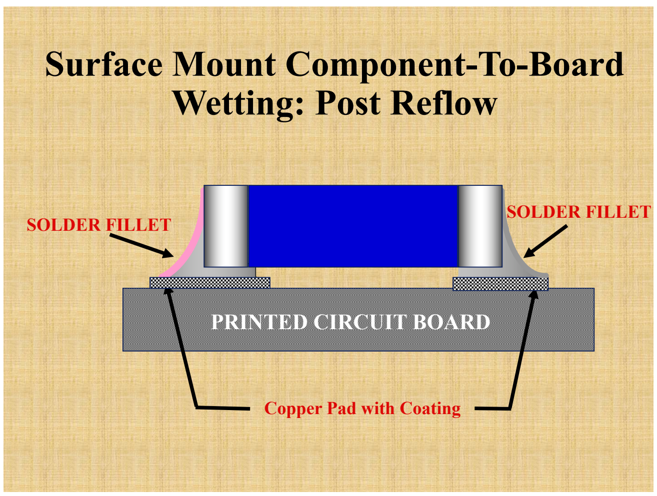


Figure 27. Solder Wetting on Surface Mounted Device. Good Concave, Low Wetting Angle Fillets

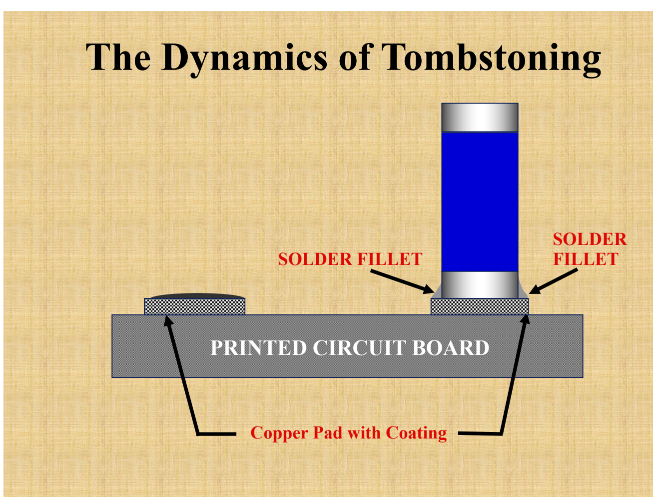
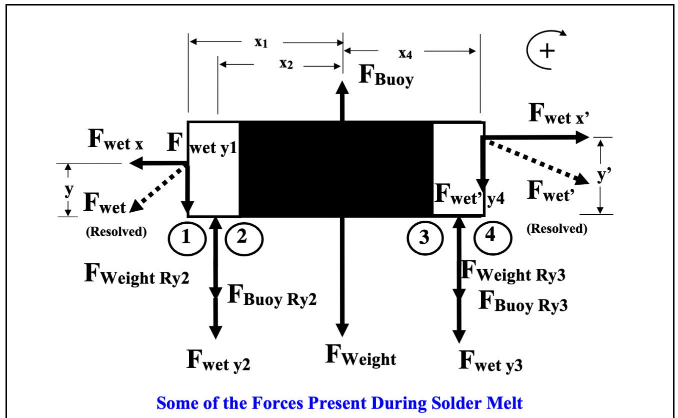


Figure 28. Solder Wetting on Surface Mounted Devices. Significant, Unbalanced Moment Causing Tombstoning



$$\Sigma M_4 = +(F_{wet\ x'})(y') - (F_{wet\ x})(y) + (F_{Buoy})(x_4) - (F_{Weight})(x_4) - (F_{BuoyRy2})(x_2 + x_4) - (F_{wet\ y1})(x_1 + x_4) + (F_{Weight\ Ry2})(x_2 + x_4) - (F_{wet\ y2})(x_2 + x_4)$$

Figure 29. Free Body Diagram of Forces and Moments (Force x Distance) Occurring During Solder Paste Reflow with Force Balance Equation for the Sum of the Moments about Point 4

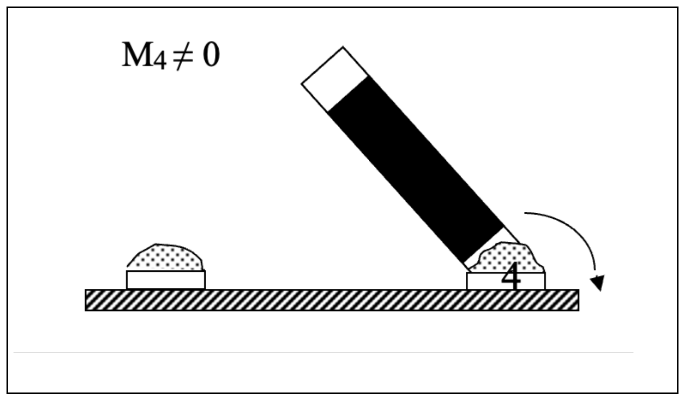


Figure 30. When the Sum of the Forces and/or Sum of the Moments About a Point do not Equal Zero

Figures 28 – 30 are representative of the analysis of SMD component movement during the transition of solder from a paste-like solid to a liquid as it melts. Not only do the students learn statics and dynamics using free body diagrams as they have traditionally but do so in a real world environment.

Figures 31 and 32 represent the development and maintenance of a capable assembly process – a defect free process whose variation always stays within the process window. Students in the EMS Center analyze real time data to ensure defects are not created by assignable cause process variation. Students automatically study Big Data to identify when an assignable cause begins to infect the normally random varying data. The school's study of statistics is more effectively taught having real world production data from the EMS Center available.

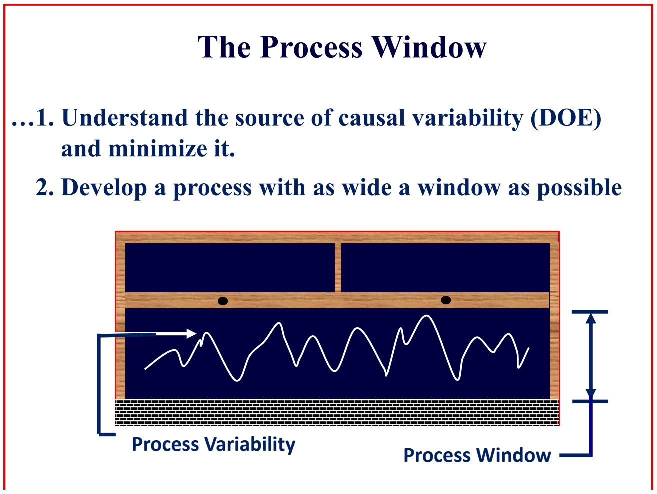


Figure 31. Process Variability - C_{pk} index greater or equal to 1.33

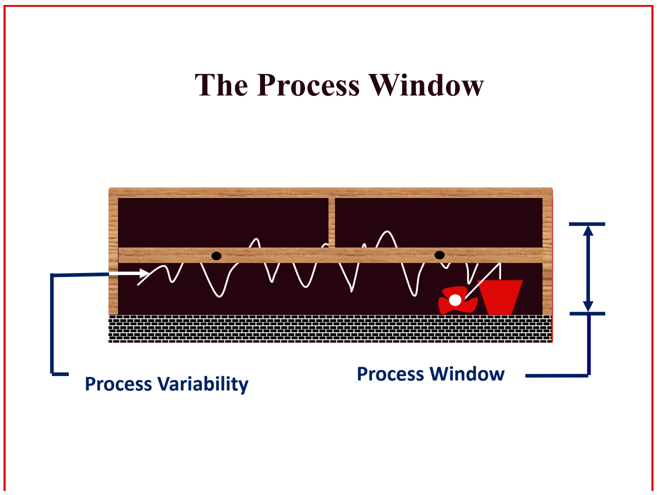


Figure 32. Process Variability - C_{pk} index less than 1.33

CONCLUSION
This paper makes the case that academia has lost sight of the needs of many industries that employ engineers. This is especially true for an industry such as electronic product design and production that is in a constant state of rapid change. While undergraduate schools continue to focus on teaching students *learning for learning,* their students need to acquire and bring to the real world leading edge *learning for earning* skills. Only 62% of students who start a degree or certificate program finish their program within six years [13]. With the real world skills learned using concurrent education, at least this population of the students who do not achieve a degree will leave academia with some expertise they can bring to the marketplace. As traditionally structured with primarily pure academics teaching in antiseptic classrooms, schools cannot hope to continually update their curricula to meet the industry's changing skill requirements – skill requirements that simply outrun the ability for academia to keep up. However, the continually growing gap between academic preparation and industry need has *multiple* causes. The paper has identified 12 reasons that contribute to this disconnect.

Colleges have begun to provide their students with an additional quote: what students will have to pay to be placed in an apprenticeship or co-op program while attending their college [14]! Apparently, a $4 billion endowment does not provide the financial security called for in a college's business model.

The U.S. is no longer the only game in town. The relative standing of the current U.S. education model produces a graduate who falls to 24th in science and 38th in math among 71 industrialized countries, while spending the most for that education [15].

The paper presents an alternate solution to this dilemma. It proposes that the gulf between academia and industry be filled in through concurrent education. A post-secondary school is wrapped around a full service EMS provider. The students concurrently learn real world *learning for earning* skills in the EMS Center. Correspondence is made between the subject matter as presented in a traditional antiseptic classroom and this subject matter, plus additional material that will be studied at the EMS Center. This paper demonstrates how a traditional *learning for learning* engineering education can be effectively supplemented with *learning for earning* skills using the sophisticated design, automation, and processes in the EMS Center. Successful completion of this 4-year program will result in the student receiving a B.S. in Applied Engineering Product Design and Production Sciences.

The EMS Center structure will be established to minimize cost. Reduction in overhead and indirect labor are controllable costs. All staff engineers are cross-functionally educated to provide a flexible workforce. There are no departments requiring the cost layers of management [16]. The EMS provider consists of only two groups: Dedicated project teams consisting of half-student and half-staff and a leadership group. The leadership group serves as an enabling function to the project teams, providing whatever the teams need to be successful. In addition, the leadership group serves as a check on the self-directed project team activities and as a resource, when necessary, to arbitrate internal team disputes [17].

The paper used elements of several concurrent school classes to demonstrate the value of concurrent education. Engineering mechanics is brought to life using EMS Center component placement robotics and additional real world equipment to teach the concepts of the school classes *Vector Mechanics for Engineers: Statics* and *Vector Mechanics for Engineers: Dynamics.*

The solder reflow oven in the EMS Center is used to teach material science and thermal principles using the formation of a metallurgical solder bond between component and PCB
- Free surface energy
- Surface tension
- Wetting (adhesive vs cohesive forces)
- Tombstoning
- PID oven zone temperature control algorithm

- Convective / Radiative and Conduction Heat Transfer

The EMS Center will provide a laboratory to study process variation and develop capable assembly processes with C_{pk} indices that are greater or equal to 1.33. This further creates the opportunity to teach the concurrent school students statistics using the real world activity in the EMS Center.

All these acquired EMS Center skills demonstrate the power of concurrent education in closing the gap between academic preparation and industry need.

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