Re-defining, De-limiting, and Activating the Engineering Learning Space with Tablet PC Convertible Computers and Associated Applications

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Abstract – The College of Engineering at Virginia Tech mandated tablet-pc convertible computers for all incoming first-year and transfer students beginning with fall 2006. These students have now percolated throughout the various departments within the college. Concurrently, tablet-specific, tablet-optimized, and/or tablet-friendly applications appropriate for the engineering learning space have become increasingly available, capable, and user-friendly and parallel improvements in wireless infrastructure and economies allow continuous, reliable broad-band access throughout the campus. These developments have delivered unprecedented opportunities for reforming and re-designing the engineering learning space. This paper reports on the various technical and human problems encountered and resolved and the way students and faculty have applied the technologies within the engineering learning space. Specific applications used will be demonstrated where appropriate.

Keywords: tablet, Dyknow, computers, active learning

ALLOW AN ABBREVIATED, RELEVANT SOAPBOX, PLEASE

The Typical "Modern" Engineering "Teaching" Space

John Medina, in his excellent book *Brain Rules* describes a 12th century university classroom as follows:

> "If you could step back in time to one of the first real Western-style universities, say the University of Bologna, … went down the hall and peered inside Bologna's standard lecture room, you wouldn't feel as if you were in a museum. You would feel at home. There is a lectern for the teacher to hold forth, surrounded by chairs where students absorb whatever is being held forth. Minus an overhead or two, it looks remarkably similar to today's classrooms. Could it be time for a change?" [Medina, 1]

Note that there has been precious little change or improvement in the classroom environment in over 1000 years!

It is my personal opinion that we are taking liberties by thinking that we (the University) define the Engineering Learning Space. Perhaps it would be better to say that we define and use the Wrong-Way-to-Learn-Engineering Learning Space. This is not a laughing matter at all because we are replicating ourselves in a sort of pedagogical in-breeding that precludes real improvement.

> "The teachers in classrooms are products of the monolithic batch-processing system that characterizes public education today. In that system, students who naturally enjoy the teaching approach they encounter in a given class are more likely to excel." [Christensen, 2]

As a faculty member in one of the small (but growing) number of PhD-granting Engineering Education departments, this is of even greater concern to me. Perhaps it would be better for my department to require that applicants have a minimum of 5 years industrial experience after their initial undergraduate degree. Perhaps we should not think positively about an applicant's comment in the following flavor: "I want to get a PhD in Engineering Education because I love teaching engineering", and look for more applicants who would be inclined to say: "Having been in industry as a practicing engineer, I have come to realize that much of my undergraduate engineering education was a

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farce and I want to be an advocate for radical, disruptive, change in that field. I have definite misgivings about seeking a PhD in Engineering Education from an institution that has the same systemic problems that I experienced but I am of the opinion that the existence of this department at this school is an indication that the program has a desire to move in the right direction." I want to admit those applicants who will help future undergraduate engineering students succeed in the engineering learning spaces of tomorrow, not the ones which are predominant today (or the last thousand years).

It's Time for Intervention

Using the classic language of families dealing with addiction is appropriate. As self-proclaimed and largely self-accredited (in other words *co-dependent*) "educators of engineers", we are a community of sorts, if not a family, and we can probably admit that most of us, for reasons often out of our control, are "addicted" somewhat to the pedagogical methodologies in use when we were undergraduates (which were the same as those in use when….which were the same as those in use when….which were the same as those in use when….). At a recent seminar at VT, Dr. Woodie Flowers, noted MIT Professor Emeritus of Mechanical Engineering, invoked this same model of classic addiction, introducing a slide labeled "BTA" and "My name is Woodie Flowers and I am a bad teacher." [Flowers, 3] The worst of it is, similar to the addict, we deny the degree of real damage that we are responsible for – the faulty construction of the brains of our students such that their brains are wired for a "classroom, sage-on-the-stage culture" of learning rather than the natural exploratory culture they were born with. [Medina, 4] Thus, we cripple them as surely as if we had amputated a limb but damage to, or miss-wiring of the brain is so much more handicapping.

A Time for Optimism – (A Time for Pessimism?)

The great news is that finally, as is so typical in free and open societies, free-market forces, new technologies, fundamental research (in this case - on how the human brain actually functions, develops, and learns), and non-conformists are combining to force change at an ever-increasing rate. An early visionary and literally prophetic work by Dr. Lewis Perelman in 1992 pointed the way and lit the fire for many an "educational technologist". [Perelman, 5] Educators who began their careers prior to 1990 cannot deny that there has been a sea change in classroom delivery capabilities and course administration made possible through technology and even current hires are hard-pressed to stay technologically even with the students. It appears that newer and smaller engineering programs have greater incentive, vision, and flexibility and they are spearheading much of the positive change seen throughout the community. Olin College and Harvey Mudd come to mind.

Pessimism is rampant among those whose predominant focus is undergraduate engineering education. Undergraduate programs, especially in the larger universities, have been squeezed for resources by the almighty research dollar for several years. With the latest economic sink hole, the perception is things are going from bad to worse. However, it is quite likely that multiple opportunities to implement rapid and radical change will present themselves if we can simply take our focus off self-preservation. It is time to rid ourselves of useless academic, curricula, and pedagogical tradition, first for the sake of our students and second for the sake of the engineering profession. "Disruption is a positive force. It is the process by which an innovation transforms a market whose services or products are complicated and expensive into one where simplicity, convenience, accessibility, and affordability characterize the industry."[Christensen, 6] Educational technologies as well as generic technologies that can be exploited for education have provided us with the equipment. Daring K-12 programs, teachers, and parents are providing us with the students. [7]

The thrust of this paper, *Re-Defining, De-limiting, Activating*, was chosen to encourage disruptive innovation. By way of illustration, I present you with the Flying Car analogy. Those of us who cut our engineering exploration teeth on old Popular Science and Popular Mechanics magazines can relate – the flying car was always just around the corner and we were always dreaming of what we would do and where we would go when we finally had one. We have been handed the educational technology equivalents of flying cars. Unfortunately, we are tending to use our flying cars to travel down the same old roads to the same old places with the same old goals as if we could not fly. Although it is "safer" it is wrong and is a waste of time and resources that we do not have.

The critical reader, justifiably, might wonder why the topics above have been addressed at such length in this venue. My answer is simply that this is a paper submitted to the American Society of Engineering Educators, that it will hopefully be read by a number of like-minded faculty, and they will be encouraged to continue to charge forward and be agents for the radical change that is necessary to get us out of the 12th century classroom. Now, please pardon the sharp transition.

EXPLORING TABLET USE IN ENGINEERING EDUCATION

Multiple schools began to explore tablet-PC use in math and engineering programs shortly after the Tablet PC operating system was announced by Bill Gates at Comdex in November, 2001. By 2005 tablets had been used in over 200 computational courses in more than 13 higher education institutions (K-12 tablet use was also growing). [Anderson,8] Although initial use tended to be presentational in nature, rapid software development of applications specifically targeting student Tablet use in the classroom provided the necessary catalyst for expanding experimentation. In particular, several applications came to the forefront, developing a common goal of transforming the typical classroom by fostering rapid, in-line assessment of student level of understanding, in-class student collaboration and participation, flexible material presentation, and positive but appropriate incentives to take notes. Not surprisingly, these three systems were initially developed by computer science faculty and used in their classes-"not surprisingly" because these faculty have the requisite knowledge of what the networked computer can do. In purely alphabetical order, three of the more dominant packages and their principle developers were Classroom Presenter (Richard Anderson) [9], Dyknow™ (David Berque) [10], and Silicon Chalk™ (Murray Goldberg) (assets acquired by Wimba in August 2005) [11]. Meanwhile, Microsoft's own note-taking applications, Windows XP Journal™, and Office OneNote™ also allowed advanced note taking and, in the case of OneNote, with wireless infrastructure or peer-to-peer networking, student collaboration and virtual white boarding over the web. Concurrent with these software developments, rapid improvements in wireless technology and its cost were providing additional encouragement and capability. By 2005, several computer vendors were marketing full "Tablet PC Convertible" computers – fully-featured and powerful notebook computers which also included the Tablet input feature - and Microsoft's Windows XP Tablet PC Edition™ was a mature and stable operating system.

At Virginia Tech, faculty began exploring tablet computer technology in spring 2003, using grants from Hewlett-Packard. In spring 2004, additional tablet computers were purchased using funds provided by Microsoft allowing additional studies. One of the early faculty adopters was Dr. Joseph Tront who immediately began to conduct research on and develop applications for the Tablet PC. [Tront, 12] These grants allowed us to experiment with "digital ink" and tablet-specific tools that were either specifically directed toward the education sector or were generically applicable to pedagogy. However, since the VT College of Engineering mandates student-owned laptop computers which require comparatively high processor speeds, fast and sophisticated video capabilities and large amounts of main memory in order to run the computational and CAD packages used, serious thought of mandating tablet computers had to wait until they became generally available from multiple manufacturers. Additionally, the applications mentioned above and the wireless web technologies that they require needed to mature to a point of reasonable stability and cost. This happened in spring 2006 and, after careful consideration and discussion led by Dr. Glenda Scales, College of Engineering Associate Dean for International Programs and Information Technology, the decision was made to require tablet PC convertible computers for the incoming class of engineers, fall 2006. It is worth mentioning that the computer hardware requirement specifications for the entering class must always project for applications and capabilities that the students will require within a typical 4-year undergraduate engineering curriculum. Inevitably, some of those applications and/or the peripheral technologies they require are not mainstream or mature when we must begin to allow for them in our specifications. This was particularly evident with respect to the tablet-specific applications and wireless access technology being considered in fall 2006. For example, no one had even tried to use applications such as Classroom Presenter or Dyknow over wireless access with 300 students in a single large classroom. Therefore, there was a great deal of coordination and collaborative research involving Dr. Scales office, the office of Educational Technologies, the office of Communications Network Services, and the college of engineering Undergraduate Technology Committee. The tablet mandate for 1200+ entering students required a particularly forward-looking commitment by Dr. Scales and the faculty of the Department of Engineering Education, who would be the first to implement the technology.

RE-DEFINING AND ACTIVATING THE ENGINEERING LEARNING SPACE (CLASSROOM)

If you asked a typical undergraduate engineering student to describe a typical engineering learning space she/he would most likely describe something similar to a modern version of the 12th century classroom described in the opening paragraph of this paper. Although it would probably have a modern computer projection system and possibly even a "document" projector to take the place of the overhead transparency projector of just a few years ago, the "context" of the space would be obvious by its structure and arrangement – the person in the front will do the talking, the persons in the seats will do the listening. The "class" would last 50 minutes despite the common knowledge that, after 10 minutes, the students begin to lose attention. [Medina, 13]. This is not a learning space, it is a teaching space. It is designed with a focus and function centered on the single person at the front of the room and not the 30 – 300 in the "audience". As Malcolm Gladwell points out in his excellent book, *The Tipping Point*, context matters [Gladwell, 14] and students enter a classroom such as that above knowing exactly what to expect. Although various activities can be injected into this environment such as the "Think, Pair, Share" [Lymna, 15], they have a limited impact in a computationally focused course and/or large, auditorium-style classes. If the instructor wants to change the focus of the classroom from teaching to learning she/he has two choices – physically rearranging the classroom which is rarely feasible or virtually rearranging the classroom which is now entirely possible with tablet PCs and Classroom Presenter, Dyknow, or Ubiquitous Presenter. For example, with Dyknow in a large classroom of 300 tablet-equipped students and reliable wireless connectivity, the engineering instructor can instantly and easily

- project his/her screen to all of the student's screens, either a panel or application screen for demonstration.
- project any student's screen to all other student screens as above.
- share screen control with a particular student, students, or co-moderator(s).
- collect "panels" from any particular student or all students, anonymously or with identification.
- instantly and easily divide the class into teams without regard to seating arrangement, automatically allowing the students to collaborate electronically via their own local "chat" and shared panels.
- replay students' ink strokes to observe exactly how they sketched an object such as a free body diagram.
- poll the students for instant assessment.
- receive continuous voluntary level-of-understanding feedback from the students.

Obviously, various combinations of the above provide several other options and it should be noted that no computer projection system is required since the students see everything on their own screens and the students capture every screen projected to them for their own notes, including their own ink notations.

When students can not only see how others have solved problems, projected onto their personal computer for their own editorial markups, but also know that their work could be chosen to be projected to all the other students, the level of classroom participation tends to increase significantly. [Hurford, 16]. The classroom focus shifts from teaching to learning.

Simply using Microsoft's OneNote application, students can form peer-to-peer networks in class and work in teams, developing solutions which can be provided to the instructor via the institution's course management system such as Blackboard, Moodle, Scholar, Sakai, etc.

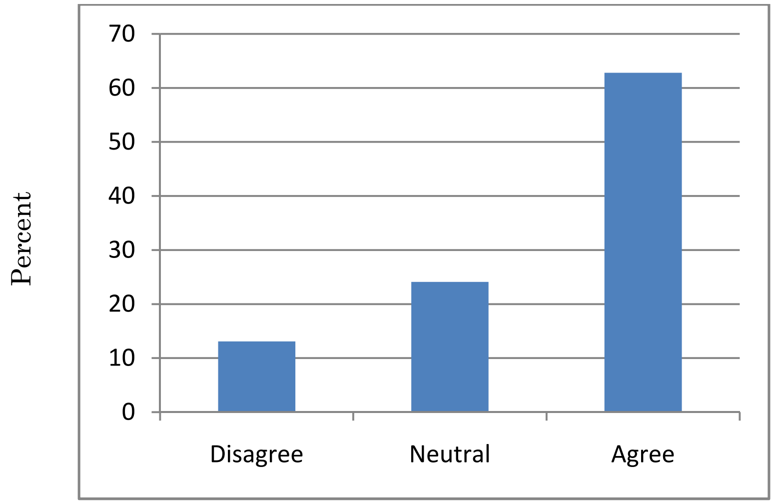
While none of the applications mentioned have an absolute tablet input requirement, the pen input is more natural, fostering rather than hindering creativity and allowing for options that either cannot be implemented with the keyboard and mouse or would require a great deal of additional hand-eye coordination.[17] Typically, the brain is wired for "pen" and paper for years before a child actually uses a keyboard as an input device and most students have received far more praise for their creativity in the "pen" and paper "art" genre than they have for computer generated art (thankfully I have yet to see the display of elementary-school student CAD or computer art drawings at my local library or fast food restaurant). As stated earlier, context matters, and the context of the input device has a great deal to do with the level of creativity encouraged. Additionally, although laptop keyboards are relatively quiet, they are not absolutely silent and when 30 or more students are typing simultaneously, the resulting noise can be quite distracting. This was a contributing factor in the VT decision to require tablets in the college of engineering.

VT engineering faculty began experimenting with Dyknow in spring 2007. With the exception of the interruption caused by the tragic events of April 16th of that year, Dyknow use has continued to grow. The relevant data as of late fall 2008 shows 49 engineering faculty using Dyknow in 95 different class meetings per week involving 2472 students.

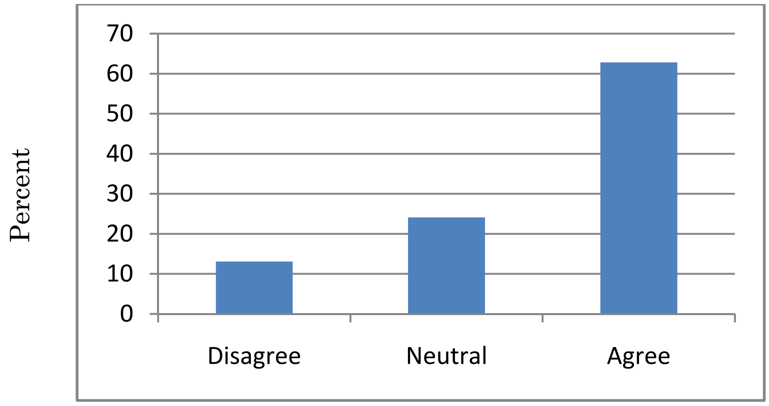
Faculty outside the college are also being encouraged and trained to use Dyknow through the Faculty Development Institute and this has resulted in some inroads into other colleges.

THE STUDENT AND INSTRUCTOR TABLET EXPERIENCE

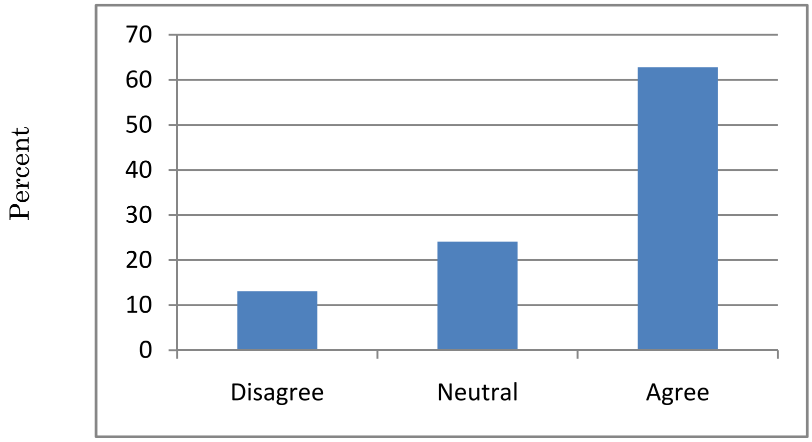
Virginia Tech College of Engineering staff continue to collect and analyze data from the first two years of our tablet computer mandate. The findings illustrated in the four bar graphs below are a small part of the College's assessment efforts and represent results from student surveys involving 138 students in a single class.



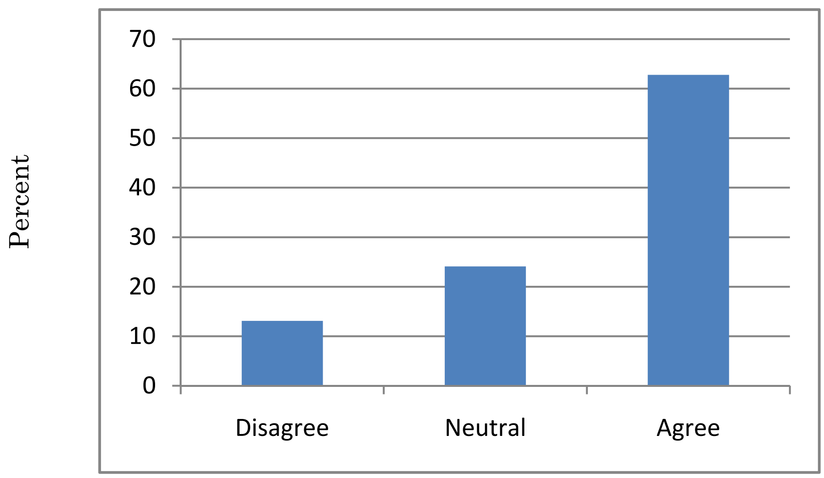
Made Class More Interactive



Resulted in More Rapid Feedback From Instructor Compared to Other Courses Without Technology



Helped Illustrate Points in Class with Visuals or other Materials



Helped Me Review Materials

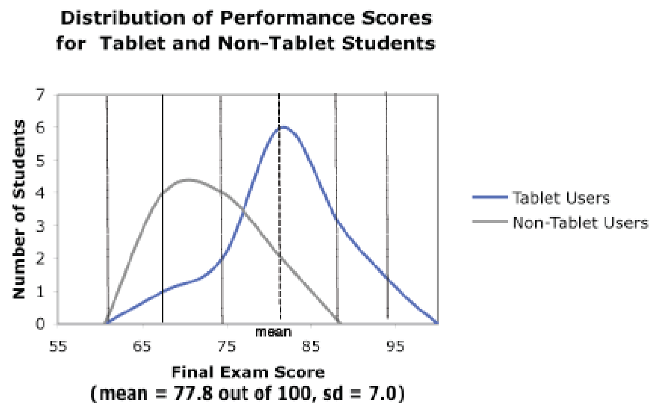
As indicated above, the majority of the students in a Tablet technology-enabled classroom think positively about the experience and that is certainly important. However, is the learning process positively impacted, specifically in engineering/science/technical courses? Only recently have definitive results been available that can answer that question. In particular, a recent study was carefully conducted in a computer science course at MIT. [Koile and Singer, 18] In brief, this study involved 43 students divided relatively evenly into two recitation sections of the same course taught by the same instructor in a very interactive style with an unbiased observer to ensure there was no prejudicial treatment of either group of students. The only difference between the two sections was tablet computer use with appropriate interactive software. The course was an introductory computer science course with common lectures involving 236 students. The following results were notable:

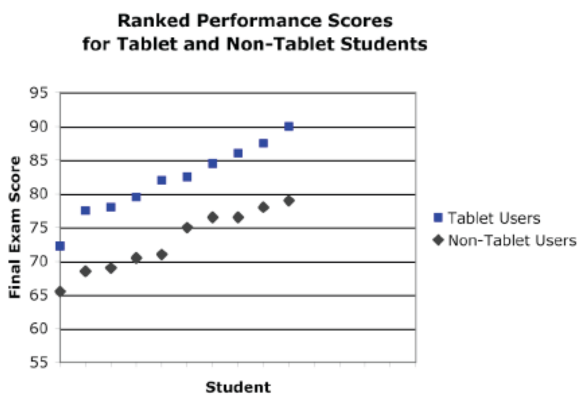
Final Exam Score

- Overall Mean (N = 236) = 77.8
- Non-tablet (control) section mean – 73.0
- Tablet section mean – 81.5
- Six of eight scores within one standard deviation above mean in tablet section

- Four of four scores between one and three standard deviations above mean in tablet section
- Four of six scores within one standard deviation below the mean in control section
- Four of five scores between one and two standard deviations below the mean in control section

Presented graphically by the authors the data look like this:





If you were a student and you were presented with this information, which class would you attend? Just as importantly, as an instructor, which learning space environment would you want to be in?

RE-DEFINING AND DE-LIMITING THE ENGINEERING LEARNING SPACE

The previous section dealt with changes made possible in the classroom. As such, returning to the Flying Car analogy, one could argue that the basic *same old way of doing things* is simply being exchanged for a different *same old way of doing things*. That is, students still attend regularly scheduled classes, typically each scheduled for 150 minutes a week for 15 weeks, at a physical location specifically designed for "education" such as a single university, college, or community college, where a faculty member is co-located and scheduled with them for the purpose of "instructional delivery". Welcome back to the 12th century classroom! This is certainly not radical change or reformation. Why are we "doing" engineering education this way? Two reasons come to mind. First, until recently, it really was the most "efficient" and second, because that is the way it has always been done. The latter reason stifles innovation (and destroys car manufacturers) and the former is no longer true. In fact, the opposite is true – most purely instructional delivery dealing with engineering educational "training-type" undergraduate courses such as

- statics
- dynamics
- math
- heat transfer
- fluids
- engineering economics
- circuits
- computer programming

can be done more efficiently via the internet using appropriate applications and media. Of course, that statement is not all that radical. Many would concede that appropriate media technology has been available for decades that allows for effective instructional delivery to motivated students for asynchronous or blended, semi-synchronous environments where virtually no classroom interaction is necessary. Most modern "distance learning" falls into this category. What is more radical is the statement that synchronous class meetings can also be done more efficiently via the internet.

In fact, none of the Dyknow capabilities listed in the previous section requires the co-location of the various participants involved!

In that light, those capabilities bear repeating. Given Dyknow and reliable, broad-band internet connectivity, the engineering instructor can

- project his/her screen to all of the student's screens, either a panel or application screen for demonstration.
- project any student's screen to all other student screens as above.
- share screen control with a particular student, students, or co-moderator(s).
- collect "panels" from any particular student or all students, anonymously or with identification.
- instantly and easily divide the class into teams without regard to seating arrangement, automatically allowing the students to collaborate electronically via their own local "chat" and shared panels.
- replay students' ink strokes to observe exactly how they sketched an object such as a free body diagram.
- poll the students for instant assessment.
- receive continuous voluntary level-of-understanding feedback from the students.
- make various combinations of the above.

I would like to pose a few questions in light of our current technological capabilities.

1. What is uniquely and positively accomplished for students by requiring them to remove themselves from the real world, spend more than $100,000 each, and gather together in a classroom with their peers for upwards of 1800 hours? [Note: "football" and "socialization" are not acceptable answers.]

2. What is uniquely and positively accomplished for the engineering and technology industry by isolating bright, young adults from the real world of real pay for real work and teaching them 1800 hours worth of stuff, most of which they will never use again, along with the idea that what really counts is the "grade", not the knowledge? [Mandatory co-op programs are exempted from this question.]

3. What is uniquely and positively accomplished for the U.S. economy by the education industry, second only to healthcare in total cost, yet virtually unaccountable for the quality of their "product"?

4. What is uniquely and positively accomplished for the U.S. society when we continue to restrict the true diversity of our students by eliminating those who cannot afford to leave home and work for four years, or those who are learning "differented", or those who don't conform in one way or another, or those who have children they need to care for, or those who have an illness or disability that prevents them from leaving home or those who want to feel immediately productive and can't persevere through hours and hours of boring, totally non-integrated and discontinuous course work before they are really allowed to do something that the real world values? [Bill Gates and Steve Jobs immediately come to mind]

Of course there are some positive answers to these questions but are they positive enough <u>in light of our current technological capabilities to deliver excellent instruction, synchronously or asynchronously</u> to continue to require the high cost of long term residency at most of our institutions? How much longer is the taxpayer going to sit idly by and hand us a major chunk of change? [Private institutions are exempted from that last question]

We should remember that our current concept of "batch-processing" students through the educational assembly line came from industry where cars were assembled in similar fashion. [Christensen, 19] It is appropriate for us to study what has happened to the U.S. auto industry, make analogies where appropriate, and take immediate action to transition as quickly as possible to a new strategy for educating the engineers of tomorrow – a student-centric, learning-centric model using online technology as opposed to the faculty-centric, teaching-centric model so prevalent in our classrooms today. It is possible that half of all high school courses will be delivered that way by 2019. [Christensen, 20] Complete K-12 curricula are already available in some states. [21] Assuming that the students who succeed in those courses are the very best; creative, willing to take risks, demonstrating a level of discipline, aptitude, and desire for knowledge rarely found in the typical high school classroom; what will we do to attract those students into engineering programs that are inflexible and anachronistic?

JOIN ME FOR DESSERT

As engineering educators, we should restrict those times we require students to meet with us in the same physical location to those when they join us for the academic dessert. That would imply that they have eaten the less enjoyable, but still required, items on the menu along with the occasional filet mignon that is served at the time and in the physical location of their choosing. During this part of the process, our job is one of coming up with the items on the main course (no pun intended) menu and providing suggestions when asked as opposed to one of making sure they all eat the exact same portions of the exact same menu items at the exact same time in the exact same place. In this part of the process, we should take full advantage of and contribute to sites such as Connexions [22] where our students can choose from an enlarged menu of items. We should also join with other faculty in focused "social networks" such as the previously mentioned Classroom 2.0 site to share our experiences for the common good of the profession. The students should look forward to the minimal times they all get together with us like an athlete looks forward to the main event after going through all the preparation and we should remember that the dessert menu should contain more than one item and should be strategically available on the table propped open with the seasoning shakers. In engineering education, we have the privilege and thrill of coming up with desserts that require special utensils and equipment to prepare and eat!

CONCLUSION

The cartoonist Walt Kelly once had his star character, Pogo, make the statement "We have met the enemy and he is us". In fact, it is a strong probability that, in order for the necessary changes in engineering education to happen, the current institutions have to die because our current structure and "customers" provide a negative inertia preventing the necessary innovation. [Christensen, 23] It doesn't have to be that way. Faculty, administrators, and students can move rapidly to allow the transition of curricula and courses in a way that encourages and rewards the necessary innovation. This must include accepting the risks that must be taken and the mistakes that will occur along the way.

ACKNOWLEDGEMENT

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