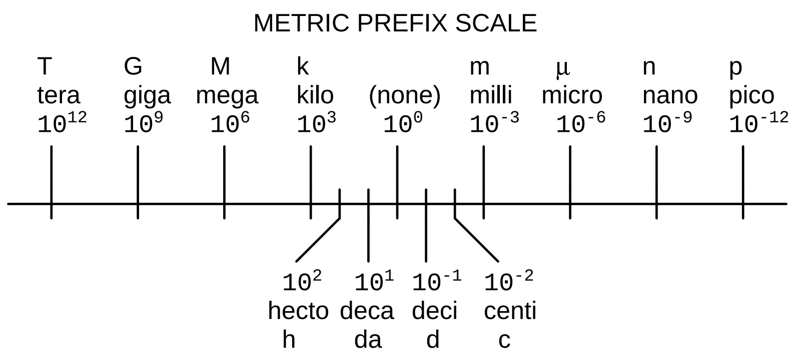
Units of measurement and conversions

Resources and methods for learning about these subjects (list a few here, in preparation for your research):

Metric prefixes and conversion constants

- **Metric prefixes**
- Yotta = 10^{24} Symbol: Y
- Zeta = 10^{21} Symbol: Z
- Exa = 10^{18} Symbol: E
- Peta = 10^{15} Symbol: P
- Tera = 10^{12} Symbol: T
- Giga = 10^{9} Symbol: G
- Mega = 10^{6} Symbol: M
- Kilo = 10^{3} Symbol: k
- Hecto = 10^{2} Symbol: h
- Deca = 10^{1} Symbol: da
- Deci = 10^{-1} Symbol: d
- Centi = 10^{-2} Symbol: c
- Milli = 10^{-3} Symbol: m
- Micro = 10^{-6} Symbol: μ
- Nano = 10^{-9} Symbol: n
- Pico = 10^{-12} Symbol: p
- Femto = 10^{-15} Symbol: f
- Atto = 10^{-18} Symbol: a
- Zepto = 10^{-21} Symbol: z
- Yocto = 10^{-24} Symbol: y



- **Conversion formulae for temperature**
- ^{o}F = (^{o}C)(9/5) + 32
- ^{o}C = (^{o}F - 32)(5/9)
- ^{o}R = ^{o}F + 459.67
- K = ^{o}C + 273.15

Conversion equivalencies for distance

1 inch (in) = 2.540000 centimeter (cm)

1 foot (ft) = 12 inches (in)

1 yard (yd) = 3 feet (ft)

1 mile (mi) = 5280 feet (ft)

Conversion equivalencies for volume

1 gallon (gal) = 231.0 cubic inches (in^3) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.) = 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm^3)

Conversion equivalencies for velocity

1 mile per hour (mi/h) = 88 feet per minute (ft/m) = 1.46667 feet per second (ft/s) = 1.60934 kilometer per hour (km/h) = 0.44704 meter per second (m/s) = 0.868976 knot (knot – international)

Conversion equivalencies for mass

1 pound (lbm) = 0.45359 kilogram (kg) = 0.031081 slugs

Conversion equivalencies for force

1 pound-force (lbf) = 4.44822 newton (N)

Conversion equivalencies for area

1 acre = 43560 square feet (ft^2) = 4840 square yards (yd^2) = 4046.86 square meters (m^2)

Conversion equivalencies for common pressure units (either all gauge or all absolute)

1 pound per square inch (PSI) = 2.03602 inches of mercury (in. Hg) = 27.6799 inches of water (in. W.C.) = 6.894757 kilo-pascals (kPa) = 0.06894757 bar

1 bar = 100 kilo-pascals (kPa) = 14.504 pounds per square inch (PSI)

Conversion equivalencies for absolute pressure units (only)

1 atmosphere (Atm) = 14.7 pounds per square inch absolute (PSIA) = 101.325 kilo-pascals absolute (kPaA) = 1.01325 bar (bar) = 760 millimeters of mercury absolute (mmHgA) = 760 torr (torr)

Conversion equivalencies for energy or work

1 british thermal unit (Btu – "International Table") = 251.996 calories (cal – "International Table") = 1055.06 joules (J) = 1055.06 watt-seconds (W-s) = 0.293071 watt-hour (W-hr) = 1.05506×10^{10} ergs (erg) = 778.169 foot-pound-force (ft-lbf)

Conversion equivalencies for power

1 horsepower (hp – 550 ft-lbf/s) = 745.7 watts (W) = 2544.43 british thermal units per hour (Btu/hr) = 0.0760181 boiler horsepower (hp – boiler)

Acceleration of gravity (free fall), Earth standard

9.806650 meters per second per second (m/s^2) = 32.1740 feet per second per second (ft/s^2)

Physical constants

Speed of light in a vacuum (c) = 2.9979×10^8 meters per second (m/s) = 186,281 miles per second (mi/s)

Avogadro's number (N_A) = 6.022×10^{23} per mole (mol^{-1})

Electronic charge (e) = 1.602×10^{-19} Coulomb (C)

Boltzmann's constant (k) = 1.38×10^{-23} Joules per Kelvin (J/K)

Stefan-Boltzmann constant (σ) = 5.67×10^{-8} Watts per square meter-Kelvin^4 ($W/m^2 \cdot K^4$)

Molar gas constant (R) = 8.314 Joules per mole-Kelvin (J/mol-K)

Properties of Water

Freezing point at sea level = 32^oF = 0^oC

Boiling point at sea level = 212^oF = 100^oC

Density of water at 4^oC = 1000 kg/m^3 = 1 g/cm^3 = 1 kg/liter = 62.428 lb/ft^3 = 1.94 slugs/ft^3

Specific heat of water at 14^oC = 1.00002 calories/g$\cdot^o$C = 1 BTU/lb$\cdot^o$F = 4.1869 Joules/g$\cdot^o$C

Specific heat of ice $\approx$ 0.5 calories/g$\cdot^o$C

Specific heat of steam $\approx$ 0.48 calories/g$\cdot^o$C

Absolute viscosity of water at 20^oC = 1.0019 centipoise (cp) = 0.0010019 Pascal-seconds (Pa$\cdot$s)

Surface tension of water (in contact with air) at 18^oC = 73.05 dynes/cm

pH of pure water at 25^o C = 7.0 (*pH scale = 0 to 14*)

Properties of Dry Air at sea level

Density of dry air at 20^oC and 760 torr = 1.204 mg/cm^3 = 1.204 kg/m^3 = 0.075 lb/ft^3 = 0.00235 slugs/ft^3

Absolute viscosity of dry air at 20^oC and 760 torr = 0.018 centipoise (cp) = 1.8×10^{-5} Pascal-seconds (Pa$\cdot$s)

Question 1

The range of industries where you may go to work is staggering, not only in its scope but also in its breadth of knowledge and skills required to be a successful instrument technician. If time permits, survey some of these industries (showcased in the "answer" section of this question).

In 2009, the *Industrial Instrumentation and Control Technology Alliance* (IICTA) conducted a survey of 23 industrial instrumentation experts from across the United States to rank the relative importance of knowledge and skill areas listed on the *Texas Skill Standards Board* (TSSB) skill standard for "Industrial Instrumentation and Controls Technician." The following is a list of knowledge/skill areas from this skill standard where "critically important" (the absolute highest importance) was the most popular vote of the experts surveyed, along with the percentage of experts voting the knowledge/skill area as "critical", and also a qualitative judgment of how difficult it is for someone to first acquire that knowledge or skill:

Knowledge / Skill area	**% vote**	**Difficulty**
Ability to learn new technology	65%	Hard
Interpret and use instrument loop diagrams	65%	Moderate
Configure and calibrate instruments	65%	Moderate
Knowledge of test equipment	61%	Hard
Interpret and use process and instrument diagrams	57%	Moderate
Interpret and use instrument specification sheets	52%	Easy
Knowledge of basic AC/DC electrical theory	52%	Hard
Knowledge of basic mathematics	48%	Moderate
Interpret and use electrical diagrams	48%	Moderate
Interpret and use motor control logic diagrams	43%	Moderate
Knowledge of system interactions (e.g. interlocks & trips)	43%	Hard
Knowledge of permits and area classifications	43%	Easy
Understanding consequences of changes	43%	Hard
Proper use of hand tools	43%	Moderate
Knowledge of control schemes (e.g. ratio, cascade)	39%	Hard
Proper tubing and wiring installation	35%	Moderate
Motor control circuit knowledge	30%	Moderate
Electrical wiring knowledge	30%	Moderate

Which of these knowledge/skill areas would you consider yourself proficient in right now?

On January 24, 2013 the Washington State Workforce Training and Education Coordinating Board presented results of a survey gathering input from over 2800 employers state-wide. One of the questions on this survey asked employers if they had experienced difficulty with entry-level employees demonstrating the following skills. A partial listing of results is shown here:

Knowledge / Skill area	**Percentage experiencing difficulty**
Solve problems and make decisions	50%
Take responsibility for learning	43%
Listen actively	40%
Observe critically	38%
Read with understanding	32%
Use math to solve problems and communicate	31%

In July and August of 2011, the Manufacturing Institute and Deloitte Development LLC worked together to adminster a "Skills Gap study" across a range of manufacturing industries in the United States. Survey results were collected from 1123 respondents, with one of the survey questions asking *"What are the most serious skill deficiencies in your current employees?"*. The responses to this question are tabulated here:

Knowledge / Skill area	**Percentage experiencing difficulty**
Inadequate problem-solving skills	52%
Lack of basic technical training	43%
Inadequate "soft skills" (attendance, work ethic)	40%
Inadequate computer skills	36%
Inadequate math skills	30%
Inadequate reading/writing/communication skills	29%

In December of 2001, the question "What qualities should an Instrumentation graduate possess in order to excel in their profession?" was posed to representatives on the Advisory Committee for BTC's Instrumentation program. In addition to a firm knowledge of fundamentals (electronics, physics, mathematics, process control), one advisor in particular noted that "self-direction and the ability to learn on your own" was even more important than these.

Do you see a pattern emerging from a comparison of these feedback results? As any economist can tell you, the highest-valued commodity is one with the greatest demand *and* the least supply. Which knowledge/skill area do you see in these survey results meeting *both* criteria? Are there other (lesser-valued) knowledge/skill areas of high value as defined by the same criteria of low supply and high demand?

Now, discuss how is it possible for a program of instruction such as BTC's Instrumentation and Control Technology program to teach students these critical knowledge and skill areas, and to do so in just two years.

file i00001

Question 2

Use a computer to navigate to the "Socratic Instrumentation" website:

`http://www.ibiblio.org/kuphaldt/socratic/sinst`

When you get there, click on the link for the quarter (Summer, Fall, Winter, or Spring) you are enrolled in, and download the INST200 "Introduction to Instrumentation" course worksheet. Today's classroom session will cover Day 1 of this worksheet.

Near the very beginning of this document, as is the case for *all* the 200-level Instrumentation course worksheets, you will find a page titled "How To . . .". Locate this page and take several minutes to read through it. The "How to . . ." tips make reference to a "Question 0" which is also found in every course worksheet. Feel free to read the points listed in Question 0 as well.

When the class is finished with the reading, it's time to have a conversation about what you've read by applying these principles to actual student scenarios. This exercise will serve as a thumbnail sketch for how all class work is handled in the second year: you complete reading and research assignments prior to each class session, and then you spend nearly the entire class session discussing what you've learned while the instructor challenges you to explore the concepts deeper.

Your instructor will also hand out copies of a release form ("FERPA form") which you may sign to grant permission to share your academic performance records with employers. This is voluntary, not mandatory. Without signed consent from student, federal law prohibits any instructor from sharing academic records with anyone but the student and appropriate college employees.

Suggestions for Socratic discussion

- One of the purposes of this exercise is to practice active reading strategies, where you interact with the text to identify and explore important principles. An effective strategy is to write any thoughts that come to mind as you are reading the text. Describe how this active reading strategy might be useful in daily homework assignments.

file i00002

Question 3

Near the beginning of every course worksheet there are some pages titled "General Student Expectations". Locate these pages and take several minutes to read through them. These expectations reference "Question 0" which is also found in every course worksheet. Feel free to read the points listed in Question 0 as well.

We will practice a proven reading technique for boosting comprehension (listed in Question 0 for future reference), which entails **summarizing the text in your own words at a suggested ratio of one sentence of your own thoughts per paragraph of text**. This exercise will not only familiarize you with the basic expectations for the second-year Instrumentation courses, but also model a sound learning strategy you will find helpful throughout the rest of your education and career.

After the class is finished summarizing the reading, we will apply the "General Student Expectations" to actual student scenarios.

Suggestions for Socratic discussion

- One of the purposes of this exercise is to practice active reading strategies, where you interact with the text to identify and explore important principles. An effective strategy is to write any thoughts that come to mind as you are reading the text. Describe how this active reading strategy might be useful in daily homework assignments.

  file i00003

Question 4

Read the "Teaching Technical Theory" section of Appendix D ("How to Use This Book – Some Advice for Teachers") in your *Lessons In Industrial Instrumentation* textbook. This will serve as the basis for a discussion on why the second-year Instrumentation courses are not lecture-based.

Imagine a child wishing to learn how to ride a bicycle. Seeking knowledge on the subject, the child approaches an adult asking for that adult to explain how to ride a bike. The adult responds with a detailed and thorough explanation of bicycle riding, including all the relevant safety rules. *After this explanation concludes, will the child be able to ride a bicycle?* Now imagine that same child reading a book on bicycle riding. The book is well-written and filled with clear illustrations to aid understanding. *After finishing this book, will the child be able to ride a bicycle?* Now imagine that same child watching a demonstration video on bicycle riding. The video is professionally shot, with very clear views on technique. The actor in the video does a great job explaining all the important aspects of bicycle riding. *After watching the video in its entirety, will the child be able to ride a bicycle?*

It should be obvious at this point that there is more to learning how to ride a bicycle than merely being shown how to do so. Bike riding is a skill born of *practice*. Instruction may be *necessary* to learn how to ride a bicycle safely, but instruction in itself is not *sufficient* to learn how to ride a bicycle safely – you must actively attempt riding a bicycle before all the pieces of information come together such that you will be proficient. *What is it about bicycle riding that necessitates <u>practice</u> in order to learn?*

Now imagine someone wishing to learn how to write poetry. Seeking knowledge on the subject, this person consults poets for advice, reads books of poetry and books about writing poetry, and even listens to audio recordings of poets presenting their work in public. *After all this instruction and research, will the person be a proficient poet?*

Here we have the same problem we had with learning to ride a bicycle: instruction may be a *necessary* part of learning to write poems, but instruction in itself is not *sufficient* to become a poet. One must actively write their own poems to become good at it. *What is it about poetry that necessitates <u>practice</u> in order to learn how to write it?*

The fundamental principle here is that *we master that which we practice*, because the brain strengthens neural pathways through repeated use. There is nothing unique about bicycle riding or poetry in this regard: if you wish to master any skill you must repeatedly *do* that skill. The problem with learning about bicycle-riding or poetry from other people is that you aren't *doing* any bicycle riding or poetry yourself. The most valuable assistance any learner can receive is prompt and constructive feedback during the learner's practice. Think of a child attempting to ride a bicycle with an adult present to observe and give practical advice; or of a person learning poetry, submitting their poems to an audience for review and then considering that feedback before writing their next poem.

When we research which skills are most valuable to instrument technicians, we find *self-directed learning* and *general problem-solving* top the list. These skills, like any other, require intensive practice to master. Furthermore, that practice will be optimized with prompt and expert feedback. In order to optimally prepare students to become instrument technicians, then, those students must be challenged to learn on their own and to individually solve problems, with the instructor coaching them on both activities.

Here is where schools tend to cheat students: the majority of class time is spent presenting information to students, rather than giving students opportunity to practice their problem-solving skills. This is primarily the consequence of *lecture* being the dominant mode of teaching, where a live instructor must spend hour upon hour verbally presenting information to students, leaving little or no time for those students to solve problems and sharpen their critical thinking skills. Assigned homework does a poor job of providing practice because the student doesn't receive detailed feedback on their problem-solving strategies, and also because many students cheat themselves by receiving inappropriate help from their classmates. Furthermore, lecture is the antithesis of self-directed learning, being entirely directed by a subject matter expert. The skills practiced by students during a lecture (e.g. taking dictation on lengthy presentations) have little value in the career of an instrument technician. More time in school could be spent practicing more relevant skills, but only if some other mode of instruction replaces lecture.

Not only does lecture displace more valuable activities in the classroom, but lecture isn't even that good of an instructional technique. Among the serious shortcomings of lecture are the following:

- Students' attentions tend to drift over the span of any lecture of significant length.
- Lecture works well to communicate facts and procedures but fails at getting students to think for themselves, because the focus and pace of any lecture is set by the lecturer and not the students.
- Lecture instills a false sense of confidence in students, because complex tasks always look easier than they are when you watch an expert do it without trying it yourself. (An oft-heard quote from students in lecture-based classes: *"I understand things perfectly during lecture, but for some reason I just can't seem to do the homework on my own!"*)
- A lecturer cannot customize ("differentiate") instruction for individual students. Rather, everyone gets the exact same presentation (e.g. the same examples, the same pace) regardless of their diverse needs. The pace of lecture is perhaps the most obvious example of this problem: since the lecturer can only present at one pace, he or she is guaranteed to bore some students by going to slow for them and/or lose others by going too fast for them.
- Students cannot "rewind" a portion of lecture they would like to have repeated without asking the entire class to repeat as well.
- Students' must simultaneously dictate notes while trying to watch *and* listen *and* think along with the instructor, a difficult task at best. Multitasking is possible only for simple tasks, none of them requiring intense focus.
- If the instructor commits some form of verbal error and doesn't realize it (which is very common because it's difficult to simultaneously present and self-evaluate), it is incumbent upon the students to identify the error and ask for clarification.
- The instructor cannot accurately perceive how each and every student is understanding the presentation, because the instructor is too busy presenting. Body language during the lecture isn't a reliable enough indicator of student understanding, and the time taken by lecture precludes the instructor visiting every student to inspect their work.
- Lecture instills an attitude of dependence on students by reinforcing the notion they need to personally consult an expert in order to learn anything new. This discourages students from even trying to learn complex things on their own.

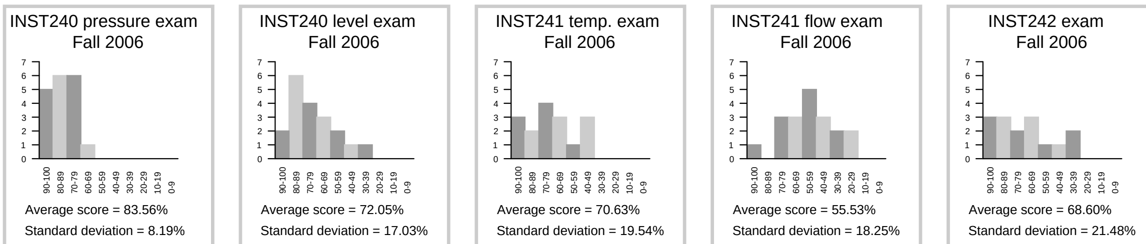
For these reasons – the fact that lecture displaces class time better spent coaching students to solve problems, as well as the many problems of lecture as an instructional mode – there is almost no lecture in any of the 200-level Instrumentation courses at BTC. Instead, students learn the basic facts and procedures of the subject matter through reading assignments prior to class, then spend class time solving problems and demonstrating their understanding of each day's major topic(s) before leaving. This is called an *inverted classroom* because the classroom and homework roles are swapped: what is traditionally lectured on in class is instead done on the students' time outside of class, while the problem-solving traditionally done as homework is instead completed during class time while the instructor is available to coach. This format is highly effective not only for learning the basic concepts of instrumentation, but also for improving technical reading and critical thinking skills, simply because *it requires students to practice the precise skills they must master*.

The primary reason *reading* was chosen as the preferred mode of instruction is feedback from employers as well as observations of student behavior, both sources revealing an aversion to technical reading. Some employers (most notably the BP oil refinery in Carson, California) noted reading comprehension as being the weakest area when testing BTC students during recruiting trips. Also, a failure to reference equipment manuals when working on real systems is a chronic problem both for novice technicians in a wide range of industries as well as students learning in a lab environment. Given the fact that far more high-quality technical information is available for continued learning in this career than high-quality videos, reading comprehension is a vital skill for technicians to keep their knowledge up to date as technology advances.

Prior to 2006 all 200-level Instrumentation courses were strictly taught by lecture. Making matters worse, many of the courses had no textbook, and homework was seldom assigned. All 200-level exams focused exclusively on rote memorization and execution of procedural problem-solving rather than problem-solving requiring creativity and synthesis of multiple concepts. It was common for second-year students to flounder when presented with a new piece of equipment or a new type of problem, because no instructor can teach procedures to cover any and all possible challenges.

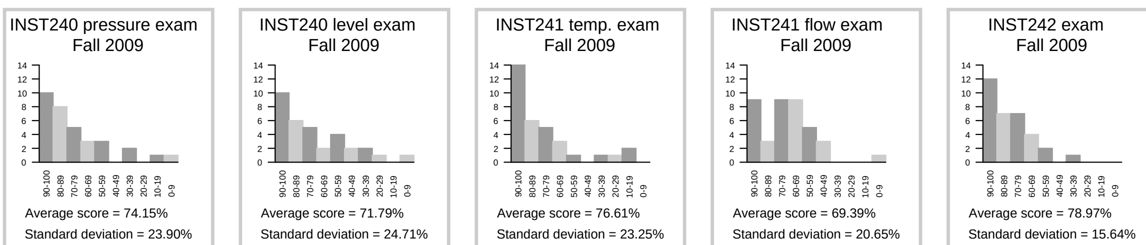
Since 2006 the 200-level Instrumentation courses have morphed from lecture to "inverted" format, with measurable gains in learning. Proportional exam scores from the Fall quarter courses (INST240, INST241, and INST242 – those courses where the content has remained most stable over this time span) demonstrate this, each histogram showing the number of students (vertical axis) achieving a certain exam score (horizontal axis):

Fall 2006: limited text resources for students (no standard textbook for the curriculum), classroom format a mixture of lecture and group discussion



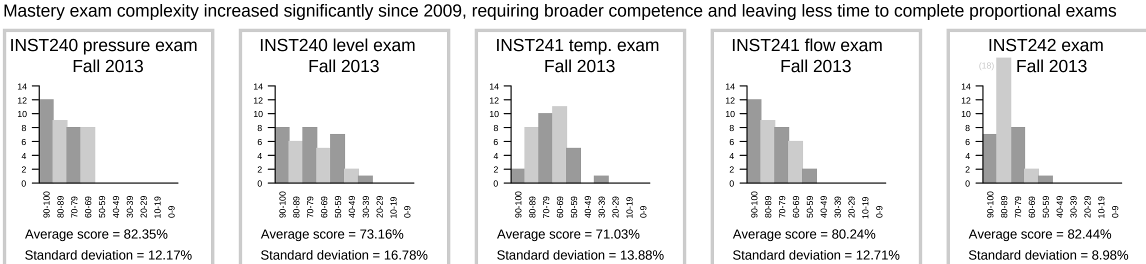
Cumulative exam score average for Fall quarter 2006 = 70.07%
Cumulative exam score standard deviation for Fall 2006 = 19.27%

Fall 2009: *Lessons In Industrial Instrumentation* textbook available to students, classroom format still a mixture of lecture and group discussion
Exam complexity increased significantly since the introduction of the new textbook in 2008



Cumulative exam score average for Fall quarter 2009 = 74.18%
Cumulative exam score standard deviation for Fall 2009 = 21.88%

Fall 2013: *Lessons in Industrial Instrumentation* textbook greatly expanded, classroom format fully inverted (i.e. no lecture)
Mastery exam complexity increased significantly since 2009, requiring broader competence and leaving less time to complete proportional exams



Cumulative exam score average for Fall quarter 2013 = 77.85%
Cumulative exam score standard deviation for Fall 2013 = 13.89%

Note the general improvement in average exam scores (2009) toward the end of the quarter, despite the exams being more complex than they were in 2006. Students were held accountable for the assigned textbook reading with graded "prep quizzes" at the beginning of each class session. Note also how the standard deviations increased, representing a greater degree of "spread" between student performance on these exams. The increased standard deviation shows some students falling behind their peers, since lecture was not providing for their needs with a more challenging curriculum.

In the third set of histograms (2013) we see general increases in average scores as well as marked improvements in standard deviation across the board (showing fewer students "left behind" their peers). The inverted classroom format allows the instructor to spend one-on-one time with each and every student to probe for misconceptions and offer assistance when needed. This kind of differentiated instruction is impossible in a lecture format.

One of the most striking improvements realized since abandoning lecture is the ease of which students grasp some of the more complex concepts throughout the year. These concepts used to be difficult to convey in a lecture format (mostly due to pacing problems, since different students would get "stuck" at different points in the presentation), and so long as some lecture existed in the classroom students would tend to give up when they encountered difficult concepts in the assigned reading (knowing they could rely on the instructor to lecture on these tough concepts in class):

- INST230 course: Three-phase electric power system calculations
- INST230 course: Normally-open versus normally-closed contact status
- INST240 course: Interface liquid level measurement (hydrostatic and displacer)
- INST240/250 courses: Force-balance versus motion-balance pneumatic mechanisms
- INST241 course: Coriolis mass flowmeters
- INST242 course: Gas chromatograph operation
- INST242 course: Non-dispersive optical analyzers (NDIR, Luft detectors, etc.)
- INST250 course: Fluid power system analysis (hydraulic and pneumatic diagrams)
- INST250 course: Split-ranged control valve sequencing
- INST250 course: Control valve characterization
- INST252/263 courses: Feedforward control strategies
- INST252 course: Loop stability analysis (based on trend recordings)
- INST260 course: Data acquisition hardware connections (e.g. differential vs. single-ended connections)
- INST262 course: FOUNDATION Fieldbus and wireless (radio) digital communications
- INST263 course: Selector and override controls

This improvement in student learning has been verified by industry representatives, when they are invited to come to BTC to review certain complex topics such as Fieldbus, WirelessHART, and control valves. The general feedback they give is that BTC students are unusually well-prepared on these subjects. The "secret" of course is that students learning in an inverted classroom format spend more time immersed in the subject matter, and the feedback they receive from their instructors in class is better tailored to their individual learning needs.

Another significant gain realized since abandoning lecture is the immediate placement of inexperienced BTC Instrumentation graduates in jobs typically reserved for engineers with 4-year degrees. This simply did not happen when BTC's Instrumentation program was lecture-based, and it is due to the fact that students explicitly learn higher-order thinking skills when they must gather information on their own outside of class and then demonstrate critical thinking before an instructor every day. This has happened once in December 2011, again in December 2012, again in March 2013, and again in August 2013.

Yet, despite the gains realized by abandoning lecture in favor of an "inverted" teaching format, some students are highly resistant to the concept. Some of the critical comments routinely heard from students against the inverted format are as follows:

(1) *"I learn better in a lecture format."*

(2) *"My learning style is visual, which means I need to* <u>see</u> *someone work the problems for me."*

(3) *"When I arrive to class after doing the assigned reading and trying to solve the homework problems, I'm completely lost."*

Discuss each of these comments in detail. Here are some starting points for conversation:

(1) What does it mean to learn something *better*? How may a student measure how well they've learned something new? What, exactly, is it that is learned better in lecture? Is there anything significant that students *don't* learn in a lecture?

(2) Would someone with an *auditory* or *kinesthetic* learning style fare any better in an inverted classroom? Does a visual learning style preclude effective reading, or independent learning? Are learning styles real or merely perceived? Are learning styles immutable (i.e. permanent), or is it possible for people to cultivate new learning styles?

(3) What does it mean if a student is lost after completing the homework for an inverted class, assuming a significant number of their classmates are *not* lost? What would be an appropriate course of action to take in response to this condition?

<u>file i00004</u>

Question 5

Lab Exercise

Your team's task is to equip working process control system with an additional layer of controls to bring it to a safe "shutdown" condition in the event of one or more detected conditions sensed by separate instrumentation.

The shutdown function must bring the process to a "safe" condition (power off, vessels drained/vented, etc.) independent of any action on the part of the loop PID controller. In other words, the shutdown should work *no matter what the loop controller is trying to do.* This shutdown condition must "latch" and be re-settable only from a manual pushbutton, also independent of the loop PID controller. You may use either a hard-wired relay, a PLC, or a dedicated safety controller to implement the latching safety shutdown function.

Each student must independently demonstrate the shutdown functionality of a different team's system by simulating a "dangerous" condition to the input of the shutdown system. This will be done given a 5-minute time limit, just like loop troubleshooting. In other words, each student needs to figure out how to make another team's (chosen by the instructor) shutdown system "think" a dangerous condition exists without actually bringing the system to that actual point (e.g. over-temperature, over-pressure, overflow level, etc.) and then correctly implement that test. Failure to correctly devise a valid shutdown test given the criteria posed by the instructor will disqualify the effort, in which case the student must re-try with a different system and/or scenario. Multiple re-tries are permitted with no reduction in grade.

<u>Objective completion table:</u>

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
Choose safety shutdowns to add	mastery	–	–	–	–	
Updated loop diagram and process inspection	mastery					– – – –
Test shutdown systems (5 minute limit)	mastery					– – – –
Lab question: Selection/testing	proportional					– – – –
Lab question: Commissioning	proportional					– – – –
Lab question: Mental math	proportional					– – – –
Lab question: Diagnostics	proportional					– – – –

Each student will be asked to correctly answer a "lab question" from each of the four categories (examples shown on the next page). These lab questions serve as a guide to knowledge and skills all team members should be learning as they progress through the lab exercise. The instructor may quiz students on these questions at any appropriate time before the lab exercise is complete.

Lab Questions

- **Selection and Initial Testing**
  - Identify all inputs and outputs on the field instruments (transmitter and FCE)
  - Explain the meanings of the various ratings specified on the instrument nameplate
  - Identify in the manufacturer documentation where to connect signal wires to the field instrument (transmitter or FCE)
  - Explain what types of test equipment were used to validate the operation of the field instrument (transmitter or FCE)
  - Explain how you could perform rudimentary tests of instrument function using simple test equipment (multimeter, air pumps, pressure gauges, resistors, batteries, etc.)

- **Commissioning and Documentation**
  - Demonstrate how to use a loop calibrator to measure signal current
  - Demonstrate how to use a loop calibrator to source signal current
  - Demonstrate how to use a loop calibrator to simulate signal current
  - Identify multiple locations (referencing a loop diagram) you may measure various 4-20 mA instrument signals in the system
  - Identify multiple locations (referencing a loop diagram) you may connect HART communicator in the system

- **Mental math** (no calculator allowed!)
  - Determine allowable calibration error of instrument (e.g. +/- 0.5% for an instrument ranged 200 to 500 degrees)
  - Convert 4-20 mA signal into a percentage of span (e.g. 13 mA = ____%)
  - Convert percentage of span into a 4-20 mA signal value (e.g. 70% = ____ mA)
  - Convert 3-15 PSI signal into a percentage of span (e.g. 11 PSI = ____%)
  - Convert percentage of span into a 3-15 PSI signal value (e.g. 40% = ____ PSI)

- **Diagnostics**
- "Virtual Troubleshooting" − referencing their system's diagram(s), students propose diagnostic tests (e.g. ask the instructor what a meter would measure when connected between specified points; ask the instructor how the system responds if test points are jumpered) while the instructor replies according to how the system would behave if it were faulted. Students try to determine the nature and location of the fault based on the results of their own diagnostic tests.
  - Given a particular component or wiring fault (*instructor specifies type and location*), what symptoms would the loop exhibit and why?
  - Identify how to electrically simulate a specified shutdown trip condition.
  - Explain why breaking a 4-20 mA loop could cause serious problems in an actual instrument loop!
  - Explain what will happen (and why) in your control loop if the transmitter suddenly fails with a low (4 mA) signal. Assume the controller is in automatic mode when this happens.
  - Explain what will happen (and why) in your control loop if the transmitter suddenly fails with a high (20 mA) signal. Assume the controller is in automatic mode when this happens.
  - Explain what will happen (and why) in your control loop if the FCE suddenly fails with the equivalent of a low (4 mA) MV signal.
  - Explain what will happen (and why) in your control loop if the FCE suddenly fails with the equivalent of a high (20 mA) MV signal.

file i00005

Question 6

What is *area*, the mathematical symbol for area, and what are some of the units used to measure area? Identify whether these units are English or metric.

file i00006

Question 7

What is *volume*, the mathematical symbol for volume, and what are some of the units used to measure volume? Identify whether these units are English or metric.

file i00007

Answer 1

A survey of some industries applying measurement and control technology

Electric power generation:

Photos taken at the Satsop nuclear generating station in Washington.

Combined-cycle (gas turbine plus steam turbine) power plant, fueled by natural gas, in Ferndale, Washington.

Antelope Valley coal-fired power plant in Beulah, North Dakota.

Hydroelectric turbine generators at Grand Coulee Dam in Washington.

Oil and natural gas exploration/production:

BP Exploration's "Atlantis" offshore rig while under construction.

BTC Instrumentation grad Paige repairing flare ignitors on an offshore rig in the Gulf of Mexico.

Oil well drilling rig in the Bakken oil play (Stanley, North Dakota). These rigs drill approximately 2 miles down, then drill horizontally and fracture the shale rock to allow oil to seep out and be collected.

Oil wellhead and pump in Stanley, North Dakota.

Oil refining:

The Phillips66 refinery in Ferndale, Washington.

Coal gasification:

Dakota Gasification plant in Beulah, North Dakota. Produces synthetic natural gas, ammonia, and a variety of other high-value chemical products from coal. A majority of the carbon dioxide produced in this process is captured and piped to oil fields in Canada for enhanced recovery operations, where the CO_2 *gas ends up sequestered in underground wells.*

Pharmaceutical manufacturing:

Photos taken at Zymogenetics in Seattle. Sorry – they wouldn't let me snap any pictures of the really cool stuff!

Natural gas compression and distribution:

Williams Northwest Pipeline's gas compression facility in Sumas, Washington.

Large reciprocating (piston) engine used to compress natural gas.

Food processing and packaging:

Plant floor at Nature's Path Foods in Blaine, Washington.

Automated boxing machine for cereal.

Alcohol production and bottling:

Mash tuns and bottling line at RedHook Brewery in Woodinville, Washington.

Municipal water and wastewater treatment:

Potable water filtering at the city of Arlington, Washington.

Wastewater clarification at West Point treatment facility in King County (Seattle), Washington.

Electrical power distribution:

Bonneville Power Administration's Custer, Washington substation switchyard (500,000 volts).

Lumber milling and treatment:

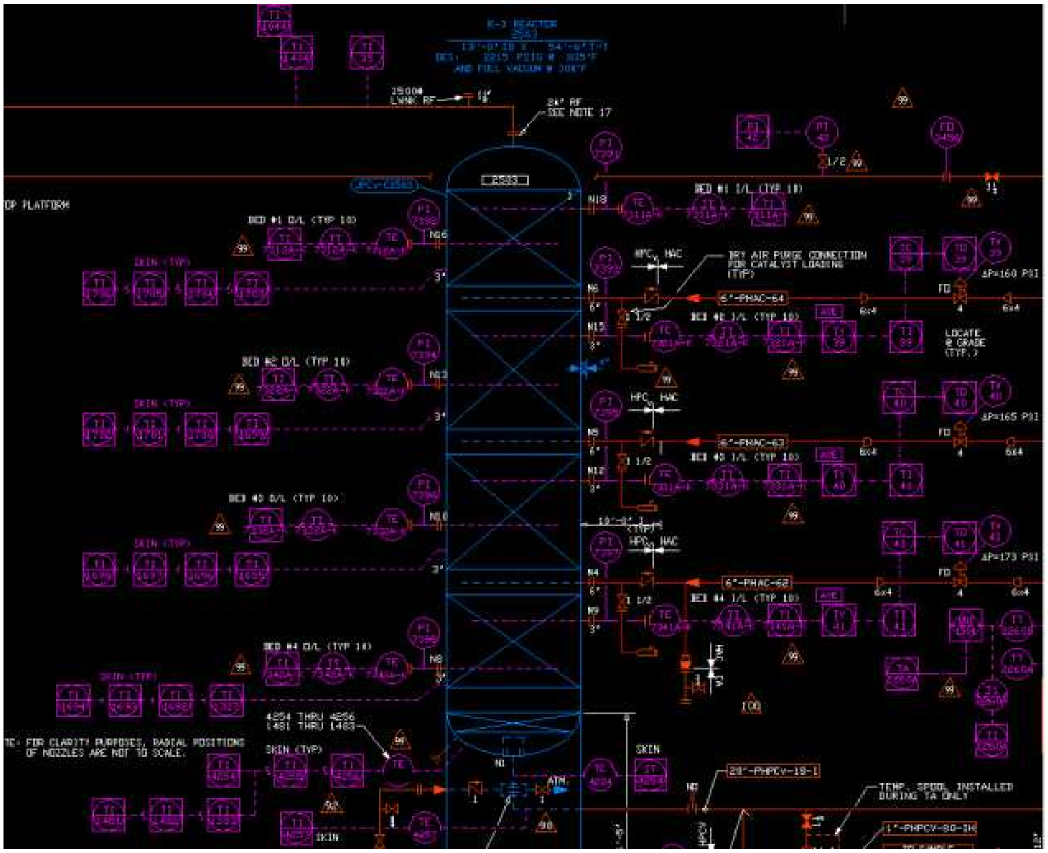
A computer-controlled drilling machine places holes into a wooden power line crossarm.

A retort used to pressure-treat lumber.

Aerospace:

Photos taken at NASA's rocket engine test facility in Stennis, Mississippi.

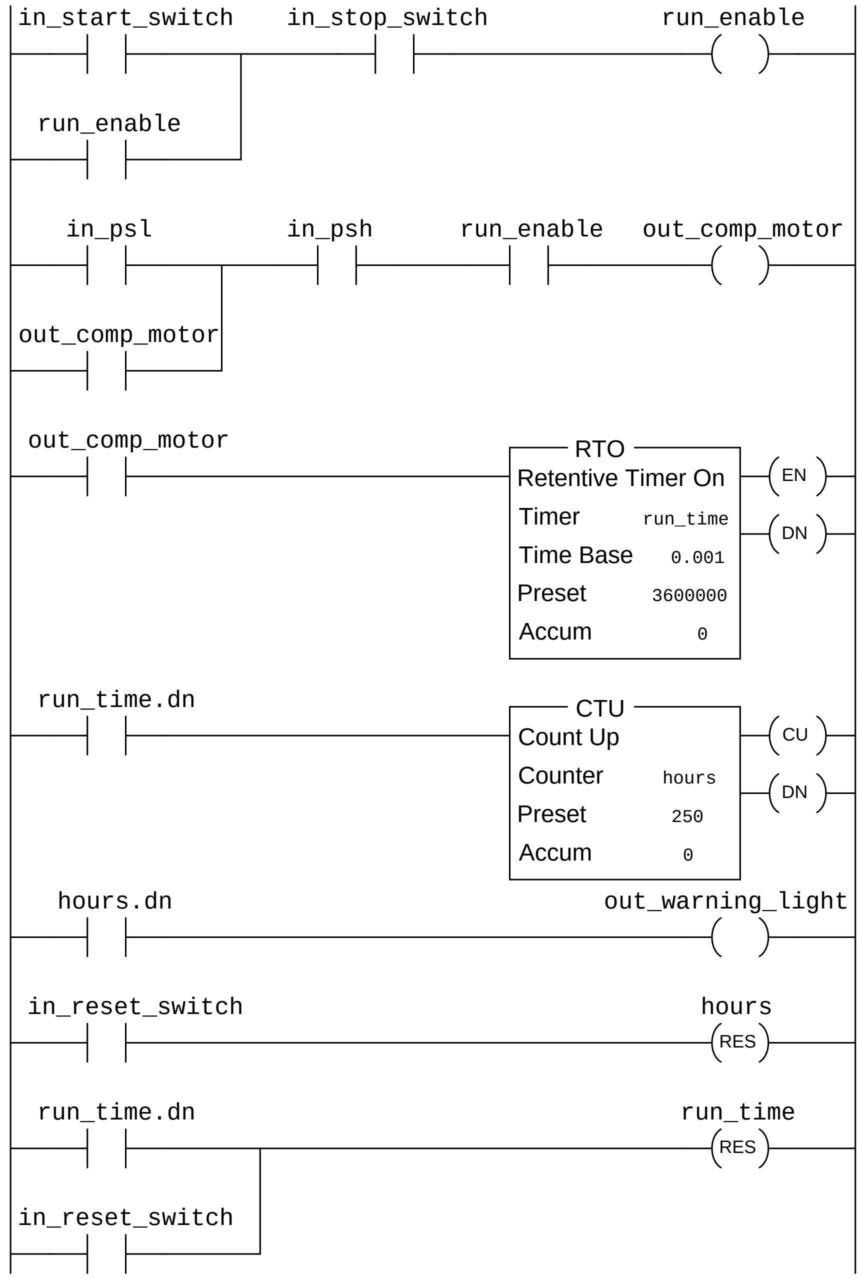
Instrument control circuit layout and design:



A typical screenshot of AutoCAD being used to draft a P&ID for an oil refinery unit.

"Potline" buildings at the Alcoa/Intalco aluminum smelter in Ferndale, Washington.

PLC programming (control system design engineering):

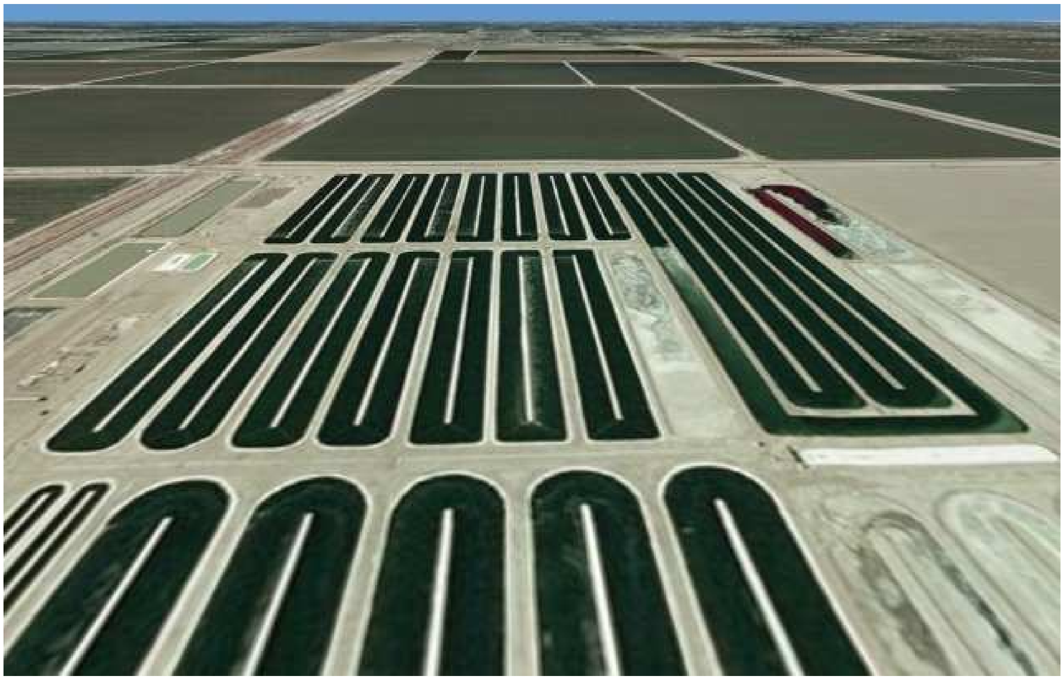


A typical PLC "ladder logic" program for an air compressor controlled by a Rockwell ControlLogix 5000 PLC is shown here.

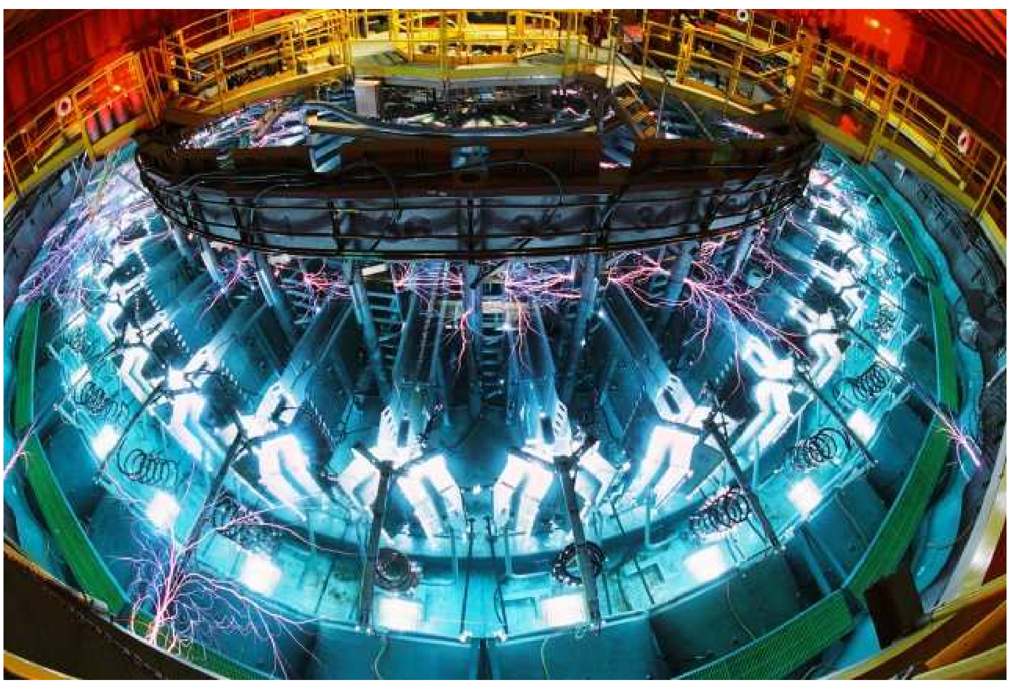
Environmental monitoring:

A Sutro weir used to measure the flow of water out of lake Padden in Bellingham, Washington.

Renewable energy:



Pacific Northwest National Laboratory's experimental algae ponds for solar-to-biomass conversion. Photo courtesy Department of Energy.



Sandia National Laboratory's pulsed power device used to conduct experiments in nuclear fusion, and also to test the effects of electromagnetic pulse energy on military hardware. Photo courtesy Department of Energy.

Wind turbines at the Wild Horse wind farm near Ellensburg, Washington.

Photovoltaic array at the Wild Horse wind farm near Ellensburg, Washington.

Mining:

BTC Instrumentation grads Micah and Mark working on a control valve near an ore crushing mill in Alaska.

Control valve service:

Customer Repair Report

EMERSON Process Management

Page 3 of 3

Customer Order Number	Fisher/Agent Order Number	Ship Date	Serial Number
		3/7/2007	

Job Number	Line Number	Description	Customer Equipment Tag
	0001	2" EZ	18-PV-22A

PICTURES INFORMATION

AS FOUND

CR72374 AS FOUND

CR72374 AS FOUND

CR72374 AS FOUND

AS LEFT

CR72374 AS LEFT

CR72374 AS LEFT

Typical "As-Found" and "As-Left" page of a control valve rebuild report.

Contract instrumentation work:

BTC Instrumentation grad Corey services a control valve at a Wyoming oil refinery during a winter shutdown.

Other career sectors not shown in this photo collection include (but are not limited to):

- Wood pulp and paper production
- Manufacturing assembly lines
- Automotive research and development
- Chemical processing
- Metals refining and foundries
- Weight scale and weighfeeder service
- Calibration standard laboratories
- University campus utility work
- Geological monitoring (volcano monitoring)
- Robotics
- CNC machine tool maintenance
- Remotely piloted vehicles
- Instrumentation sales

Answer 2

Answer 3

Answer 4

Answer 5

Answer 6

Area (symbol: A) is the measurement of two-dimensional space.

Area may be expressed in terms of squared distance units (square inches, square miles, square centimeters, etc.), or in special units unique to the variable of area (such as acre or hectare).

Answer 7

Volume (symbol: V) is the measurement of three-dimensional space.

Like area, volume may be expressed in terms of cubed distance units (cubic inches, cubic miles, cubic centimeters, etc.), or in special units unique to the variable of area (such as the English unit of "gallon" or the metric unit of "liter").