# Design of Effective Examples

Prof. Suzanne Kresta
(New) Faculty Forums
March 12, 2013

Department of Chemical & Materials Engineering

# What makes a good example?

- Compelling story directly related to key learning objectives
- Non-trivial problem
- Data and calculations are correct
- Physics and assumptions are correct
- Results are representative of the real world
- Can be completed in one class

# Big Messages

- Effective examples are central to student learning (90%)
- Begin with the end in mind: an understanding of learning objectives dramatically improves your effectiveness as an instructor (86%)
- Alignment of learning objectives AND cognitive levels between notes, examples, assignments, and testing is critical to pushing student learning to the next level

# Some things you may find helpful before we start.

- Examples engage students in understanding.
- Students learn differently than professors.
- Application of concepts to new problems requires a very high level of cognitive development (making the right connections is hard!).

# 1. Active Learning (examples) Work.

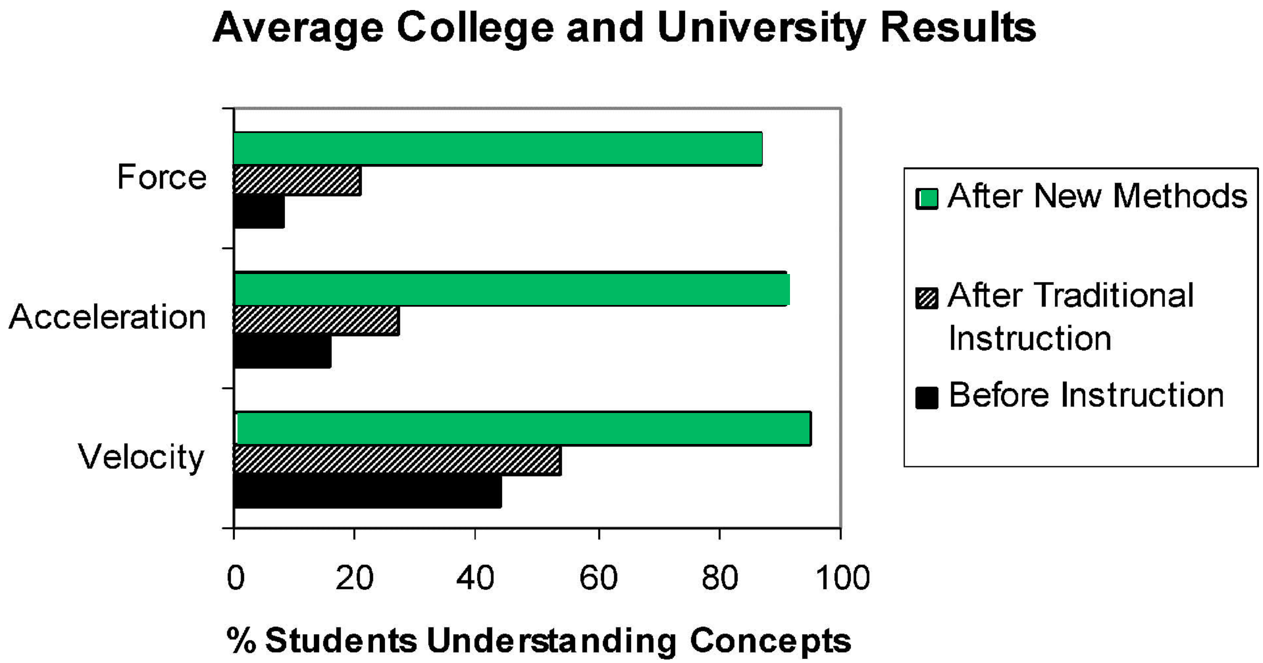



*Figure 1: Active-engagement (examples) vs. traditional instruction for improving students' conceptual understanding of basic physics concepts*

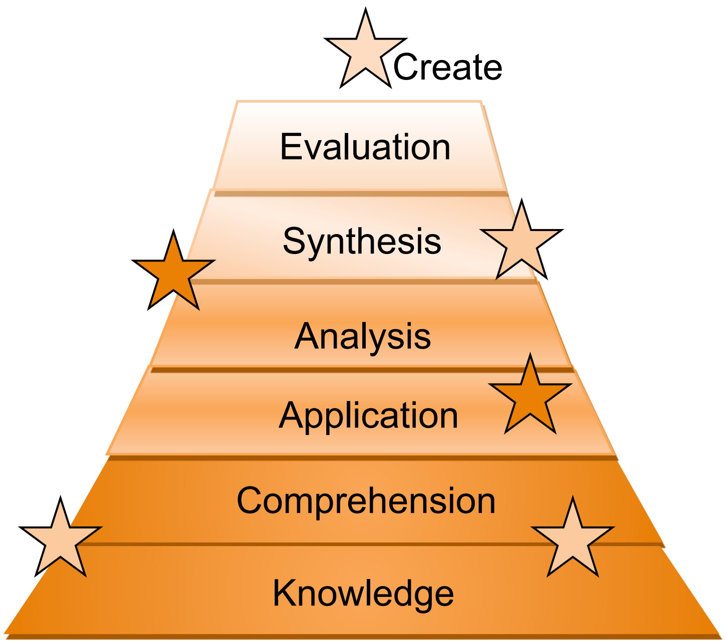
(Laws, P., D. Sokoloff, and R. Thornton, "Promoting Active Learning Using the Results of Physics Education Research," *UniServe Science News, Vol. 13, July 1999; see also Carl Weiman's work at UBC.)*

*How many of your favorite professors did this?*

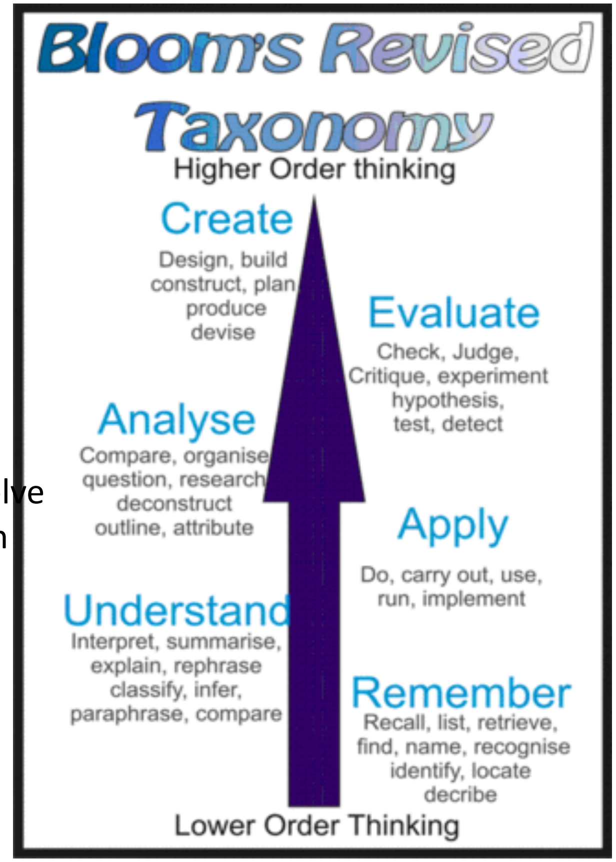
# 2. Students are sequential learners.

- Felder's Learning Styles Inventory administered to (http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Learning_Styles.html)
  - over 100 new professors and over 1000 students
  - Similar balance on (**Visual (8.5)** to Verbal (1.5), **Active (6.5)** to Reflective (3.5), and **Sensing (7.0)** to Intuitive (3.0).
  - BIG mismatch on **Sequential (7.5)** to Global (2.5) domain (Larry Unsworth referred to this as the inductive vs deductive teaching style)
- Professors prefer global learning (3.5/6.5), students sequential
  - Sequential learners tend to gain understanding in linear steps, with each step following logically from the previous one. They tend to follow logical stepwise paths in finding solutions.
  - Global learners need the big picture of a subject before they can master details. They may be able to solve complex problems quickly or put things together in novel ways once they have grasped the big picture. They may also have difficulty explaining how they did it.
- **Examples open the door between these learning styles!**

# Bloom's Very Powerful Idea




**Synthesis:**
Combine or rearrange elements to propose alternative solutions or solve a new problem

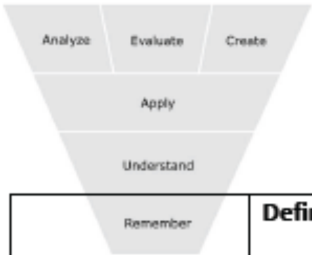


# Bloom's Taxonomy of Learning – Revised[i]

CENTRE for TEACHING and LEARNING

## Cognitive Domain

Involves knowledge and the development of intellectual skills




| | Definition: | Verbs: | Evaluating example: | Activity Example |
|---|---|---|---|---|
| **REMEMBERING** | retrieving information from short and long term memory | accumulate, arrange, recognize, list, label, locate, define, describe, identify, retrieve, name, match, recall, repeat | Can the student **recall** information? | memory of specific facts, terminology, rules, sequences, procedures, classifications, categories, criteria, methodology, principles, theories, and structure |
| **UNDERSTANDING** | changing from one form of representation to another; illustrating a concept; drawing conclusions, determining cause and effect | choose, cite, summarize, paraphrase, exemplify, compare, infer, translate, clarify, classify, extrapolate, conclude, give an example, discuss, explain, restate, respond, express, describe | Can the student **explain** ideas or concepts? | stating problem in own words, translating a chemical formula, understanding a flow chart, translating words and phrases from a foreign language |
| **APPLYING** | applying or demonstrating knowledge in a routine or non-routine task | apply, interpret, implement, carry out, use, utilize, demonstrate, execute, illustrate, generalize, predict, make, clarify why, utilize, show, | Can the student **use** the new knowledge in another situation? | taking principles learned in math and applying them to figuring the volume of a cylinder in an internal combustion engine |
| **ANALYZING** | Breaking down objects or ideas into simpler parts and seeing how the parts relate and are organized; | analyze, appraise, conclude, contrast, correlate, determine, discriminate, distinguish, compare, attribute, deconstruct, integrate, outline, find coherence | Can the student **differentiate** between vital parts? | discussing how fluids and liquids differ, detecting logical fallacies in a student's explanation of Newton's 1st law of motion; distinguishing relevant from irrelevant; |
| **EVALUATING** | distinguishing whether a process/product has internal consistency, inconsistencies or fallacies; | assess, choose, critique, check, judge, evaluate, hypothesize, test, detect, measure, rate, monitor, rank, score, justify, validate, test | Can the student **justify** a decision or course of action? | writing a comprehensive report on a problem-solving exercise, , writing a comprehensive term paper; detecting appropriateness of a procedure for a given task |
| **CREATING** | developing a hypothesis; devising a procedure; inventing a product | compose, design, plan, construct, produce, develop, create, devise, modify, organize, predict | Can the student **generate** new products, ideas or ways of viewing. | evaluating alternative solutions to a problem, detecting inconsistencies in the speech of a student government representative |

*Center for Teaching and Learning, University of Alberta, 2012

# 3. Teaching Advanced Problem Solving is a bit tricky.

1. Math skills in x, y, z unknowns
2. Translation map to real physical variables
   (the word problem– Junior High and HS)
3. Using one skill to solve one problem
   (text book drill problems – HS, 1st and 2nd year)
4. Selecting from several tools to solve from a small range of problems (1st 2nd and 3rd year) e.g. dynamics

*As we go through the next steps, identify the course where you first became aware of doing this.*

5. Selecting the right tool* for a problem with a new twist (2nd 3rd and 4th year) e.g. MEB, HTF, Unit Ops
6. Given a new problem in one subject area, identify the right tools to apply to solve it. (4th year and graduate school) e.g. Process control
7. Given a new problem with many facets, define the key aspects of the problem and select the correct tools to apply to find the best solution. (4th year design course, graduate school thesis, experienced engineering design)

* It takes several guided examples (3) for students to start to see which tools to select for a new problem.
*(e.g. Ross, BH and Kennedy, PT, Generalizing From the Use of Earlier Examples in Problem Solving, J Exptl Psych – Learning Memory and Cognition, 16 (1): 42-55 Jan 1990)*

*Do the steps in Cognitive Development for Problem Solving correlate with Bloom's Hierarchy?*

# What next?

**The good news:** These tools allow us to take the students much further along the path to advanced critical thinking and problem solving!

**What comes next?** Start with the learning objective (content and cognitive level), then design an example.

**Moral of the story:** Be aware of matching the level of teaching in examples and homework to the level of exam questions you would like to ask! Select all of these with an awareness of the students' developmental level(s!).

*Sometimes learning objectives first appear to us as a failure to teach/learn a key concept in the course!*

# Teaching by Example: The Case of the Linear Momentum Balance

- Changing the direction of motion requires application of a force. (Know)
- What does the momentum of a fluid mean? (Understand)
- How to select co-ordinates and decompose the vector equation into components? (Analyse, Apply and Synthesize!)
- What assumptions are needed to complete the problem solution? Are they reasonable? (Evaluate, Understand)

...for the rest of this story...

# Teaching by Example: The Case of the Linear Momentum Balance

- Changing the direction of motion requires application of a force. (Know)
- What does the momentum of a fluid mean? (Understand)
- How to select co-ordinates and decompose the vector equation into components? (Analyse, Apply and Synthesize!)
- What assumptions are needed to complete the problem solution? Are they reasonable? (Evaluate, Understand)

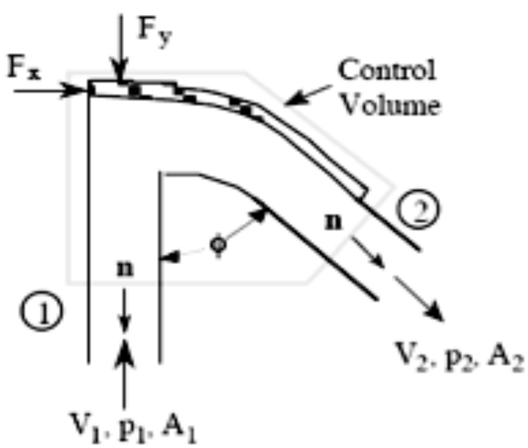
# First step: What cognitive barriers?

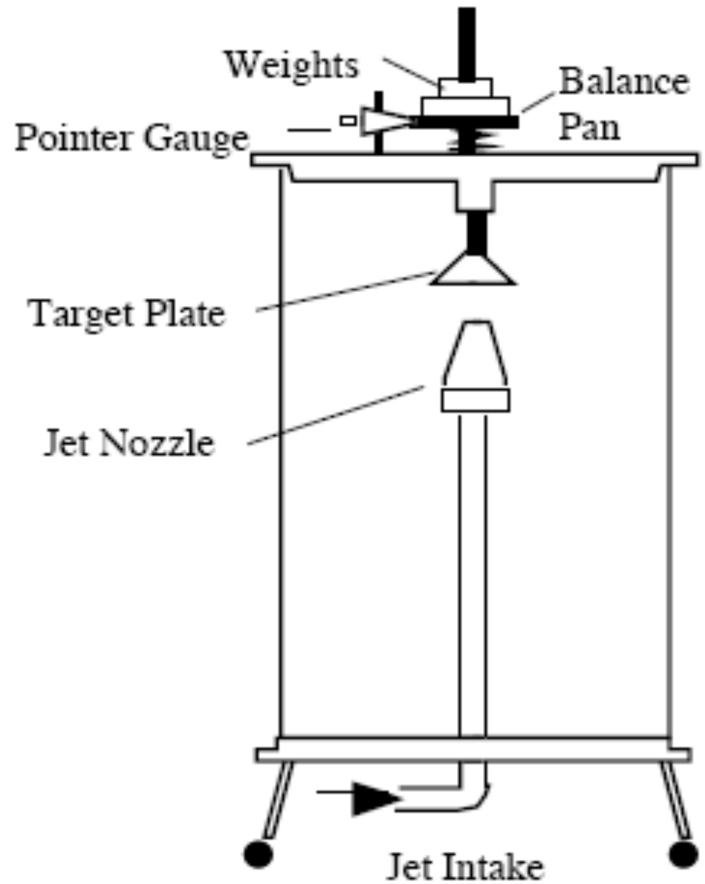
1. Motivation.
2. Vector equation.
3. Concrete, “gut feeling” for linear momentum of a fluid.
4. Assumptions can be counter-intuitive.
5. Results can be counter-intuitive.

*Identify at least one cognitive barrier in your own difficult concept.*
*Explain the barrier to the person sitting next to you.*
*Reframe the barrier as an illustrative example to clarify the point.*

# Jet deflection by a target

- Firefighter aims a hose at a trash can lid target and the stream of water is deflected.
- What is the force on the trash can lid?




http://www.me.uvic.ca/~mech345/

# What became clear?

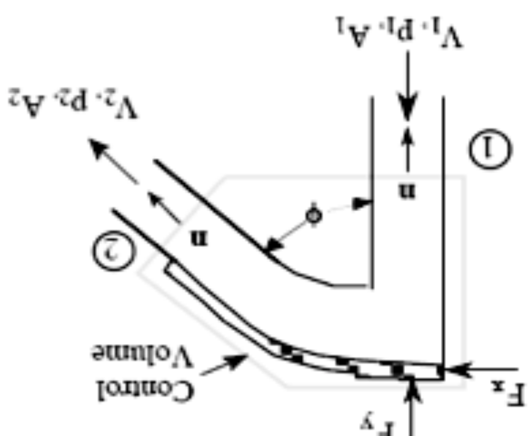
- Classic illustrative example is deeply flawed.
- Not enough time is spent on the key concepts:
  - selection of the coordinate system
  - validation of necessary assumptions
  - decomposition of the problem into three component problems
- More than one example will be needed to get to understanding and competent application!

# Modified Introductory Examples

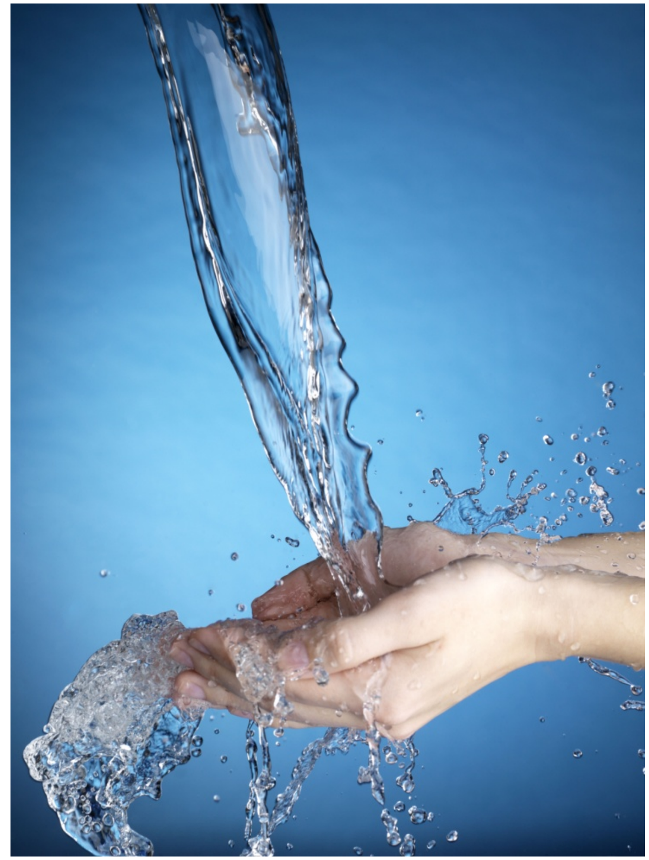
- Water from a faucet
  - Easily accessible
  - Physical, sensory, force of fluid
  - No numerical analysis – focus on the "gut feeling"
- Flixborough Plant Explosion
  - Emotional impact (this concept matters)
  - Adds a second component to the problem and motivates the vector solution

# Changing Fluid Direction Requires Force

- Water from a faucet
  - Easily accessible
  - Physical, sensory, force of fluid
  - One dimension, aligned with gravity so intuition is simpler
  - This image clearly shows some of the places where the student experience does not align with the very idealized trash can lid example!
  - Do not do analysis here – point out complications with analysis!

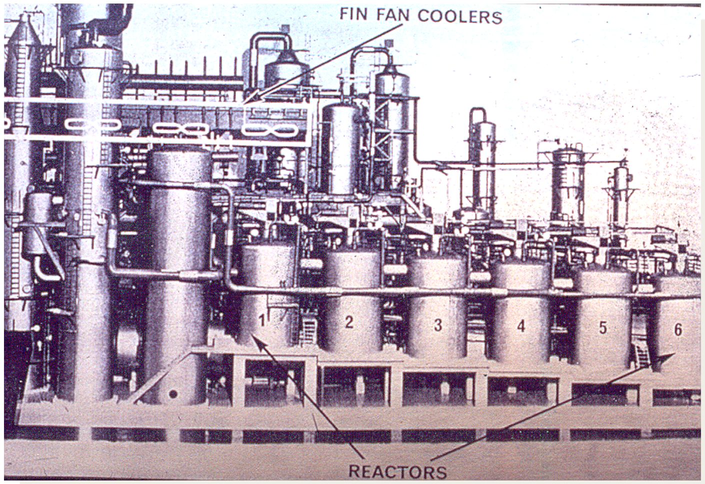



*What are the problems with the deflection example?*

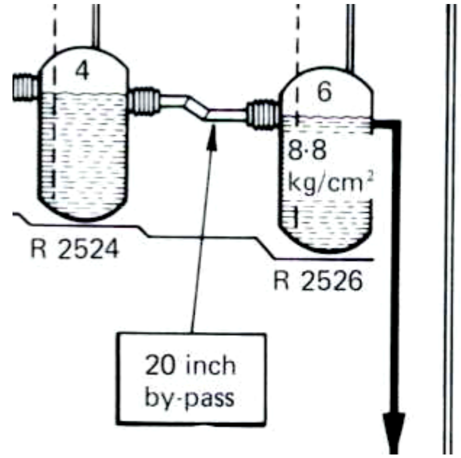


*Think about water hitting your hands. Do you **feel** the force of the fluid?*

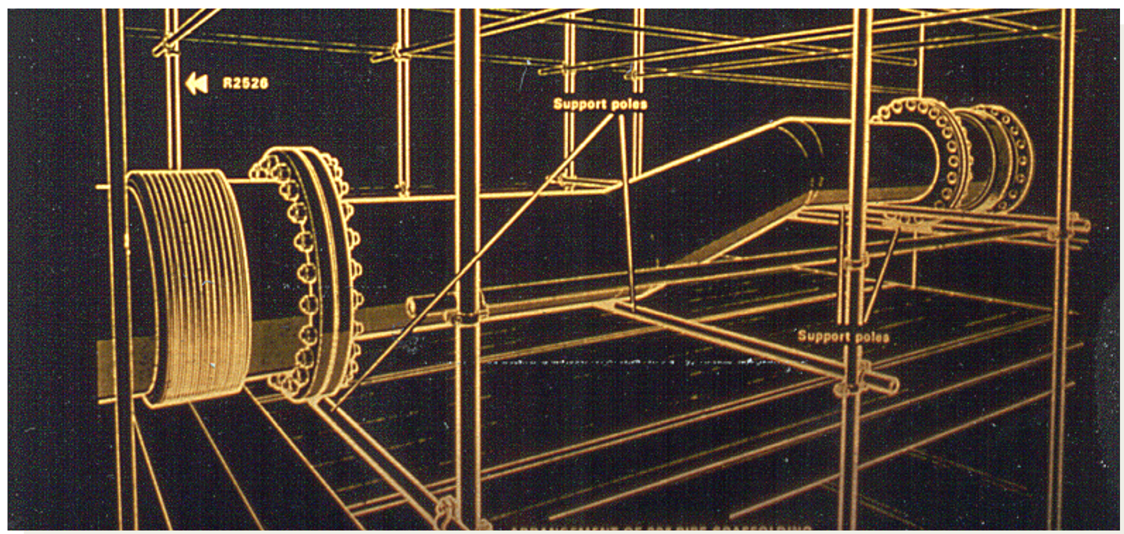
# Flixborough Reactor Train




Bypass
Reactor 5

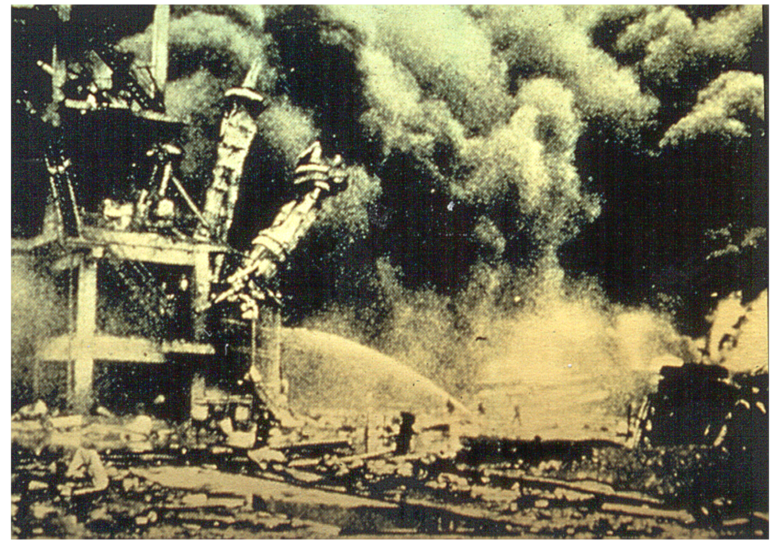



Unstamped design did not consider forces due to momentum



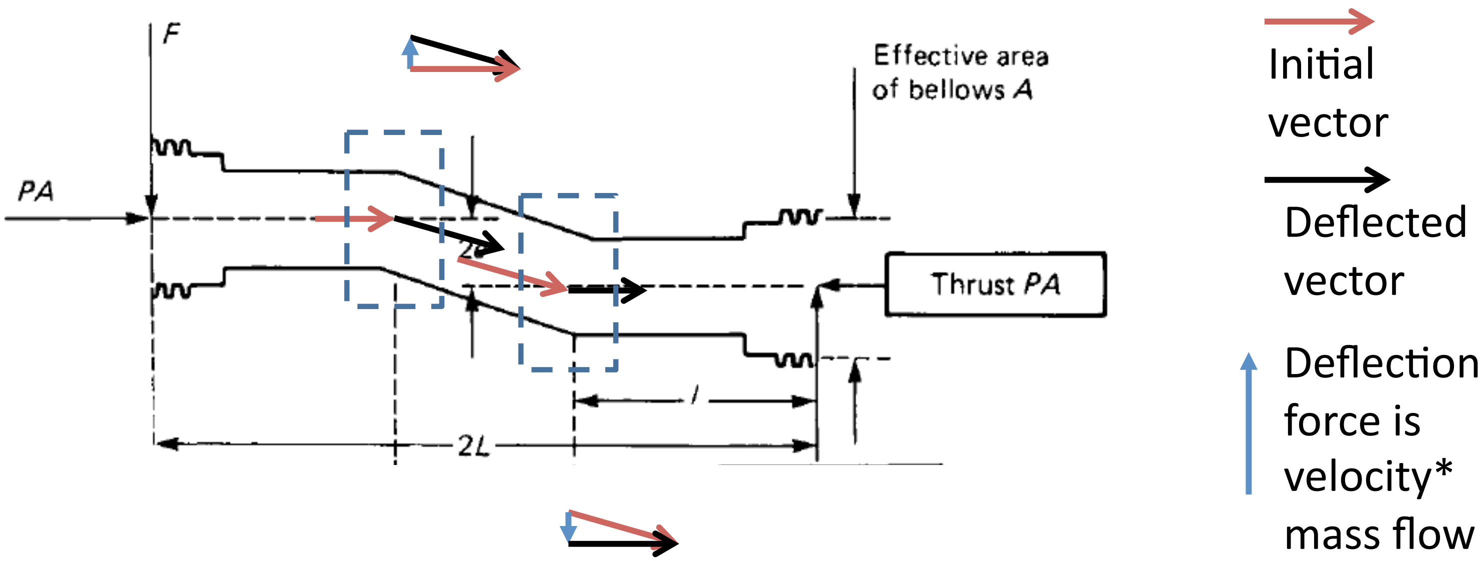
# Flixborough Fire and Explosion - 1974

- The resulting blast waves and fires leveled the entire plant.
- Twenty-eight people were killed, including all 18 in the control room. Thirty-six people were hospitalized.
- The explosion demolished 1,800 houses and 160 shops and factories in surrounding villages.
- The fires burned for 10 days.



# What went wrong?*

$$\sum_{i=outlets} m_i \vec{u}_i - \sum_{i=inlets} m_i \vec{u}_i + \frac{d(M\vec{u})_{system}}{dt} = \sum_i \vec{F}_i$$




Both the forces needed to change the fluid direction and the pressure forces induce a clock-wise moment on the joint. There was a sudden increase in pressure which made this worse, and actually tore the joint away from the bellows.

*Kletz, Trevor, Learning from Accidents, 2001, Butterworth.

# What is right about this example?

- Contained flow!
  - Assumption of uniform flow matches observation.
- Viscous forces are negligible
  - With high flow rate $(\rho QA)V$ is very large
- Context matches student learning goal
  - Chemical engineer and PEng vs. Firefighter!
- Vector formulation is clearly necessary!

# Reinforcing the Concepts

- Additional examples show different combinations of forces and deflections
- Assignment problem combines several ideas and requires definition of coordinates and control volumes
- Final exam question is another new context with the assumptions clearly stated
  - Requires vector application and calculation of force
  - Students must *either* evaluate validity of assumptions in this new context *or* set the control volume

# Begin with the End in Mind: Lesson Plan*

1. Provide a tactile example of fluid momentum.
2. Provide compelling industrial example of fluid forces (#1 Flixborough). Decompose into linear momentum components at a conceptual level.
3. Present the momentum equation in its general integral form. Decompose into 3 simplified components.
4. Apply to a problem (#2 Pipe Elbow). In this example, discuss simplifying assumptions, why they are problematic on first glance, why they are OK in practice, and where they may fail.
5. Apply to a third example (#3 Go-Devil) in seminar. Seminar comes after the lectures and at least 3 days before the assignment is due. Reinforce all key concepts in 1 through 4 in solution.
6. Apply to modified example on assignment (#4 Snow Making Wand), with support of example in text (#5) and last years' assignments (#6).
7. Examine at the same cognitive level on exam (#7 Sand Blaster problem with short answer questions on the necessary assumptions and their plausibility in the new case).

*See ftp://ftp.colorado.edu/cuboulder/courses/chen3200/Lectures/Balan3200_4.pdf for another set of 5 examples

# Some more examples...

Incorporating Engineering Design into Core Courses

# Example 2: The Failed Copper Pipe

Problem statement:
*Size a pump for an 8 story apartment building with 2 inch ID copper pipe.*

- Pressure drop and piping calculations correct. Pump will give great showers to the penthouse dwellers.
- Data incomplete.
- TA's father was a plumber. Properties of copper pipe not suitable for the application. Pipe fails at the first floor of the apartment building.
- Professional responsibility to close this loop with the class. Use it as an opportunity for discussion and development of critical thinking.
- Moral of the story: The real world is complicated! Talk to your students. Learn from them.

# Example 3: Critical Pipe Diameter

Questionable Example: *There is an optimum pipe diameter that exactly matches the balance between material cost (small pipe is better) and pumping cost (bigger pipe is better)*

- Math is delightfully complex and iterative and the physical principles are solid
- The problem misses the main point in design, which is material selection and corrosion allowance for the required pressure and fluids
- Worse yet: real pipes only come in fixed standard sizes!

# Example 4: Plastic Inserts in Aging Piping

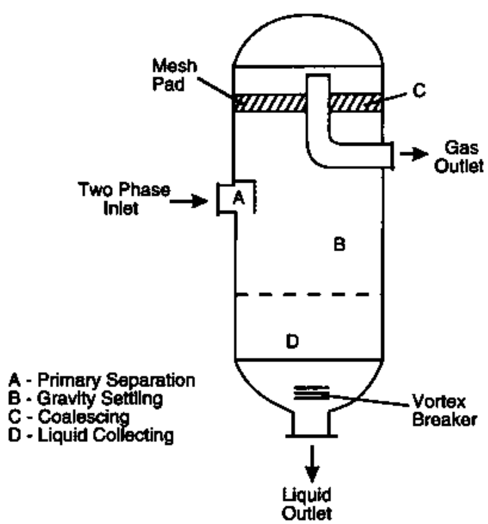
Better example: *Use a plastic insert to rehabilitate aging carbon steel gas lines. Drop in friction due to pipe roughness compensates for increase friction due to the drop in pipe diameter and increased velocity.*

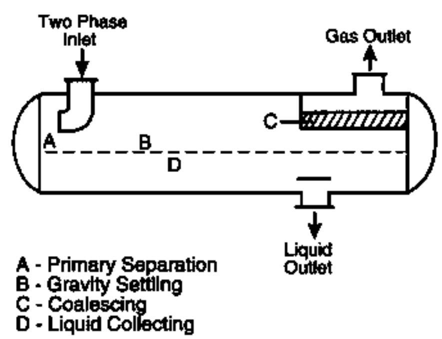
- Correct physics and assumptions
- Representative of the real world
- Student brought sample matching calculations.
- Victory!

# Example 5: Horizontal vs Vertical

Sizing of a flash drum to allow separation of droplets by gravity *(not completely resolved!)*:

- Both drums work. Sizing methods are quite different. Students found it very difficult to decide which one to pick
- The difficulty in this problem was to find the key distinguishing feature for initial vessel selection
- Answer: depends on whether the liquid or the gas flow rate is bigger. Horizontal is cheaper and is preferred if possible. Vertical will handle large gas flow rates better.



# Moral of the Story

- This is not so easy!!!
- Outstanding examples that clearly illustrate the physical principles can (and should be)
  - refined and reused
  - shared with colleagues and refined again
  - published and credited like any other scholarly or intellectual work!*

*Our colleagues in business call examples "case studies," provide an extensive teaching resource guide with the context, and collect licensing fees per student for their use.

# Mechanics and Time

# Getting it done in one class…

- Only 20% of student notes match the professor’s original notes. I recommend posting the original version on a website.
- I use 30% of lecture time on examples.
- To teach basic skills, do a simple example step by step on the board.  Repetition is a good thing. Commentary is a great thing. Be sure to write it down.
- Stop to reflect on difficult assumptions and concepts, data sources, verify units, sign and magnitude of results
- Noise is an indication that learning is happening, or that it is time to check in for possible confusion.

# Directly Engaging Students in Solutions

- Start slow and build up; set them up to win
- Select key steps in the solution for them to do:
  - problem definition
  - ambiguous step
  - distinctions between two definitions
- Think-Pair-Share
  - do it, compare your answer with a neighbor, share questions and/or difficulties and/or ideas with the class

# TAPPS (Thinking Aloud Paired Problem Solving)

- Ideal for long problems, or complex discussion.
- One example:
  - Work out the solution to a long example problem.
  - Hand out copies to the students, who work in pairs. (also works for text, essay, or other analysis)
  - For the first 5 minutes, student A explains the solution, while student B can only ask questions.
  - Pause for group discussion and clarification
  - Students trade roles.
- Allows coverage of a 2 hour example in a 50 minute class, with the students critiquing my solution in the process!

# Conclusion

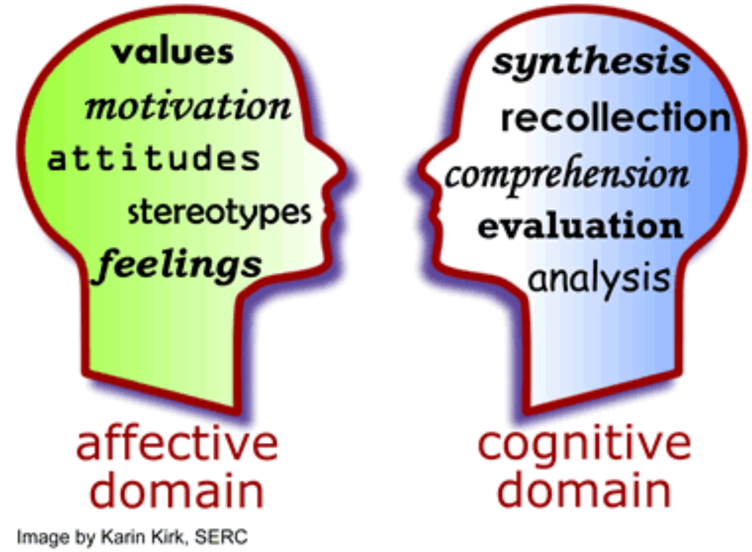
*Examples provide a powerful way to implement and model higher level thinking skills and learning objectives.*

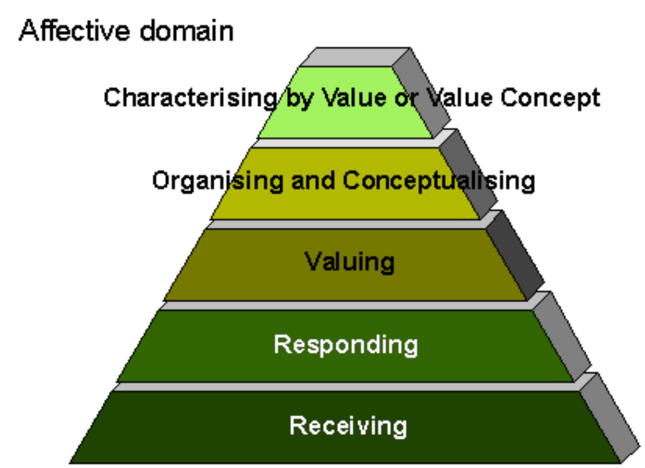
$\Leftrightarrow$

*Learning objectives and cognitive levels provide a powerful structure for the design of great examples.*

# ...one last thing..Affective Domain

- The affective domain can enrich or inhibit student learning
- It forms a large part of effective communication, stake holder engagement, building a safety culture, and the ability to embrace change and diversity
- Outside the scope of today's talk – expect more here as we see implementation of learner outcomes



## Bloom's Taxonomy of Learning

CENTRE for TEACHING and LEARNING

### Affective Domain

The manner in which we deal with emotions, such as feelings, values, appreciation, enthusiasms, motivations, and attitudes

| | Definition: | Verbs: | Evaluating example: | Activity Example: |
|---|---|---|---|---|
| **RECEIVING** | Being aware of or attending to something in the environment. | ask, accept, attend, acknowledge, concentrate, follow, give, identify, select, recognize, retain | Does the student identify ideas or concepts from an **experience**? | listening to discussions of controversial issues with an open mind, respecting the rights of others |
| **RESPONDING** | Showing some new behaviors as a result of experience. | complete, contribute, comply, conform, cooperate, discuss, describe, examine, formulate, perform, provide other references/examples, react, respond, seek, use | Does the student **participate actively**? | completing homework assignments, participating in team problem-solving activities |
| **VALUING** | Showing some definite involvement or commitment. | argue, criticize, debate, decide worth, defend, devote, explain, join, justify, persuade, present, propose pursue, refute, share | Does the student **express** opinions? | accepting the idea that integrated curricula is a good way to learn, participating in a campus blood drive |
| **ORGANIZATION** | Integrating a new value into one's general set of values, giving it some ranking among one's general priorities. | alter, arrange, build, codify, construct, compare, develop, discriminate, display, generalize, modify, order, organize, prioritize, reconcile | Does the student **state** beliefs and reasons? | recognizing own abilities, limitations, and values and developing realistic aspirations |
| **CHARACTERIZATION by VALUE** | Acting consistently with the new value. | act, display, influence, internalize, integrate, relate, resolve, qualify, practice, verify | Does the student **practice** in accordance to their beliefs? | a person's lifestyle influences reactions to many different kinds of situations |

[i] Adapted from:
Anderson, L. & Krathwohl D. (2001). *A taxonomy for learning and assessing: A revision of Bloom's Taxaonomy of educational objectives.* New York: Longman.
Atherton J S (2011) *Learning and Teaching; Bloom's taxonomy* [On-line: UK] retrieved 12 April 2011 from http://www.learningandteaching.info/learning/bloomtax.htm
Krathwohl, D. (2002). A revision of Bloom's Taxonomy: An Overview. *Theory into Practice 41(4), 212-218.*
http://www.businessballs.com/bloomstaxonomyoflearningdomains.htm
http://www.personal.psu.edu/bxb11/Objectives/ActionVerbsforObjectives.pdf
Rogers, G. http://www.abet.org/defining-student-outcomes/

*Center for Teaching and Learning, University of Alberta, 2012