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IDENTIFIERS Competency Matrix

ABSTRACT

This document consists of a workshop presentation on curriculum development, design, specification, and assessment in the engineering classroom. Ten sessions focus on: (1) the format and purpose of the workshop, which is designed to help instructors develop an understanding of the basic principles of curriculum and instruction and the ability to apply these principles to the development, design, specification, and assessment of a curriculum or course; (2) cognitive aspects of learning science; (3) the state of instruction in the engineering sciences and definitions of learning; (4) the elements of learning systems, learning styles, and taxonomies of learning; (5) educational states evaluation exercises; (6) educational goals and competencies; (7) past, present, and future classroom structures; (8) the classification of outcomes and competencies, as well as curriculum and course design; (9) the transformation of goals and outcomes into competencies; and (10) sequencing competencies. An appendix contains outlines of various cognitive models. A supplementary volume contains sample competency matrices, a guide to self-evaluation and documentation of educational states, a guide to the documentation of technical work, learning structures for students, excerpts from "Cognitive Aspects of Learning Science" (Jose Mestre), a collection of information on change in education, and four papers on intellectual development and student assessment. (MDM)

Curriculum Development, Design, Specification and Assessment

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Curriculum Development, Design, Specification and Assessment

Session 0. **(10 minutes / 10 minutes total)**

Getting Started

Forming Groups
Focus on Facilitator Signal
Issue Bin
Reflection (the Academic Journal)
Code of Cooperation

Session 1. **(30 minutes / 40 minutes total)**

A Private Universe (video tape)

Question: Determine at least TWO issues illustrated in the tape which are relevant to your Engineering classroom?
Active Learning Delivery: Formulate-Share-Listen-Create (Think-Pair-Share)

Session 2. **(5 minutes / 45 minutes total)**

Why are we (me and my absent team member) here?
How did we get here?
Cognition Defined
Cognitive Science Domains

Session 3. **(10 minutes / 65 minutes total)**

Learning Systems Elements
Learning Styles
Blooms Taxonomy (Cognitive and Affective)

Session 4. **(100 minutes / 165 minutes total)**

Educational States Evaluation

Active Learning Delivery: Jigsaw

BREAK **(60 to 90 minutes but the next day is better)**

Session 5. **(60 minutes / 60 minutes total)**

Educational Goals, Curriculum Outcomes and Competencies

Developing an Assessment Instrument

Session 6. **(10 minutes / 70 minutes total)**

Classroom Structures (Yesterday, Today and Tomorrow)

Session 7. **(20 minutes / 90 minutes total)**

Classifying Outcomes, Competencies
Curriculum (Course) Development Model
Competencies versus Level of Learning and Degree of Internalization
The Competency Matrix

Session 8. **(25 minutes / 115 minutes total)**

Transforming Goals Into Competencies; Building the Tree (Part I)

Session 9. **(40 minutes / 155 minutes total)**

Sequencing the Tree

Competencies,
Levels of Learning,
Degrees of Internalization

Disclaimer

The material presented in this workshop is based on fictional accounts of dramatized experiences of non existent faculty members and any resemblance to actual institutions of higher education or faculty members therein is coincidental.

Please do not confuse enthusiasm or interest with any form of actual expertise or advanced stage of knowledge. The views expressed herein are not those of the Foundation Coalition.

The Environment and the Purpose

❖ Learning Environment

- active (as opposed to Passive)
- group or team based
- workshop facilitators (not Lecturers)

❖ Purpose and Expected Participant Outcomes

- an understanding of the Basic Principles of Curriculum and Instruction (RalphW. Tyler, 1949)
- an ability to apply these priciples to the development, design, specification and assessment of a curriculum or course

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Getting Started

- Forming Groups
- 'Focus on the Facilitator' Signal
- Issue Bin
- Reflection (e.g., the Academic Journal)
- Code of Cooperation

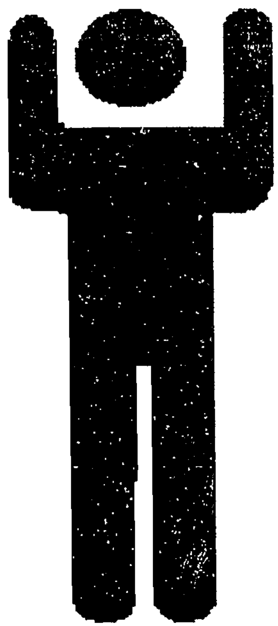
Forming Groups

- Groups of 6 or more are appropriate for this workshop.

- Take a seat an any table or arrange the chairs in the room to accommodate 6 or more people.

- Make an effort to seat yourself with people who have a similar academic background or interest if possible. The exercises will be based on developing materials for a specific topic, course or discipline.

‘Focus on Facilitator’ Signal



The facilitator needs you attention:

- *Raise your hands to inform your neighbors*
- *Finish your sentence*
- *Do NOT finish your paragraph*
- *Turn toward the Facilitator*

Slide 6

Issue Bin (a useful tool !)

- Someone will be assigned to be the Issue Bin Collector
- The following issues will be assigned to the Issue Bin:
  - topics that will or may be addressed later
  - questions that can or should be deferred until the end of the workshop
  - items that can or should be the subject of future workshops
- Paraphrase the issue and record on the board or a piece of paper which is always visible
- At the conclusion of the session or workshop, the issues in the issue bin are brought out, one at a time, and discussed to see if they are still issues.
- Any issues which remain after the discussion must be addressed in a future workshop.

Reflection (the Academic Journal)

What is a Journal? A journal is a place to practice writing and thinking. It differs from a diary in that it should not be merely a personal recording of the day's events. It differs from your class notebook in that it should not be merely an objective recording of academic data. Think of your journal rather as a personal record of your educational experience, including this class, other classes, and your current extracurricular life..

What to Write. Use your journal to record personal reactions to class, topics, students, teachers. Make notes to yourself about ideas, theories, concepts, problems. Record your thoughts, feelings, moods, experiences. Use your journal to argue with the ideas and readings in the course and to argue with me, express confusion, and explore possible approaches to problems in the course.

When to Write. Try to write in your journal at least three or four times a week (aside from your classroom entries). It is important to develop the *habit* of using your journal even when you are not in an academic environment. Good ideas, questions, etc. don't always wait for convenient times for you to record them.

How to Write. You should write however you feel like writing. The point is to think on paper without worrying about the mechanics of writing. The quantity you write is as important as the quality. Use language that expresses your personal voice -- language that comes natural to you.

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Reflection (the Academic Journal continued)

Suggestions:

1. Chose a notebook you are comfortable with' I recommend a small (6" x 9") looseleaf.
2. Date each entry; include time of day.
3. Don't hesitate to write long entries and develop your thoughts as fully as possible.
4. Use a pen (pencils smear, but are ok if you prefer them).
5. Use a new page for each new entry.
6. Include both "academic" and "personal" entries; mixed or separate as you like.

Interaction -- Professor. I'll ask to see your journal at least twice during the term; I'll read selected entries and, upon occasion, argue with you or comment on your comments. Mark any entry that you *don't want me to read* and I'll honor your privacy. None of the dialogue with you will affect how much your journal is "worth." A *good* journal will be full of lots of long entries and reflect active, regular use.

Interaction -- Corespondent. Choose a colleague (a fellow student in your base group, for example) to read and respond to your journal entries.

Adapted by Karl Smith from Fulwiler, T. *Teaching with writing.* Portsmouth, NH; Boynton/Cook, 1987.

Code Of Cooperation

1. EVERY member is responsible for the team's progress and success.
2. Attend all team meetings and be on time.
3. Come prepared.
4. Carry out assignments on schedule.
5. Listen to and show respect for the contributions of other members; be an active listener.
6. CONSTRUCTIVELY criticize ideas, not persons.
7. Resolve conflicts constructively.
8. Pay attention, avoid disruptive behavior.
9. Avoid disruptive side conversations.
10. Only one person speaks at a time.
11. Everyone participates, no one dominates.
12. Be succinct, avoid long anecdotes and examples.
13. No rank in the room.
14. Maintain confidentiality; who says what stays in the team room; minutes, results, reports, etc. are shared with appropriate individuals.
15. Ask questions when you do not understand.
16. Attend to your personal comfort needs at any time but minimize team disruption.
17. HAVE FUN !!!
18. ?

adapted from the Boeing Airplane Group team Member Training Manual

A Private Universe (video tape)

- The video tape, A Private Universe, will be viewed for approximately 18 minutes.
  - The tape and its' implications for higher education are discussed at length in a paper by *Mestre, Jose P., 'Cognitive Aspects of Learning and Teaching Science' , Pre-College Teacher Enhancement in Science and Mathematics: Status, Issues and Problems (both a final paper and an earlier DRAFT are available).*

- *At the end of the tape, there will be a*

  Formulate-Share-Listen-Create exercise

  and an individual in each group of 2 will be selected at random to present the group's results to the workshop.

Formulate-Share-Listen-Create

Focus Question	Determine at least TWO issues illustrated in the tape which are relevant to the Engineering classroom.

1. Formulate your answer to the question (individually)

2. Turn to the person next to you (find a partner)

   Share your answer

   Listen carefully to your partner's answer

3. Create a new answer through discussion

Why are we here ?

❖ Zilmon says

To be successful in life requires that
a person know only one thing;

You must know what you don't know !

How did we get here ?

The Way We Wish it had Happened (1)	The Way it Should Have Happened (2)	The Way it Really Happened (3)

(1) We read the
The Board on Engineering Education Working Paper on Major Issues in Engineering Education, section III.B Undergraduate Engineering Experience, Issue #2 - Are Teaching methods appropriate?, Options for Action (Issue #2), Option "G" : Increase faculty awareness of cognitive research, and decided to do something about finding out what we don't know.

(2) How should it have happened in a well run institution of higher education?

(3) In a state of despair and desperation about our failed attempts at improving student performance in our courses, we were chasing any and all rabbits, possums and raccoons when we fell quite by accident into the swamp of cognitive science where we still languish knowing we don't know anything!

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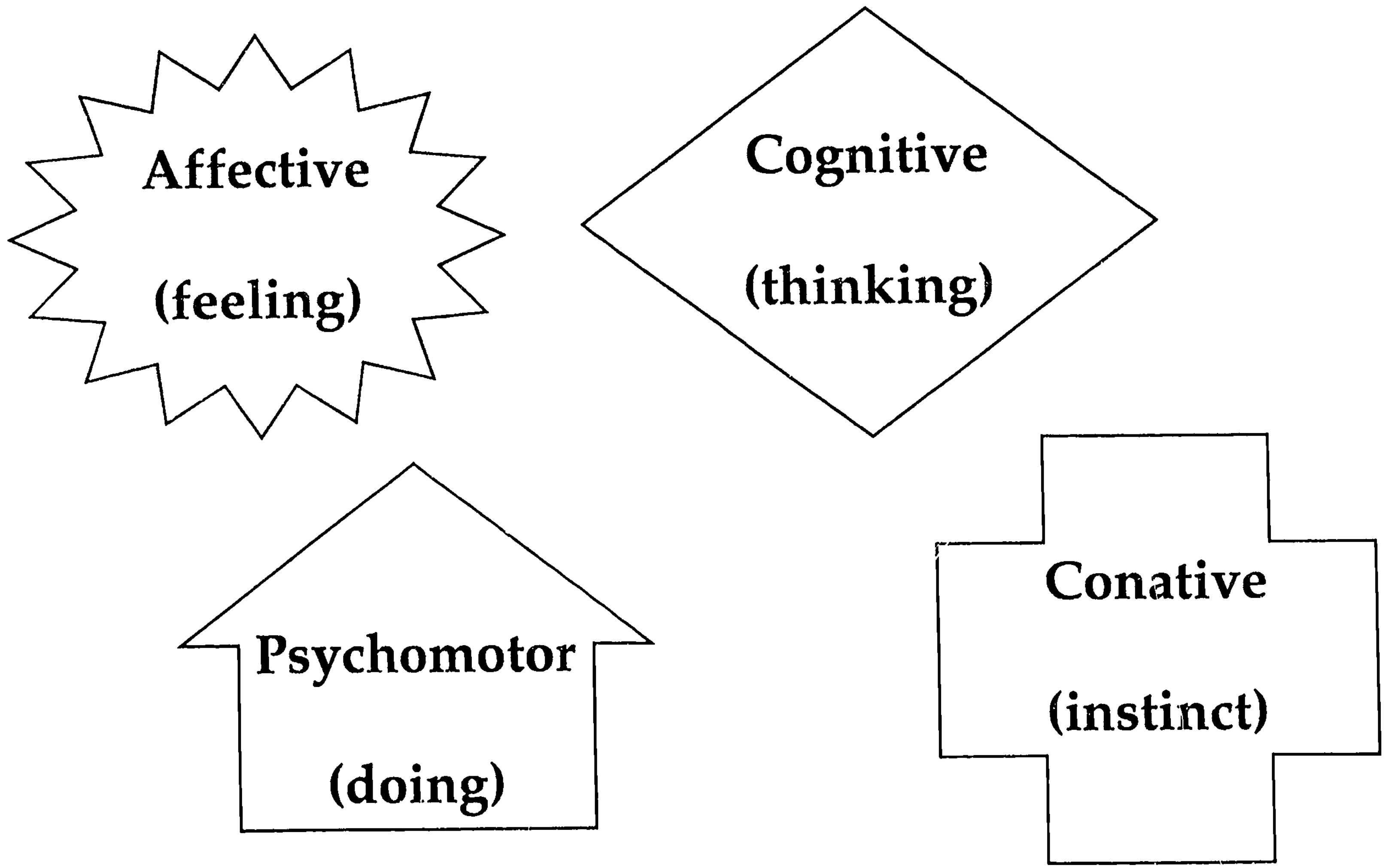
Cognition Defined

- The mental process or faculty by which knowledge is acquired and processed (i.e., encoded, interpreted, labeled)

- That which comes to be known, as through perception, reasoning, or intuition; knowledge

The American Heritage Dictionary of the English language, 1975

Cognitive Science Domains



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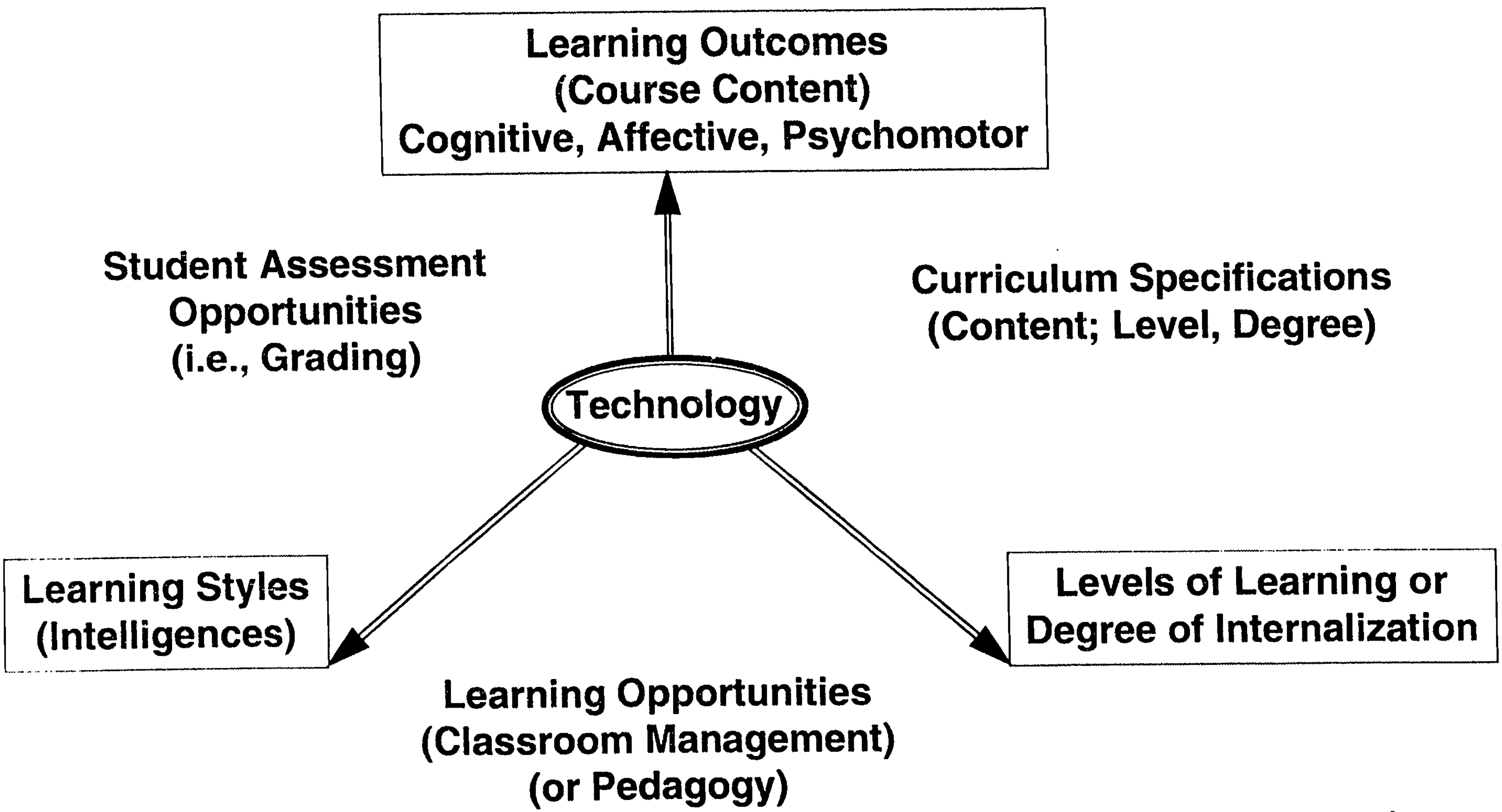
Some Learning Systems Elements

- Evaluation (i.e., aggregate assessment, college level ?)
- Classroom Assessment (i.e., aggregate, classroom)
- Student Assessment (i.e.,by the student or teacher)
- Classroom Management (i.e., Active Learning)
- Curriculum Content (Cognitive, Affective, Psychomotor)
- Technology (i.e., in support of student learning and assessment at all levels)

Another View of Learning System Elements



Seven Styles of Learning [17]

TYPE	LIKES TO	IS GOOD AT	LEARNS BEST BY
LINGUISTIC LEARNER "The Word Player"	read write tell stories	memorizing names, places, dates and trivia	saying, hearing and seeing words
LOGICAL/ MATHEMATICAL LEARNER "The Questioner"	do experiments figure things out work with numbers ask questions explore patterns and relationships	math reasoning logic problem solving	categorizing classifying working with abstract patterns/relationships
SPATIAL LEARNER "The Visualizer"	draw, build, design and create things daydream look at pictures/slides watch movies play with machines	imagining things sensing changes mazes/puzzles reading maps, charts	visualizing dreaming using the mind's eye working with colors / pictures
MUSICAL LEARNER "The Music Lover"	sing, hum tunes listen to music play an instrument respond to music	picking up sounds remembering melodies noticing pitches / rhythms keeping time	rhythm melody music
BODILY/KINESTHETIC LEARNER "The Mover"	move around touch and talk use body language	physical activities (sports/dance/acting) crafts	touching moving interacting with space processing knowledge through bodily sensations
INTERPERSONAL LEARNER "The Socializer"	have lots of friends talk to people join groups	understanding people leading others organizing communicating manipulating mediating conflicts	sharing comparing relating cooperating interviewing
INTRAPERSONAL LEARNER "The Individual"	work alone pursue own interests	understanding self focusing inward on feelings / dreams following instincts pursuing interests/goals being original	working alone individualized projects self-paced instruction having own space

Based on material presented in Howard Gardner's *The Unschooled Mind; How Children Think and How Schools Should Teach.* Basic Books, 1991.

Other Learning Styles [9]

Abilities by Style

Sensing / Thinking, 35%

Good at working with and remembering details

Able to speak and write directly to the point

Approaches task in an organized and sequential manner

Sensing / Feeling, 35%

Spontaneous and open to impulse, does what feels good

Able to express personal feelings

Aware of others' feelings and makes judgements based on personal likes and dislikes

Intuiting / Thinking, 20%

Takes time to plan and contemplate consequences of actions

Able to organize and synthesize information

Weights the evidence and risks judgement based on logic

Intuiting / Feeling, 10%

Good at intepreting facts and details tosee the broader picture

Able to express ideas in new and unusual ways

Approaches tasks in a variety of ways or in an exploratory manner

Hanson, Silver, Strong and Associates,
'The Thoughtful Education People',
34 Washington Road , Princeton Jct. , NJ 08550
(609) 799-6300 Phone (609) 799-6301 FAX

Other Learning Styles [14]

- **Sensing** vs. Intuitive
- **Visual** vs. Auditory
- **Inductive** vs. Deductive
- **Active** vs. Reflective
- **Global** vs. Sequential

Bold styles on the left hand side are LESS often exhibited by students

The 'New' Calculus Book [13]

❖ The Rule of Three:

Every topic should be presented

- Geometrically,
- Numerically, and
- Algebraically .

❖ The Way of Archimedes:

Formal Definitions and procedures evolve from the investigtion of Practical Problems.

Bloom's Taxonomy : Cognitive Domain (1950)

1. Knowledge of :

1.1 Specifics

1.2 Ways & Means of Dealing with Specifics

2. Comprehension

2.1 Translation

2.2 Interpretation

2.3 Extrapolation

3. Application (Out of Context)

4. Analysis of :

4.1 Elements

4.2 Relationships

4.3 Organizational Principles

5. Synthesis

5.1 Production of a Unique Communication

5.2 Production of a Plan,
or Proposed set of Operations

5.3 Derivation of a set of Abstract Relations

6. Evaluation ... Judgment in Terms of :

6.1 Internal Evidence

6.2 External Criteria

Bloom's Taxonomy : Affective Domain (1964)

1. *Receiving (Attending)*
   - 1.1 Awareness
   - 1.2 Willingness to Receive
   - 1.3 Controlled or Selected Attention
2. *Responding*
   - 2.1 Acquiescence in Responding
   - 2.2 Willingness to Respond
   - 2.3 Satisfaction in Response
3. *Valuing*
   - 3.1 Acceptance of a Value
   - 3.2 Preference for a Value
   - 3.3 Commitment
4. *Organization*
   - 4.1 Conceptualization of a Value
   - 4.2 Organization of a Value System
5. *Characterization by a Value or Value Complex*
   - 5.1 Generalized Set
   - 5.2 Characterization

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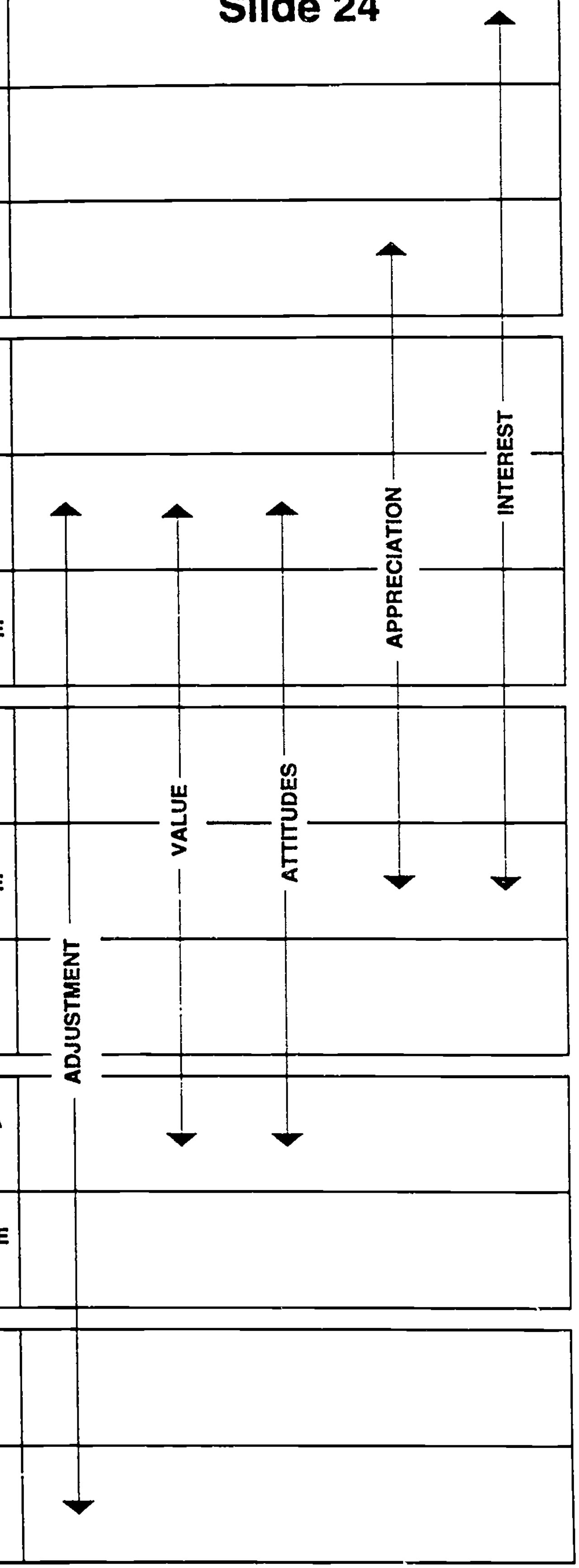
1.0 RECEIVING	1.1	AWARENESS
	1.2	WILLINGNESS TO RECEIVE
	1.3	CONTROLLED OR SELECTED ATTENTION
2.0 RESPONDING	2.1	ACQUIESCENCE IN RESPONDING
	2.2	WILLINGNESS TO RESPOND
	2.3	SATISFACTION IN RESPONSE
3.0 VALUING	3.1	ACCEPTANCE OF A VALUE
	3.2	PREFERENCE FOR A VALUE
	3.3	COMMITMENT
4.0 ORGANIZATION	4.1	CONCEPTUALIZATION OF A VALUE
	4.2	ORGANIZATION OF A VALUE SYSTEM
5.0 CHARACTERIZATION BY A VALUE COMPLEX	5.1	GENERALIZED SET
	5.2	CHARACTERIZATION



The range of meaning typical of commonly used affective terms measured against the *Taxonomy* continuum.

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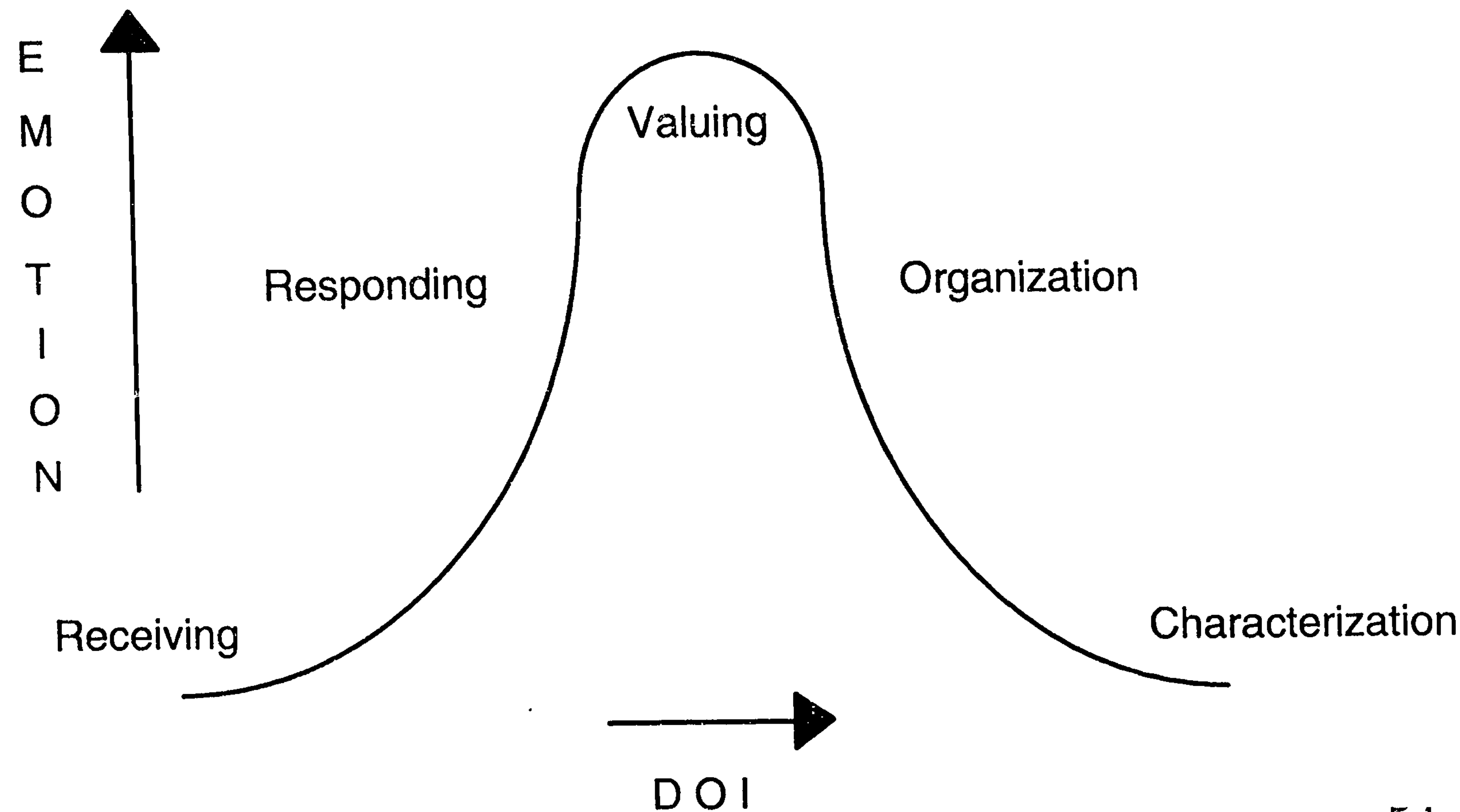
Affective Domain and Emotion Levels



Evaluation Exercise

- ❖ Evaluation of Educational State
- ❖ Jigsaw on Bloom's Levels of Learning
- ❖ Jigsaw Group Reports

Evaluation of Educational State

- Learning Outcomes Translated into Competencies
  - set by course instructor
  - statements of what topics are to be covered
- Levels of Learning (or Degrees of Internalization)
  - characterizations of the different types of learning possible for the learning outcomes
  - defined by the activities done of student and teacher
  - Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation (for example)
- Competency Matrix
  - shows relationship between learning outcomes and levels of learning or degrees of internalization

Sample Evaluation Matrix

Instructions for filling in the matrix

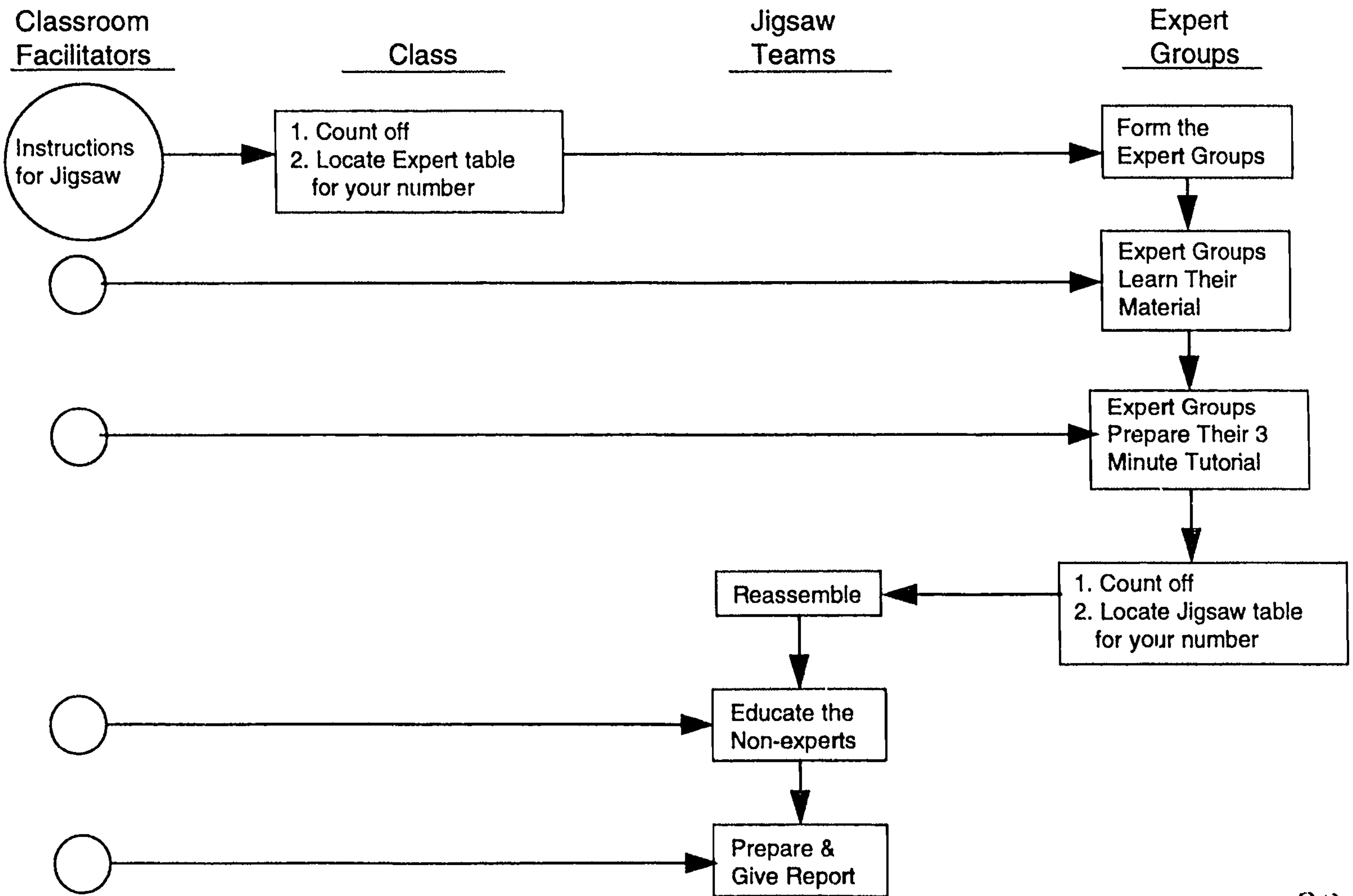
a. **For each competency area darken the row up to and including the column which indicates your current level of learning for the competency. You can refer to the following pages to assist you in understanding the meaning of these levels of learning.**

b. **If you do not know or recognize a competency area then you only blank the first column (Before Knowledge)**

c. **Each time you re-evaluate your state of learning for a competency, if your level of learning has increased then move the bar farther to the right using a different color or pattern to fill in the column(s).**

Competency Category	Competencies	Before Knowledge	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
Cooperative Learning	Code of Cooperation							
	Face to Face Interaction							
	Individual Accountability							
	Jigsaw							
	Structure Before Task							
	Structured Controversy							
Teams	Gatekeeper							
	Storming							
	Team Diversity							
	Team Member							
Assessment	Competency Matrix							
	Grades							
	Knowledge							
	Know-How							
	Stages of Learning							

Levels of Learning Jigsaw



Forming Expert Groups

- Count off within room
- Depending on your number you will read the material in the Appendix
  - 1's read about Knowledge
  - 2's read about Comprehension
  - 3's read about Application
  - 4's read about Analysis
  - 5's read about Synthesis
  - 6's read about Evaluation
- Look around the room until you see where the numbered expert tables are located
- All the 1's will get up and move to Table 1; all the 2's will get up and move to Table 2; etc.

Becoming an 'Expert' (30 minutes)

- ❖ Determine what Level of Learning your table has been assigned.
- ❖ Read the material in the Appendix which relates to your groups' assigned Level of Learning.
- ❖ Discuss the reading with your 'expert' team members to reach consensus on meaning and importance of the various ideas.
- ❖ Develop a class assignment for ____________________ for Knowledge, Comprehension, and Application or for ____________________ for Analysis, Synthesis, and Evaluation.
- ❖ As a team, develop a three minute tutorial which you can use to teach other members of the class about your level.

Forming Jigsaw Groups (3 minutes)

- Count off within expert groups starting at 1
- Look around the room until you see where the various numbered tables are located
- All the 1's will get up and move to Table 1; all the 2's will get up and move to Table 2; etc.
- If there is no table for your number let the course facilitator know and she will assign you to a jigsaw group

Presenting the Tutorial (25 minutes)

- Starting at the lowest level of learning and moving sequentially to the highest level, each expert should take three minutes to deliver her/his tutorial to the other jigsaw team members (18 minutes)

  - It is a good idea to check each other to ensure that everyone is learning the material to at least the Comprehension level of learning

- After all tutorials have been delivered spend a few moments in clarification (7 minutes)

Reporting Out (30 minutes)

- Using the examples generated in the Expert Groups as starting points, develop an integrated, consistent example showing how the various learning levels could be demonstrated (20 minutes)
- Outline the example on the overhead slides provided
- One group, selected at random (the presenter also selected at random) will present their example as a basis for discussion (10 minutes)
- Turn in transparencies used in report so copies for the workshop can be made.

Transforming Educational Goals into Curriculum Outcomes

❖ Review a Taxonomy, or hierarchical classification system,

- which may be useful in translating broad, educational goals into meaningful learner outcomes, or competencies,

- which can then be quantitatively assessed in terms of student behaviors.

❖ Use the Taxonomy to develop, test and evaluate a **process** for generating competency matrices which represent these broad educational goals.

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Source of Educational Goals for Engineerng Graduates

- Employers
- Graduate Schools
- Other Educational Institutions
- Federal, State and Local Government
- Society (i.e., its representatives)
- Professional Societies
- Parents, Spouses
- Students

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Source of Competencies and Levels or Degrees for Engineering Courses

- ❖ Engineering Faculty
- ❖ Engineering Administration
- ❖ Other Academic Faculty
- ❖ Academic Administration

Documentation - Process & Product

- Product Documentation
  - educational goals or outcomes
  - competency matrices for these goals or outcomes
- Process Documentation
  - each of you should journal (reflect on process) in your blue books -- try to use the terms which you will be learning about during this workshop
  - reflection can be done anytime up to 24 hours after the process has been completed
  - if you complete your journal before you leave turn them in, otherwise, turn them in to the Dean's Office. They will transcribe them and return them.

How Would You Know?

- Goal
  - solve a non linear algebraic equation
  - be a life long learner
- How would you know if a person met this goal?

  Discusss in your team
- Create an assessment instrument in some form ;

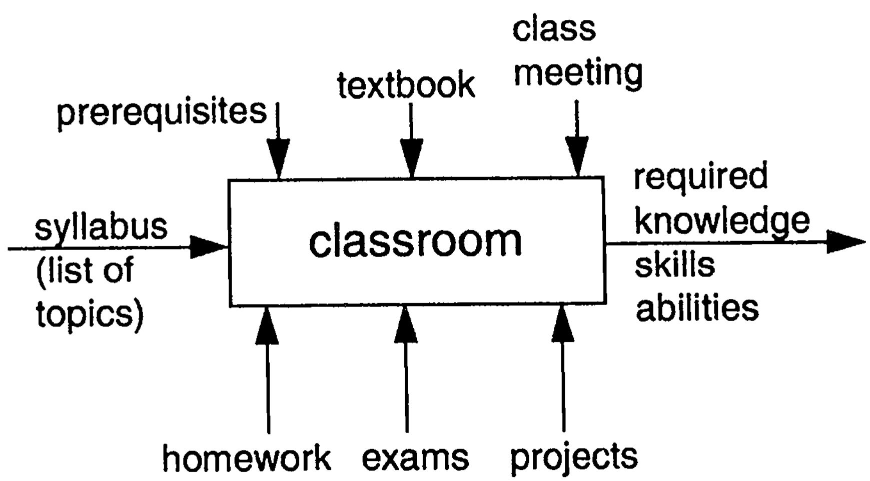
  i.e., written, oral, painted, sung, tumbled, drawn, performed in any way, etc. ,

  which could be used to determine if a person met the goal

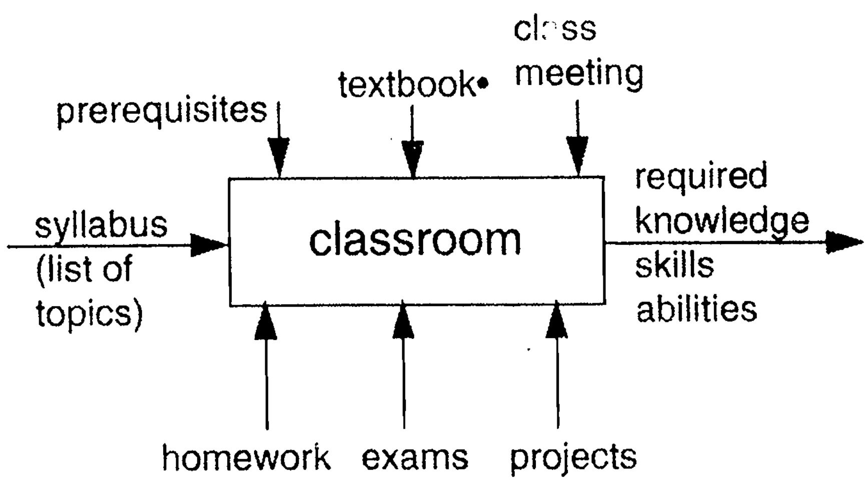
Reflection & Reporting

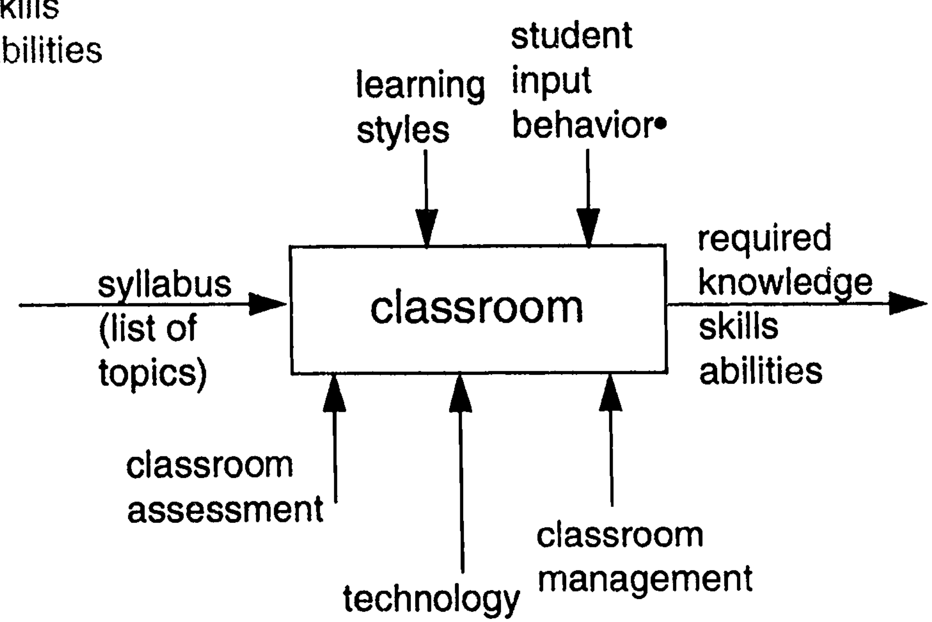
- Reflection (15 minutes)
  - product
    why does your instrument
    demonstrate achievement of the goal?
  - process
    did you have a process?
    what changes to the process would you suggest?
    why was the process difficult?
- Reporting (10 minutes)
  - the team recorder is to present a two minute presentation of the results of the team's reflections
- Clarification (5 minutes)

Yesterday's Classroom



Yesterday's & Todays' Classroom





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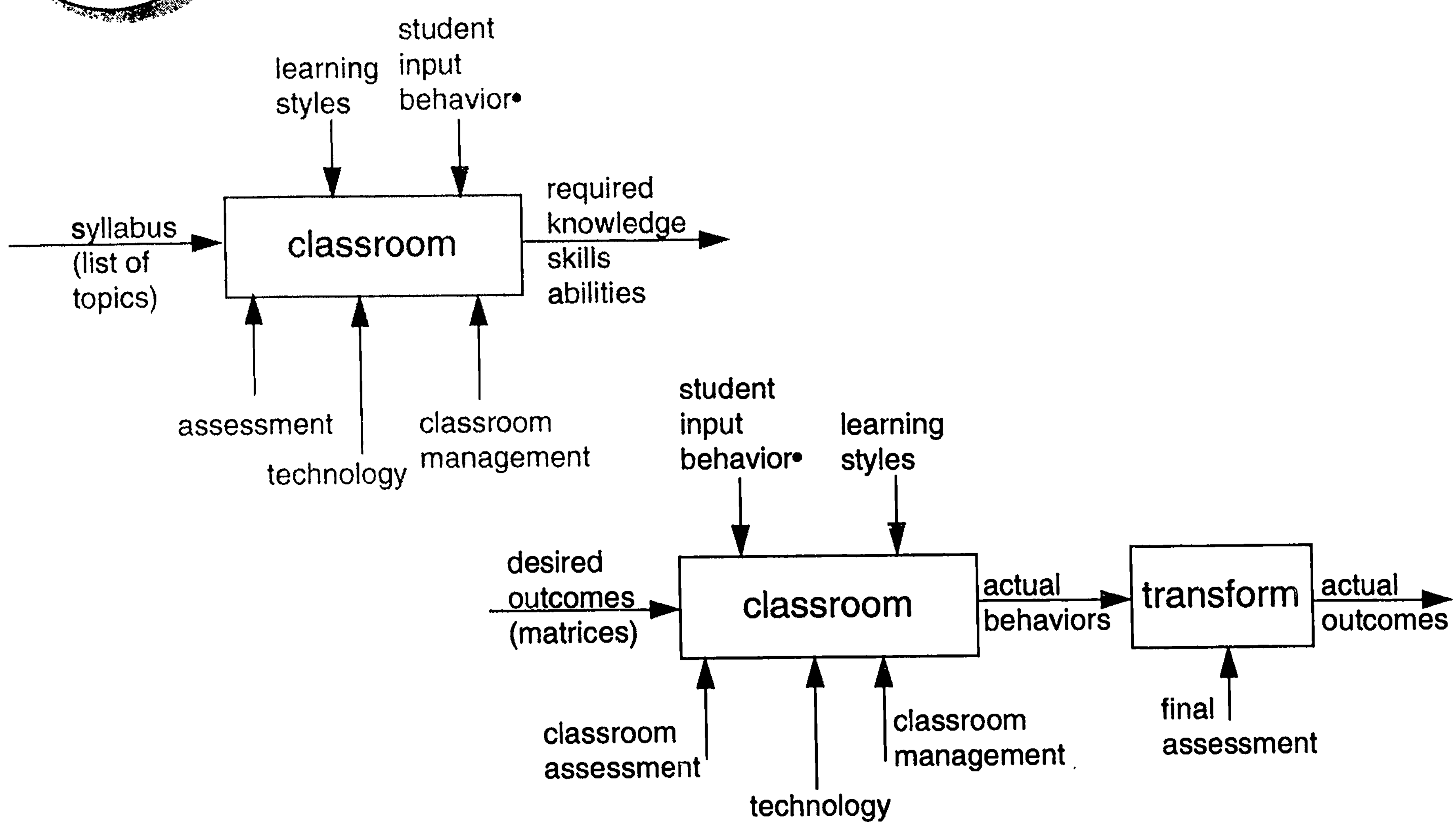
Today's & Tomorrow's Classroom



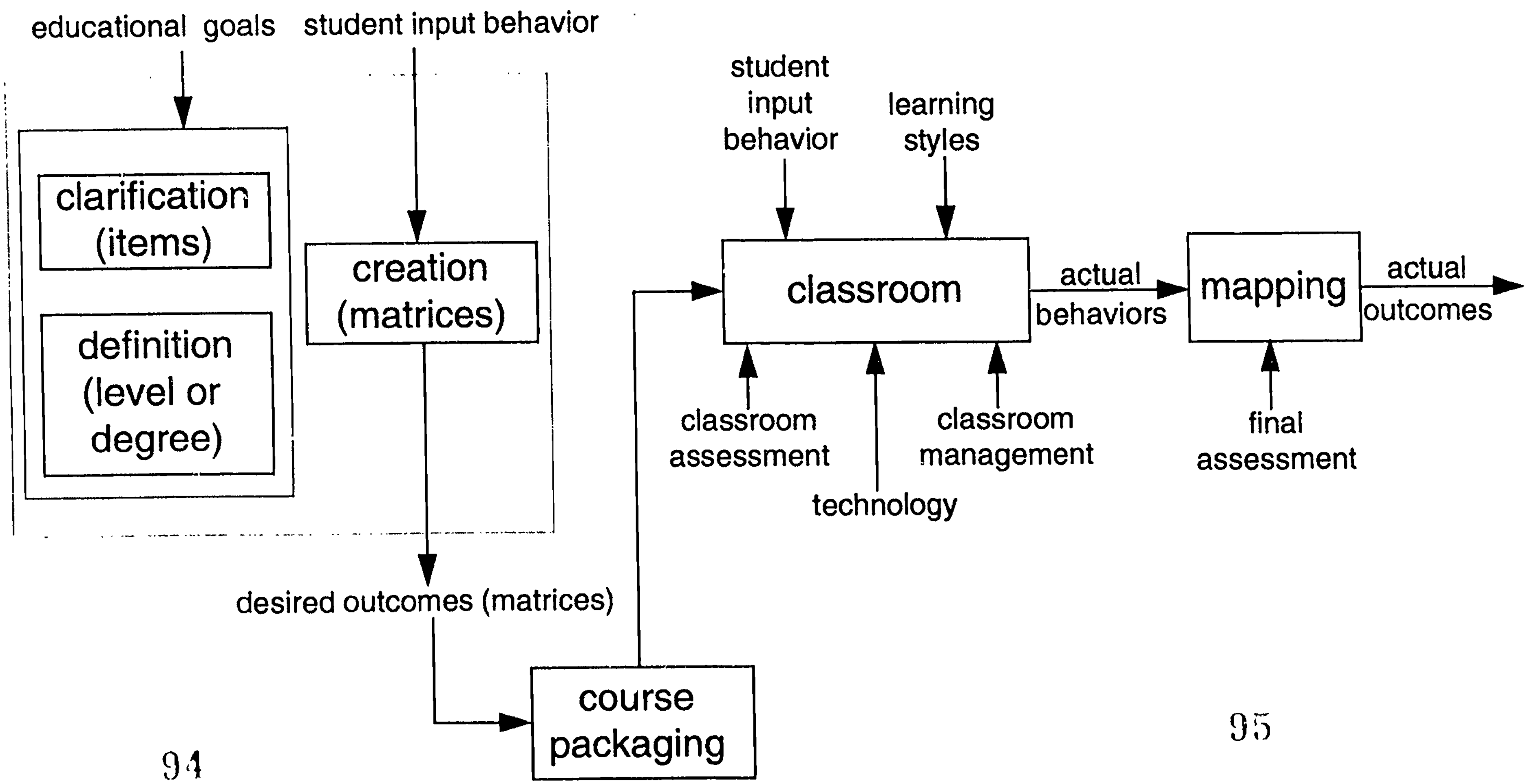
Classifying Outcomes - Granularity

- **Tradition et al.(5000 BC to 1980's)**
  - mostly topics except for Plato's mental processes and reality
  - mental processes : imagination, opinion, reasoning, understanding
  - reality : images, sense objects, math realities & science, forms & dialectic
- **Bloom et al. (1950's) for EACH TOPIC !**
  - cognitive domain
  - affective domain
  - psychomotor domain
- **Myron Tribus (1980's & 1990's)**
  - academ**ICS**, do**ING** technology , func**TIONS** of society
  - **knowledge** (fundamentals), **know-how** (techniques), **wisdom** (decisions and setting priorities), and **character** (self-esteem, honesty, etc. from Covey)
- **Alexander and Judy (1988) : NSF/A&M Core**
  - declarative (fundamentals), procedural (methods), conditional (decisions)

Classifying Outcomes - Taxonomies

- Bloom et al (1948 - 1964) for EACH TOPIC
  - 6 Levels of Learning
    - knowledge, comprehension, application, analysis, synthesis, evaluation
  - 5 Degrees of Internalizaion (intrinsic motivation in Quality)
    - receiving, responding, valuing, organization, characterization
- Canelos & Catchen (1989)
  - fractal learning, concept learning, rule learning, problem solving
- Dreyfus & Dreyfus (1983)
  - novice, advanced beginner, competent performer, proficient performer, expert
- Merrill's (1983) for constructivist learning environments
- Gagne's (1987) for constructivist learning environments

Curriculum (Course) Development and Delivery Model



Reflections on Competencies vs Level

- Very specific sorts of things tend to be amenable to the lower levels of learning but not to the higher levels
- The more general (abstract) goals tend to be amenable to the higher levels of learning but not to the lower levels
- Application is very difficult to assess
- Affective behaviors seem to be *attributes* associated with cognitive behavior
- The connectivity of the affective behavior development is not as obvious as for the cognitive behaviors

Competency Matrix

e.g., Affinity headers may go here

		K	C	Ap	An	Sy	Ev
Outcome	competency 1						
	competency 2						
	competency 3						
Outcome	competency 7						
	competency 8						
	competency 10						
	competency 11						

Level and Degree vs Year in School

- Affective and Cognitive behaviors change with learning, going up the scale
- Baroldo's Hypothesis on Levels (p. 49, Krathwohl)
  - senior work: evaluation and application level
  - junior work: analysis, synthesis, evaluation level
  - sophomore work: knowledge, comprehension (aka know-how), and analysis level
  - freshman work: knowledge, comprehension level
- Baroldo's Hypothesis on Degrees (p. 49, Krathwohl)
  - senior work: valuing - preference
  - junior work: valuing - acceptance
  - sophomore work: responding - satisfaction
  - freshman work: receiving - controlled attention

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Student Behavior Levels and Year in School

Where do students ENTER and EXIT on the matrix?

What structure, if any, fits what students at what level?

Concrete to Abstract ? vs. Abstract to Concrete ?

Simple to Complex ? vs. Complex to Simple ?

Level of Learning

Degree of Internalization

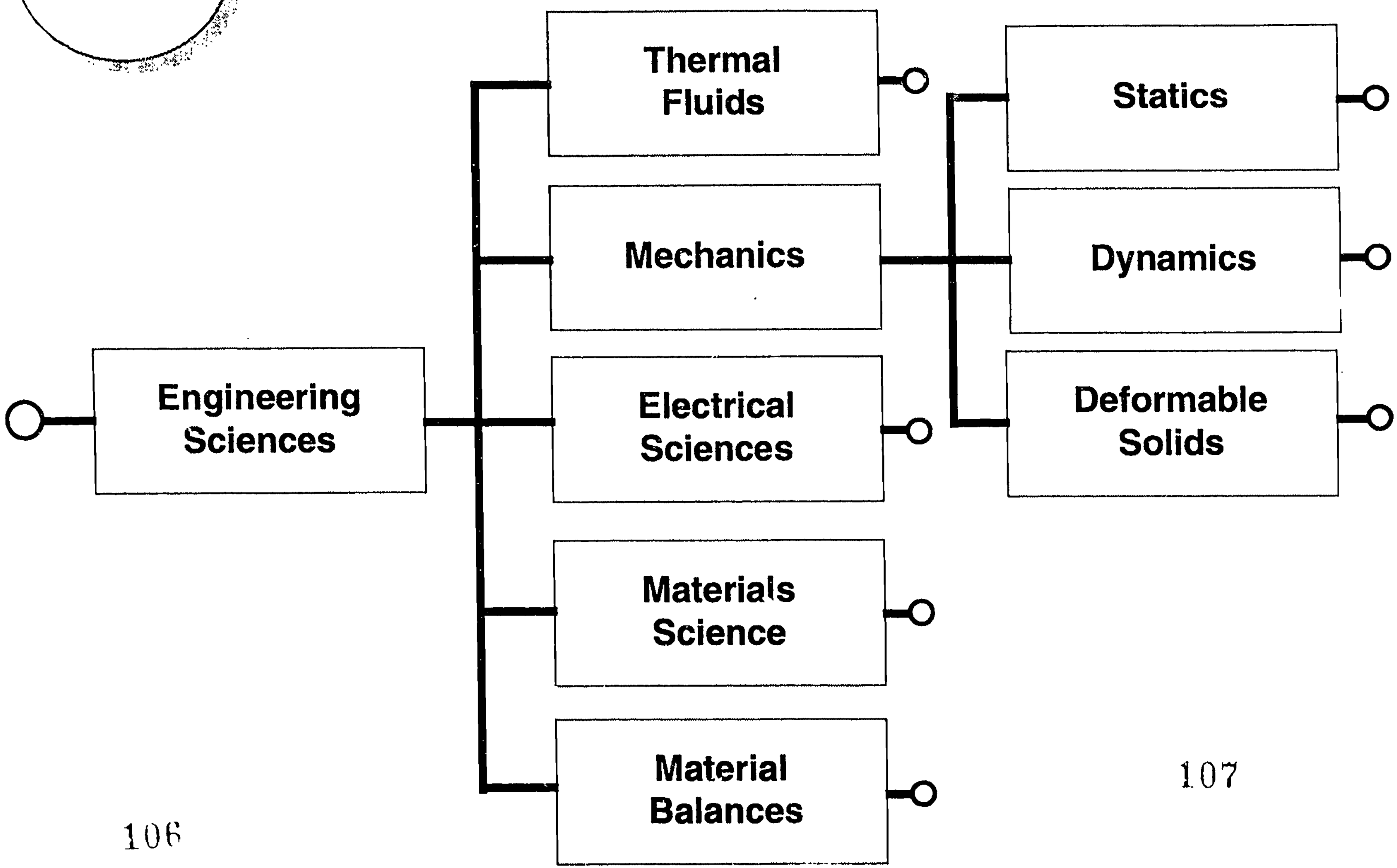
Degree of Internalization	Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
5.20 Char terization 5.10 Gene alized Set 5.00 Characterization by a Value or Value Complex 4.20 Organization of a Value System 4.10 Conceptualization of a Value 4.00 Organization						
3.30 Commitment 3.20 Preference for a Value 3.10 Acceptance of a Value 3.00 Valuing						
2.30 Satisfaction in Response 2.20 Willingness to Respond 2.10 Acquiescence in Responding 2.00 Responding 1.30 Controlled or Selected Attention 1.20 Willingness to Receive 1.10 Awareness 1.00 Receiving						

Building the Tree (Part I)

❖ In your team, specify one or more educational goals that are relevant to your team and this workshop

- break it down into its parts
- show the parts as 'children'
- keep generating 'children' until you reach 'recognizable' outcomes
- repeat this process for your goals until time expires

Tree Diagrams, An Example



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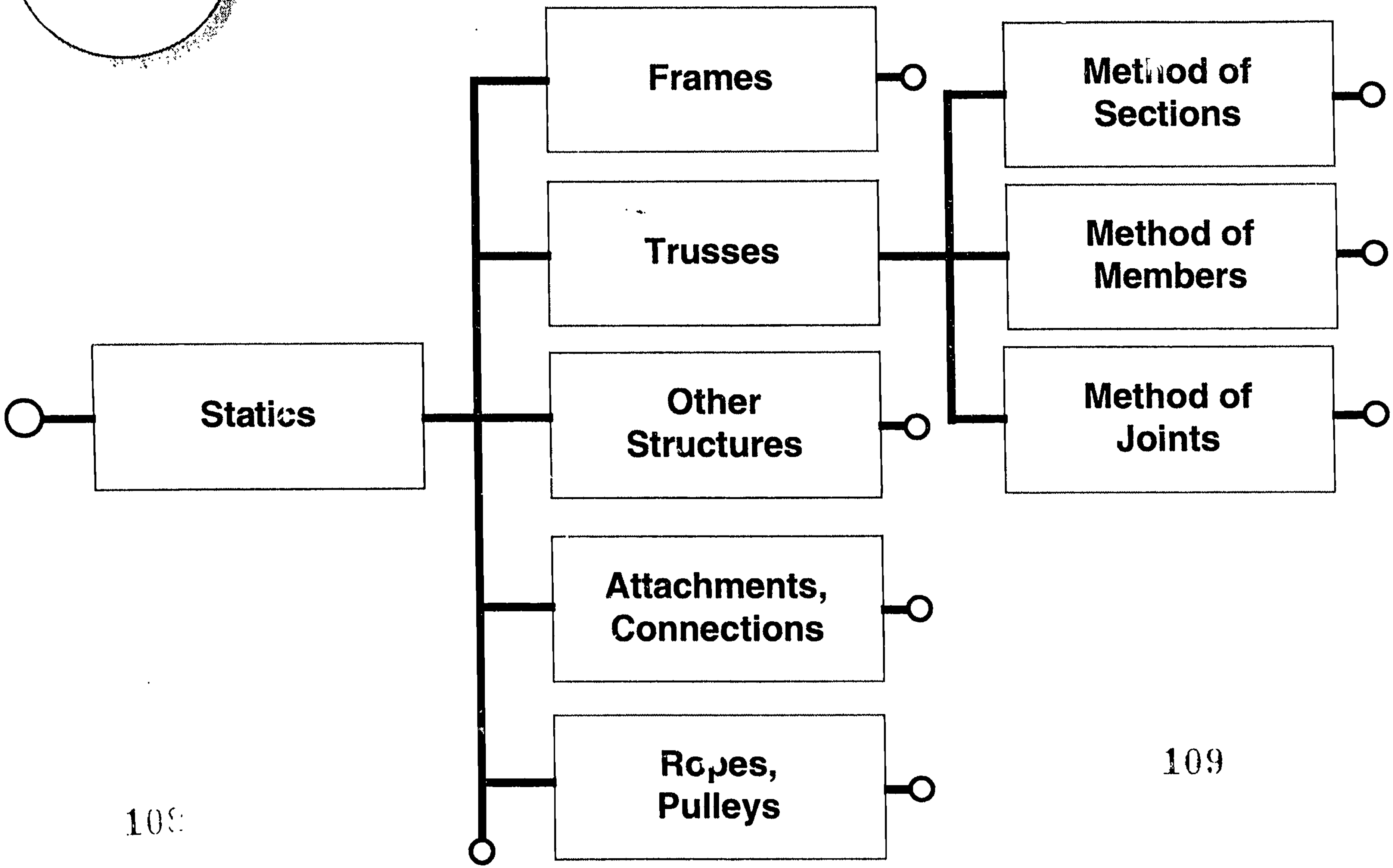
Tree Diagrams, An Example (cont.)

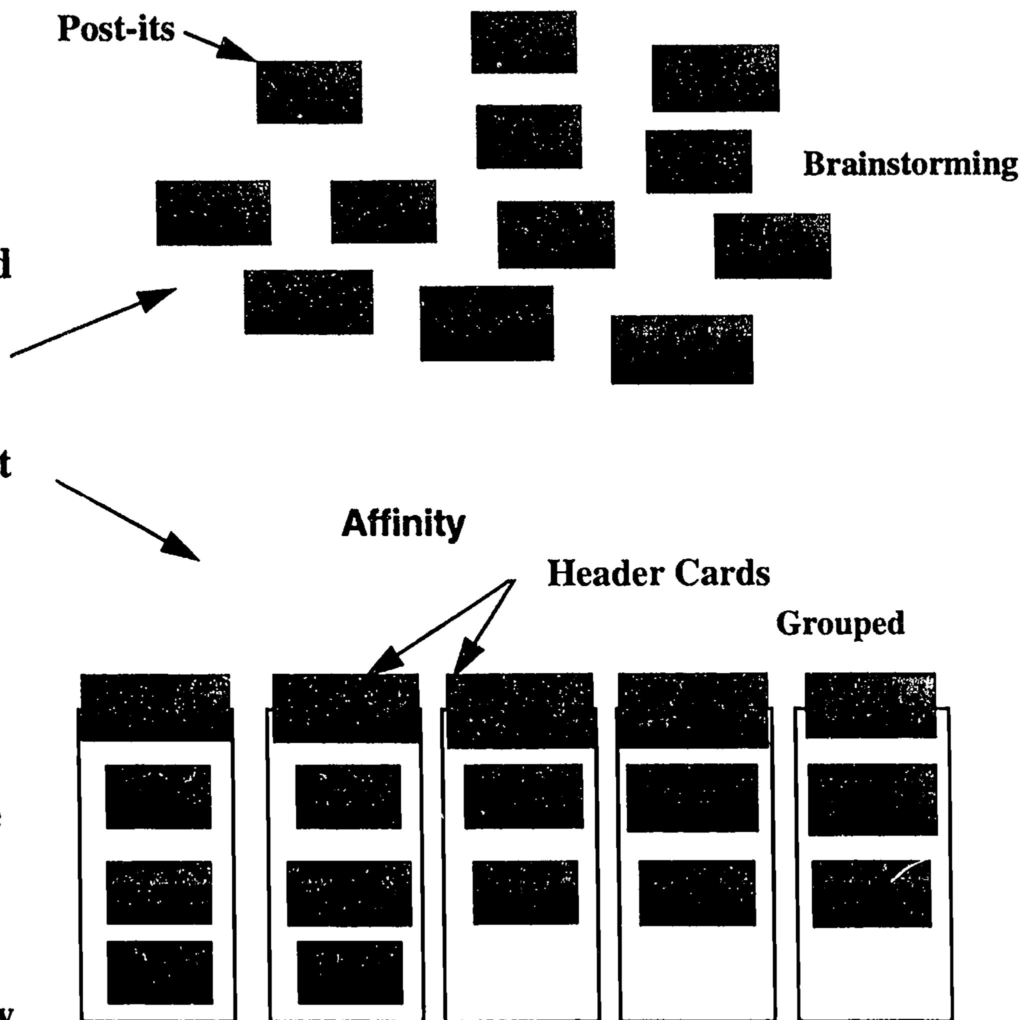


Tree Diagrams, Conventions

- Each item placed on the tree has, for example, a direct cause-and-effect relationship with the item to the left of it, i.e., the second level of detail directly causes the first level of detail to happen.
- Each level of detail, for example, answers the question, 'How will this be accomplished'?
- As you go from left to right, the level of detail gets finer.
- If the items at the lowest level of detail are 'recognizable' modules that can be implemented (e.g., can be assigned to someone else to accomplish), the tree is complete.
- Ask the following questions for example:
  - Going from right to left: 'Will these actions really accomplish the next higher level of the task?'
  - Going from left to right: 'If I want to accomplish this, do I really need to do all of these lower levels of detail?'

Brainstorming and Affinity Process

- Purpose:
- To organize a large set of items into a smaller set of related items.
- Guidelines:
- The rules of brainstorming are followed but each idea is written (in 7 words or less, including a noun and a verb) on a self-adhesive Post-it note or card
- Team members <u>*silently*</u> move the Post-it cards around to form closely-related idea groups
- If disagreement exists when grouping, make copies of the contested card and place in more than one group
- Label each group with a *header card* which clearly identifies and reflects the theme of the cards
- If there are single idea cards that don't fit well with the other ideas, have the team decide if they should be kept (they may be excellent ideas thought of only by one person)



Sequencing the Tree (Part II)

- ❖ Sequencing Competencies and Eliminating Duplicates
- ❖ Assigning Levels and Degrees
  (i.e., converting Outcomes into Behaviors)

  - process of sequencing the tree
  - precedence must be followed

  (i.e., knowledge before comprehension,
  receiving before responding, etc.)

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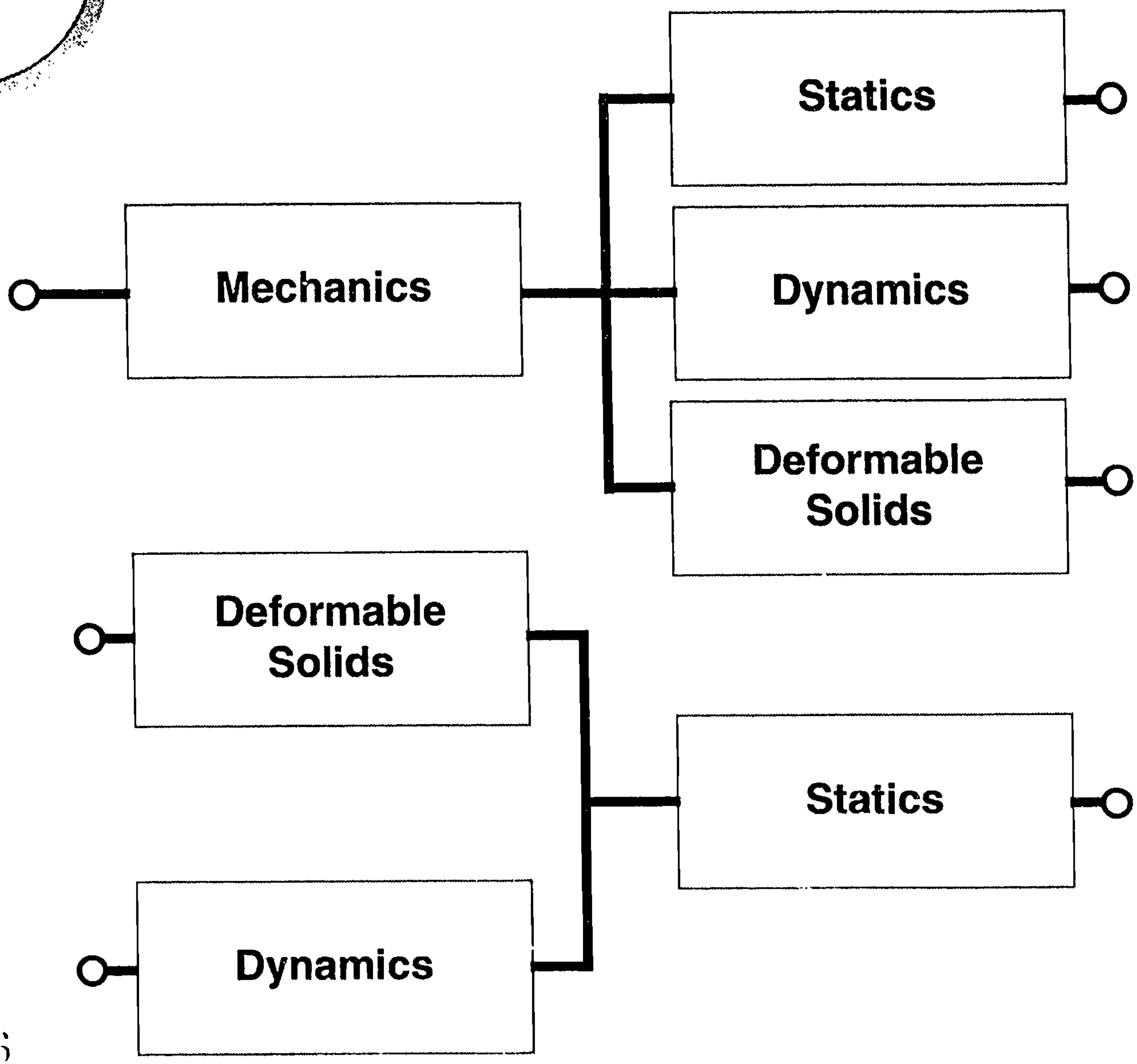
Tree Diagrams, An Example (cont.)



Learning Experiences Defined

- ... NOT the same as the content with which a course deals NOR the activities performed by the teacher
- Learning takes place through the active behavior of the student; it is what the student does that the student learns, NOT what the teacher does.
- This means that the teacher must have some understanding of the kinds of interests and background the students have so that she can make some prediction as to the likelihood that a given situation will bring about a reaction from the student; and, furthermore, will bring about the kind of reaction which is essential to the learning desired.

Organizing Learning Experiences

Learning experiences must be organized to reinforce each other. Their relationship over time and from one area to another must be considered; often referred to as vertical and horizontal relationships.

- **CONTINUITY**

  the vertical reiteration or recurring emphasis of major curriculum elements, themes or organizing threads

- **SEQUENCE**

  increasing the breadth and depth of vertical reiteration

- **INTEGRATION**

  the horizontal relationship of curriculum experiences (i.e., with the objective of allowing the student to develop a unified view)

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General Principles in Selecting Learning Experiences

- the learning experience must provide the student with an opportunity to practice the kind of behavior implied by the objective
- the student must derive some satisfaction from exhibiting the kind of behavior implied by the objectives
- the learning experience must be within the range of possibility for the students involved
- there are many particular experiences that can be used to attain the same educational objectives
- the same learning experience will usually bring about several outcomes

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Reflection & Revision

❖ Reflection

- each team presents the results of their work from the previous sessions

- if the team used a modified or different process to generate the tree (outcomes), the process should be presented

- discuss the process used to establish levels and degrees

- work is critiqued by the other teams

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Appendix

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Knowledge (Information)

Process verbs:		
define	memorize	record
label	name	relate
list	read	repeat
listen	recall	view

How do I know I have reached this level?
I recall information? I bring to mind the appropriate material at the appropriate time? I have been exposed to the information and I can respond to questions, tasks, etc.

What do I do at this level?
I read material, listen to lectures, watch videos, take notes and I am able to pass a test of knowledge on the subject area. I learn the vocabulary of the competency area, i.e., the terminology. I learn the conventions used.

How will the teacher know I am at this level?
The teacher will provide opportunities (either orally or in written tests), regardless of complexity, that can be answered through simple recall of previously learned material.

What does the teacher do at this level?
The teacher directs, tells, shows, identifies, examines the information necessary at this level.

What are typical ways I can demonstrate my knowledge?
1. Define technical terms by giving their attributes, properties or relations.
2. Recall the major facts about a particular subject.
3. List the characteristic ways of treating and presenting ideas (i.e., list conventions associated with the subject).
4. Name the classes, sets, divisions, and arrangements which are regarded as fundamental for a given subject field or problem.
5. List the criteria used to judge facts, principles, and ideas.
6. Describe the method(s) of inquiry or techniques and procedures used in a particular field of study.
7. List the relevant principles and generalizations.
8. Fill in the blank.

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

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Comprehension / Understanding

Process verbs:			
describe	identify	report	tell
explain	locate	restate	work
express	recognize	review	

How do I know I have reached this level?
I comprehend and understand what is being communicated and make use of the ideas but without relating them to other ideas or material. I may not yet understand the fullest meaning. I understand what others are discussing concerning this idea. This level requires Knowledge.

What do I do at this level?
I successfully work assignments in which the appropriate approach is evident either because of material in the problem statement or because of the problem's relative location in the book to the appropriate method. I translate information into my own words (translation from one level of abstraction to another. I translate symbolic information (e.g., tables, commas, diagrams, graphs, mathematical formulas, etc.) into verbal forms, and vice versa. I interpret or summarize communications (written/graphical/oral). I determine implications, consequences, corollaries , effects, etc. which are extensions of trends or tendencies beyond the given data.

How will the teacher know I am at this level?
The teacher will often ask questions or give tests that can be answered by merely restating or reorganizing material in a rather literal (clearly stating the facts or primary meaning of the material) manner to show that I understand the essential meaning, e.g., give the ideas in your own words.

What does the teacher do at this level?
The teacher demonstrates, works problems, listens, questions, compares, contrasts, and examines the information and your knowledge of it.

What are typical ways I can demonstrate or can show on my own my comprehension and understanding.
1. Read Comprehension level problems, know what is being asked for, and successfully work the problems.
2. Clearly chronicle the process used in working the problem.
3. Clearly describe the results of working the problem.
4. Draw conclusions (interpret trends) from the results of solving the problem.
5. Compare/contrast two different problems (i.e., what things are the same? / what things are different?)
6. Restate and idea, theory, or principle in your own words.

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

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Application (Thinking)

Process verbs:		
apply	illustrate	practice
demonstrate	interpret	recognize
employ	operate	

How do I know I have reached this level?

I have the ability to recognize the need to use an idea, method, concept, principle, or theory without being told to use it, i.e., I have the ability to use ideas, methods, concepts, principles and theories in new situations. I know and comprehend the information and can apply it to a new situation. I also have the ability to recognize when a certain task, project, theory or concept is beyond my current competency. Application requires having Knowledge and Comprehension.

What do I do at this level?

I work problems for which the solution method is not immediately evident or obvious. I take knowledge that has been learned at the Knowledge and Comprehension levels of learning and apply it to new situation. I solve problems on my own and make use of other techniques. This requires not only knowing and comprehending information, but deep thinking about the usefulness of this information and how it can be used to solve new problems that I create or identify.

How will the teacher know I am at this level?

I will show the teacher through my work that I am involved in problem solving in new situations with minimal identification or prompting of the appropriate rules, principles, or concepts by the teacher. The teacher will be able to ask general questions like, How much protection from the sun is enough? and I will know how to attack the problem.

What are the typical ways I can demonstrate or show, on my own, my application of Knowledge and Comprehension?

1. Solve problems which require recognition of the appropriate concepts, theories, solution techniques, etc.
2. Apply the laws of mathematics, chemistry, physics, and engineering to practical situations.
3. Work *project type* problems.

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

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Analysis (Thinking)

Process verbs:	
break apart	examine
break down	explain

How do I know I have reached this level?
I can explain *why*. I can examine, methodically, ideas, concepts, writing etc. and separate into parts or basic principles. I have the ability to break down information into component parts in order to make organization of the whole clear. Work at this level requires having Knowledge and Comprehension levels of learning (application is not required).

What do I do at this level?
I analyze results by breaking concepts, ideas, theories, equations, etc. apart. I can explain the logical interconnections of the parts and can develop detailed cause and effect chains.

What does the teacher do at this level?
The teacher probes, guides, observes, and acts as a resource.

What are typical questions I can pose for myself to answer which will demonstrate or show my Analysis level of learning?
1. Why did this (result) happen?
2. What reasons does she give for her conclusions?
3. Does the evidence given support the hypothesis, the conclusion?
4. Are the conclusions supported by facts, opinions, or analysis of the results?
5. What are the causal relationships between the results for the whole and the parts?
6. What are the unstated assumptions?

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

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Synthesis (Thinking)

Process verbs:			
arrange	construct	manage	propose
assemble	create	organize	set up
collect	design	plan	write
compose	formulate	prepare	

<u>How do I know I have reached this level?</u>
I have the ability to put together parts and elements into a unified organization or whole which requires original, creative thinking. I recognize new problems and develop new tools to solve them. I create my own plans, models, and/or hypotheses for finding solutions to problems. This level of learning requires Knowledge, Comprehension, Application and Analysis levels of learning.

<u>What do I do at this level?</u>
put ideas together to create something. This could be a physical object, a process, a design method, a communication, or even a set of abstract relations (i.e., mathematical models). I produce reports, (written/oral) which create a desired effect (e.g., information acquisition, acceptance of a point of view, continued support, etc.) in the reader (listener). I generate project plans, I propose designs, I formulate hypotheses based on the analysis of pertinent factors. I am able to generalize from a set of axioms, principles.

<u>How will the teacher know I am at this level?</u>
I show that I can combine ideas into a statement, plan, product, etc., that is new for me; e.g., I can develop a program that includes the best parts of each of those ideas

<u>What does the teacher do as this level?</u>
The teacher reflects, extends, analyses, and evaluates.

<u>What are the typical questions I can answer which will demonstrate or show my Synthesis?</u>
1. Can I create a project plan?
2. Can I develop a model?
3. Can I propose a design?

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

Appreciation / Evaluation (Wisdom)

Process verbs:	
appraise	judge
choose	predict (quality)
compare	rate value
estimate (quality)	select
evaluate	

How do I know I have reached this level?

I have the ability to judge and appreciate the value of ideas, procedures and methods using appropriate criteria. To work at this level requires having achieved Knowledge, Comprehension, Application, Analysis and Synthesis levels of learning.

What do I do at this level?

I make value judgments based on certain considerations such as usefulness, effectiveness, and so on. Based on information gained through application, analysis ,and synthesis I can rationally select a process, a method, a model, a design, etc. from among a set of possible processes, methods, models, designs, etc. I evaluate competing plans of action before actually starting the planned work. I evaluate work based on internal standards of consistency, logical accuracy and the absence of internal flaws (e.g., I can certify if design feasibility has been demonstrated in a report). I evaluate work based on external standards of efficiency, cost, utility to meet particular ends (e.g., I can certify that design quality has been demonstrated in a report).

How will the teacher know I am at this level?

I can demonstrate that I can make a judgment about something using some criteria or standard for making the judgment.

What does the teacher do at this level?

The teacher clarifies, accepts, harmonizes, aligns, and guides.

What are typical statements and questions I can respond to which will demonstrate or show my appreciation/evaluation?

1. I can evaluate an idea in terms of ...
2. For what reasons do I favor...
3. Which policy do I think would result in the greatest good for the greatest number?
4. Which of these models i.e., modeling approaches is the best for my current needs. How does this report show that the design is feasible? How does this report show the quality of the design?

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

Affective (Character) Traits

What are some affective traits?

Ability to work alone	Curiosity	Interest
Ability to work in teams	Honesty	Self Esteem
Attention	Initiative	Truthfulness
Cooperativeness	Integrity	

What questions can I ask myself to determine if I am exhibiting these characteristics?

1. Do I come to class (meetings) prepared?
2. Do I come to class (meetings) on time?
3. Do I seek out material on a subject beyond what is suggested by the instructor?
4. Do I admit when I do not know something?
5. Do I talk about class subjects with my friends during informal gatherings.
6. Do I help others when they are having difficulties?
7. Do I invest the time expected working on the class (meetings)?
8. Do I do the work I say I will do and have it done when I say I will have it done?
9. Do I know I can solve problems?

A Condensed Version of the COGNITIVE Domain of the Taxonomy of Educational Objectives (3)

1.00 KNOWLEDGE

Knowledge, as defined here, involves the recall of specifics and universals, the recall of methods and processes, or the recall of a pattern, structure, or setting. For measurement purposes, the recall situation involves little more than bringing to mind the appropriate materials. Although some alteration of the material may be required, this is a relatively minor part of the task.. The knowledge objectives emphasize most the psychological processes of remembering. The process of relating is also involved in that a knowledge test situation requires the organization and reorganization of a problem such that it will furnish the appropriate signals and cues for the information and knowledge the individual processes. To use an analogy, if one thinks of the mind as a file, the problem in a knowledge test situation is that of finding in the problem or task the appropriate signals, cues, and clues which will most effectively bring out whatever knowledge is filed or stored.

1.10 Knowledge Of Specifics

The recall of specific and isolable bits of information. The emphasis is one symbols with concrete referents, This material, which is at a very low level of abstraction, may be thought of as the elements, from which more complex and abstract forms of knowledge are built.

1.11 Knowledge of Terminology

Knowledge of the referents for specific symbols (verbal and nonverbal). This may include knowledge of the most generally accepted symbol referent, knowledge of the variety of symbols which may be used for single referent, or knowledge of the referent most appropriate to a given use of a symbol.

To define technical terms by giving their attributes, properties, or relations.
Familiarity with a large number of words in their common range of meanings.

1.12 Knowledge of Specific Facts

Knowledge of dates. events, persons, places, etc. This may include very precise and specific information such as the specific day or exact magnitude of a phenomenon. It may also include approximate or relative information such as an approximate time period or the general order of magnitude of a phenomenon.

The recall of major facts about particular cultures.
The possession of a minimum knowledge about the organisms studied in the laboratory.

1.20 Knowledge Of Ways And Means Of Dealing With Specifics

Knowledge of the ways of organizing, studying, judging, and criticizing. This includes the methods of inquiry, the chronological sequences, and the standards of judgment within a field as well as the patterns of organization through which the areas of the fields themselves are determined and internally organized. This knowledge is at an intermediate level of abstraction between specific knowledge on the one hand and knowledge of universals on the other. It does not so much demand the activity of the student in using the materials as it does a more passive awareness of their nature.

1.21 Knowledge of Conventions

Knowledge of characteristics ways of treating and presenting ideas and phenomena. For purposes of communication and consistency, workers in a field employ usages, styles, practices, and forms which best suit their purposes and/or which appear to suit best the phenomena with which they deal. It should be recognized that although these forms and conventions are likely to be set up on arbitrary, accidental, or authoritative bases, they are retained because of the general agreement or concurrence of individuals concerned with the subject, phenomena, or problem.

Familiarity with the forms and conventions of the major types of works; e.g., verse, plays, scientific papers, etc.
To make pupils conscious of correct form and usage in speech and writing.

1.22 Knowledge of Trends and Sequences

Knowledge of the processes, directions, and movements of phenomena with respect to time.

> Understanding of the continuity and development of American culture as exemplified in American life.
> Knowledge of the basic trends underlying the development of public assistance programs.

1.23 Knowledge of Classifications and Categories

Knowledge of the classes, sets, divisions, and arrangements which are regarded as fundamental for a given subject field, purpose, argument, or problem.

> To recognize the area encompassed by various kinds of problems or materials.
> Becoming familiar with a range of types of literature.

1.24 Knowledge of Criteria

Knowledge of the criteria by which facts, principles, opinions, and conduct are tested or judged.

> Familiarity with criteria for judgment appropriate to the type of work and the purpose for which it is read.
> Knowledge of criteria for the evaluation of recreational activities.

1.25 Knowledge of Methodology

Knowledge of the methods of inquiry, techniques, and procedures employed in a particular subject field as well as those employed in investigating particular problems and phenomena. The emphasis here is on the individual's knowledge of the method rather than his ability to use the method.

> Knowledge of scientific methods for evaluating health concepts.
> The student shall know the methods of attack relevant to the kinds of problems of concern to the social sciences.

1.30 Knowledge Of The Universals And Abstractions In A Field

Knowledge of the major schemes and patterns by which phenomena and ideas are organized. These are the large structures, theories, and generalizations which dominate a subject field or which are quite generally used in studying phenomena or solving problems. These are at the highest levels of abstractions and complexity.

1.31. Knowledge of Principles and Generalizations

Knowledge of particular abstractions which summarize observations of phenomena. These are the abstractions which are of value in explaining, describing, predicting, or in determining the most appropriate and relevant action or direction to be taken.

Knowledge if the important principles by which our experience with biological phenomena is summarized.
The recall of major generalizations about particular cultures.

1.32 Knowledge of Theories and Structures

Knowledge of the body of principles and generalizations together with their interrelations which present a clear, rounded, and systematic view of a complex phenomenon, problem, or field. These are the most abstract formulation, and they can be used to show the interrelation and organization of a great range of specifics.

The recall of major theories about particular cultures.
Knowledge of a relatively complete formulation of the theory of evolution.

Intellectual Abilities And Skills

Abilities and skills refer to organized modes of operation and generalized techniques for dealing with materials and problems. The materials and problems may be of such a nature that little or no specialized and technical information is required. Such information as is required can be assumed to be part of the individual's general fund of knowledge. Other problems may require specialized and technical information at a rather high level such that specific knowledge and skill in dealing with the problem and the materials are required. The abilities and skills objectives emphasize the mental processes of organizing and reorganizing material to achieve a particular purpose. The materials may be given or remembered.

2.00 COMPREHENSION

This represents the lowest level of understanding. It refers to a type of understanding or apprehension such that the individual knows what is being communicated and can make use of the material or idea being communicated without necessarily relating it to other material or seeing its fullest implications.

2.10 Translation

Comprehension as evidenced by the care and accuracy with which the communication is paraphrased or rendered from one language or form of communication to another. Translation is judged on the basis of faithfulness and accuracy; that is, on the extent to which the material in the original communication is preserved although the form of the communication has been altered.

The ability to understand non literal statements (metaphor, symbolism, irony, exaggeration).
Skill in translating mathematical verbal material into symbolic statements and vice versa.

2.20 Interpretation

The explanation or summarization of a communication. Whereas translation involves an objective part-for-part rendering of a communication, interpretation involves a reordering, rearrangement, or new view of the material.

The ability to grasp the thought of the work as a whole at any desired level of generality.
The ability to interpret various types of social data.

2.30 Extrapolation

The extension of trends or tendencies beyond the given data to determine implications, consequences, corollaries, effects, etc., which are in accordance with the conditions described in the original communication.

The ability to deal with the conclusion of a work in terms of the inference made from the explicit statements.
Skill in predicting continuation of trends.

3.00 APPLICATION

The use of abstractions in particular and concrete situation. The abstractions may be in the form of general ideas, rules of procedures, or generalized methods. The abstractions may also be technical principles, ideas, and theories which must be remembered and applied.

Application to the phenomena discussed in one paper of the scientific terms or concepts used in other papers.
The ability to predict the probable effect of a change in a factor on a biological situation previously at equilibrium.

4.00 ANALYSIS

The breakdown of a communication into its constituent elements or parts such that the relative hierarchy of ides is made clear and/or the relations between the ideas expressed are made explicit. Such analyses are intended to clarify the communication, to indicate how the communication is organized, and the way in which it manages to convey its effects, as well as its basis and arrangement.

4.10 Analysis Of Elements

Identification of the elements included in a communication.

The ability to recognize unstated assumptions.
Skill in distinguishing facts from hypotheses.

4.20 Analysis Of Relationships

The connections and interactions between elements and parts of a communication.

Ability to check the consistency of hypotheses with given information and assumption.
Skill in comprehending the interrelationships among the ideas in a passage.

4.30 Analysis Of Organizational Principles

The organization, systematic arrangement, and structure which hold the communication together. This includes the "explicit" as well as "implicit" structure. It includes the bases, necessary arrangement, and mechanics which make the communication a unit.

The ability to recognize form and pattern in literary or artistic works as a means of understanding their meaning.
Ability to recognize the general techniques used in persuasive materials, such as advertising, propaganda, etc.

5.00 SYNTHESIS

The putting together of elements and parts so as to form a whole. This involves the process of working with pieces, parts, elements, etc., and arranging and combining them in such a way as to constitute a pattern or structure not clearly there before.

5.10 Production Of A Unique Communication

The development of a communication in which the writer or speaker attempts to convey ideas, feelings, and/or experiences to others.

Skill in writing, using an excellent organization of ideas and statements.
Ability to tell a personal experience effectively.

5.20 Production Of A Plan, Or Proposed Set Of Operations

The development of a plan of work or the proposal of a plan of operations. The plan should satisfy requirements of the task which may be given to the student or which he may develop for himself.

Ability to propose ways to testing hypotheses.
Ability to plan a unit of instruction for a particular teaching situation.

5.30 Derivation Of A Set Of Abstract Relations

The development of a set of abstract relations either to classify or explain particular data or phenomena, or the deduction of propositions and relations from a set of basic propositions or symbolic representations.

Ability to formulate appropriate hypotheses based upon an analysis of factors involved, and to modify such hypotheses in the light of new factors and considerations.
Ability to make mathematical discoveries and generalizations.

6.00 EVALUATION

Judgments about the value of material and methods for given purposes. Quantitative and qualitative judgments about the extent to which material and methods satisfy criteria. Use of a standard of appraisal. The criteria may be those determined by the student or those which are given to him.

6.10 Judgments In Terms Of Internal Evidence

Evaluation of the accuracy of a communication from such evidence as logical accuracy, consistency, and other internal criteria.

Judging by internal standards, the ability to assess general probability of accuracy in reporting facts from the care given to exactness of statement, documentation, proof, etc.
The ability to indicate logical fallacies in arguments.

6.20 Judgments In Terms Of External Criteria

Evaluation of material with reference to selected or remembered criteria.

The comparison of major theories, generalizations, and facts about particular cultures.
Judging by external standards, the ability to compare a work with the highest known standards in its field-especially with other works of recognized excellence.

(1) Each sub category is followed by illustrative educational objectives selected from the literature.
(3) Bloom, David R., et al., *Taxonomy of Educational Objectives*, Longman, 1964, p. 176 - 185.

A Condensed Version of the AFFECTIVE Domain of the Taxonomy of Educational Objectives (1)

1.0 RECEIVING (ATTENDING)

At this level we are concerned that the learner be sensitized to the existence of certain phenomena and stimuli; that is, that he be willing to receive or to attend to them. This is clearly the first and crucial step if the learner is to be properly oriented to learn what the teacher intends that he will. To indicate that this is the bottom rung of the ladder, however, is not at all to imply that the teacher is starting de novo. Because of previous experience (formal or informal). the student brings to each situation a point of view or set which may facilitate or hinder his recognition of the phenomena to which the teacher is trying to sensitize him.

The category of Receiving has been divided into three subcategories to indicate three different levels of attending to phenomena. While the division points between the subcategories are arbitrary, the subcategories do represent a continuum. From an extremely passive position or role on the part of the learner, where the sole responsibility for the evocation of the behavior rests with the teacher-that is, the responsibility rests with him for "capturing" the student's attention-the continuum extends to a point at which the learner directs his attention, at least at a semiconscious level, toward the preferred stimuli.

1.1 Awareness

Awareness is almost a cognitive behavior. But unlike Knowledge, the lowest level of the cognitive domain, we are not so much concerned with a memory of, or ability to recall, an item of fact as we are that, given appropriate opportunity, the learner will merely be conscious of something-that he take into account a situation, phenomena, object, or stage of affairs. Like Knowledge it does not imply an assessment of the qualities or nature of the stimulus, but unlike Knowledge it does not necessarily imply attention. There can be simple awareness without specific discrimination or recognition of the objective characteristics of the object, even though these characteristics must be deemed to have an effect. The individual may not be able to verbalize the aspects of the stimulus which cause the awareness.

Develops awareness of aesthetic factors in dress, furnishings, architecture, city design, good art, and the like.

Develops some consciousness of color, form, arrangement, and design in the objects and structures around him and in descriptive or symbolic representations of people, things, and situation. (2)

1.2 Willingness to Receive

In this category we have come a step up the ladder but are still dealing with what appears to be cognitive behavior. At a minimum level, we are here describing the behavior of being willing to tolerate a given stimulus, not to avoid it. Like Awareness, it involves a neutrality or suspended judgment toward the stimulus. At this level of the continuum the teacher is not concerned that the student seek it out, nor even, perhaps, that in an environment crowded with many other stimuli the learner will necessarily attend in a field with relatively few competing stimuli, the learner is not actively seeking to avoid it. At best, he is willing to take notice of the phenomenon and give it his attention.

Attends (carefully) when others speak-in direct conversation, on the telephone, in audiences.
Appreciation (tolerance) of cultural patterns exhibited by individuals from other groups-religious, social, political, economic, national, etc.
Increase in sensitivity to human need and pressing social problems.

1.3 Controlled or Selected Attention

At a somewhat higher level we are concerned with a new phenomenon, the differentiation of a given stimulus into figure and ground at a conscious or perhaps semiconscious level-the differentiation of aspects of a stimulus which is perceived as clearly marked off from adjacent impressions. The perception is still without tension or assessment, and the student may not know the technical terms or symbols with which to describe it correctly or precisely to others. In some instances it may refer not so much to the selectivity of attention as to the control of attention, so that when certain stimuli are present they will be attended to. There is an element of the learner's controlling the attention here, so that the favored stimulus is selected and attended to despite competing and distracting stimuli.

Listens to music with some discrimination as to its mood and meaning and with some recognition of the contributions of various musical elements and instruments to the total effect.
Alertness toward human values and judgments on life as they are recorded in literature.

2.0 Responding

At this level we are concerned with responses which go beyond merely attending to the phenomenon. The student is sufficiently motivated that he is not just 1.2 Willing to attend, but perhaps it is correct to say that he is actively attending. As a first stage in a "learning by doing" process the student is committing himself in some small measure to the phenomena involved. This is a very low level of commitment, and we would not say at this level that this was "a value of his" or that he had "such and such an attitude." These terms belong to the next higher level that we describe. But we could say that he is doing something with or about the phenomenon besides merely perceiving it, as would be true at the next level below this of 1.2 Controlled or selected attention.

This is the category that many teachers will find best describes their "interest" objectives. Most commonly we use the term to indicate the desire that a child become sufficiently involved in or committed to a subject, phenomenon, or activity that he will seek it out and gain satisfaction from working with it or engaging in it.

2.1 Acquiescence In Responding

We might use the word "obedience" or "compliance" to describe this behavior. As both of these terms indicate, there is a passiveness so far as the initiation of the behavior is concerned, and the stimulus calling for this behavior is not subtle. Compliance is perhaps a better term than obedience, since there is more of the element of reaction to a suggestion and less of the implication of resistance or yielding unwillingly. The student makes the response, but he has not fully accepted the necessity for doing so.

Willingness to comply with health regulations.
Obeys the playground regulation.

2.2 Willingness To Respond

The key to this level is in the term "willingness," with its implication of capacity for voluntary activity. There is the implication that the learner is sufficiently committed to exhibiting the behavior that he does so not just because of a fear or punishment, but "on his own" or voluntarily. It may help to note that the element of resistance or of yielding unwillingly, which is possibly present at the previous level, is here replaced with consent or proceeding from one's own choice.

Acquaints himself with significant current issues in international, political, social, and economic affairs through voluntary reading and discussion.
Acceptance of responsibility for his won health and for the protection of the health of others.

2.3 Satisfaction In Response

The additional element in the step beyond the Willingness to respond level, the consent, the assent to responding, or the voluntary response, is that the behavior is accompanied by a feeling of satisfaction, an emotional response, generally of pleasure, zest, or enjoyment. The location of this category in the hierarchy has given is a great deal of difficulty. Just where in the process of internalization the attachment of an emotional response, kick, or thrill to a behavior occurs has been hard to determine. For that matter there is some uncertainty as to whether the level of internalization at which it occurs may not depend on the particular behavior. We have even questioned whether it should be a category. If our structure is to be a hierarchy, then each category should include the behavior in the next level below it. The emotional component appears gradually through the range of internalization categories. The attempt to specify a given position in the hierarchy as the one at which the emotional component is added is doomed to failure.

The category is arbitrarily placed at this point in the hierarchy where it seems to appear most frequently and where it is cited as or appears to be an important component of the objectives at this level on the continuum. The category's inclusion at this point serves the pragmatic purpose of reminding us of the presence of the emotional component and its value in the building of affective behaviors. But it should not be thought of as appearing and occurring at this one point in the continuum and thus destroying the hierarchy which we are attempting to build.

Enjoyment of self-expression in music and in arts and crafts as another means of personal enrichment.
Finds pleasure in reading for recreation.
Takes pleasure in conversing with many different kinds of people.

3.0 Valuing

This is the only category headed by a term which is in common use in the expression of objectives by teachers. Further, it is employed in its usual sense: that a thing, phenomenon, or behavior has worth. This abstract concept of worth is in part a result of the individual's own valuing or assessment, but it is much more a social product that has been slowly internalized or accepted and has come to be used by the student as his own criterion of worth.

Behavior categorized at this level is sufficiently consistent and stable to have taken on the characteristics of a belief or an attitude. The learner displays this behavior with sufficient consistency in appropriate situations that he comes to be perceived as holding a value. At this level, we are not concerned with the relationships among values but rather with the internalization of a set of specified, ideal, values. Viewed from another standpoint, the objectives classified here are the prime stuff from which the conscience of the individual is developed into active control of behavior.

This category will be found appropriate for many objectives that use the term "attitude" (as well as, of course, "value").

An important element of behavior characterized by Valuing is that it is motivated, not by the desire to comply or obey, but by the individual's commitment to the underlying value guiding the behavior.

3.1 Acceptance Of A Value

At this level we are concerned with the ascribing of worth to a phenomenon, behavior, object, etc. The term "belief", which is defined as "the emotional acceptance of a proposition or doctrine upon what one implicitly considers adequate ground" (English and English, 1958, p. 64), describes quite well what may be thought of as the dominant characteristic here. Beliefs have varying degrees of certitude. At this lowest level of Valuing we are concerned with the lowest levels of certainty; that is, there is more of a readiness to re-evaluate one's position than at the higher levels. It is a position that is somewhat tentative.

One of the distinguishing characteristics of this behavior is consistency of response to the class of objects, phenomena, etc. with which the belief or attitude is identified. It is consistent enough so that the person is perceived by others as holding the belief or value. At the level we are describing here, he is both sufficiently consistent that others can identify the value, and sufficiently committed that he is willing to be so identified.

Continuing desire to develop the ability to speak and write effectively.
Grows in his sense of kinship with human beings of all nations.

3.2 Preference For A Value

The provision for this subdivision arose out of a feeling that there were objectives that expressed a level of internalization between the mere acceptance of a value and commitment or conviction in the usual connotation of deep involvement in an area. Behavior at this level implies not just the acceptance of a value to the point of being willing to be identified with it, but the individual is sufficiently committed to the value to pursue it, to seek it out, to want it.

Assumes responsibility for drawing reticent members of a group into conversation.
Deliberately examines a variety of viewpoints on controversial issues with a view to forming opinions about them.
Actively participates in arranging for the showing of contemporary artistic efforts.

3.3 Commitment

Belief at this level involves a high degree of certainty. The ideas of "conviction" and "certainty beyond a shadow of a doubt" help to convey further the level of behavior intended. In some instances this may border on faith, in the sense of it being a firm emotional acceptance of a belief upon admittedly non rational grounds. Loyalty to a position, group, or cause would also be classified here.

The person who displays behavior at this level is clearly perceived as holding the value. He acts to further the thing valued in some way, to extend the possibility of his developing it, to deepen his involvement with it and with the things representing it. He tries to convince others and seeks converts to his cause. There is a tension here which needs to be satisfied; action is the result of an aroused need or drive. There is a real motivation to act out the behavior.

Devotion to those ideas and ideals which are the foundations of democracy.
Faith in the power of reason and in methods of experiment and discussion.

4.0 ORGANIZATION

As the learner successively internalizes values, he encounters situation for which more than one value is relevant. Thus necessity arises for (a) the organization of the values into a system, (b) the determination of the interrelationships among them, and (c) the establishment of the dominant and pervasive ones. Such a system is built gradually, subject to change as new values are incorporated. This category is intended as the proper classification for objectives which describe the beginnings of the building of a value system. It is subdivided into two levels, since a prerequisite to interrelating is the conceptualization of the value in a form which permits organization. Conceptualization forms the first subdivision in the organization process, Organization of a value system the second.

While the order of the two subcategories seems appropriate enough with reference to one another, it is not so certain that 4.1 Conceptualization of a value is properly placed as the next level above 3.3 Commitment. Conceptualization undoubtedly begins at an earlier level for some objectives. Like 2.3 satisfaction in response, it is doubtful that single completely satisfactory location for this category can be found. Positioning it before 4.2 Organization of a value system appropriately indicates a prerequisite of such a system. It also calls attention to a component of affective growth that occurs at least by this point on the continuum but may begin earlier.

4.1 Conceptualization Of A Value

In the previous category, 3.0 Valuing, we noted that consistency and stability are integral characteristics of the particular value or belief. At this level (4.1) the quality of abstraction or conceptualization is added. This permits the individual to see how the value relates to those that he already holds or to new ones that he is coming to hold.

Conceptualization will be abstract, and in this sense it will be symbolic. But the symbols need not be verbal symbols. Whether conceptualization first appears at this point on the affective continuum is a moot point, as noted above.

Attempts to identify the characteristics of an art object which he admires.
Forms judgments as to the responsibility of society for conserving human and material resources.

4.2 Organization Of A Value System

Objectives properly classified here are those which require the learner to bring together a complex of values, possibly disparate values, and to bring these into an ordered relationship with one another. Ideally, the ordered relationship will be one which is harmonious and internally consistent. This is, of course, the goal of such objectives, which seek to have the student formulate a philosophy of life. In actuality, the integration may be something less than entirely harmonious. More likely the relationship is better described as a kind of dynamic equilibrium which is, in part, dependent upon those portions of the environment which are salient at any point in time. In many instances the organization of values may result in their synthesis into a new value or value complex of a higher order.

Weighs alternative social policies and practices against the standards of the public welfare rather than the advantage of specialized and narrow interest groups.
Develops a plan for regulating his rest in accordance with the demands of his activities.

5.0 CHARACTERIZATION BY A VALUE OR VALUE COMPLEX

At this level of internalization the values already have a place in the individual's value hierarchy, are organized into some kind of internally consistent system, have controlled the behavior of the individual for sufficient time that he has adapted to behaving this way; and an evocation of the behavior no longer arouses emotion or affect except when the individual is threatened or challenged.

The individual acts consistently in accordance with the values he has internalized at this level, and our concern is to indicate two things; (a) the generalization of this control to so much of the individual's behavior that he is described and characterized as a person by these pervasive controlling tendencies, and (b) the integration of these beliefs, ideas, and attitudes into a total philosophy or world view. These two aspects constitute the subcategories.

5.1 Generalized Set

The generalized set is that which gives an internal consistency to the system of attitudes and values at any particular moment. It is selective responding at a very high level. It is sometimes spoken of as a determining tendency, an orientation toward phenomena, or a predisposition to act in a certain way. The generalized set is a response to highly generalized phenomena. It is a persistent and consistent response to a family of related situation or objects. It may often be an unconscious set which guides action without conscious forethought. The generalized set may be thought of as closely related to the idea of an attitude cluster, where the commonality is based on behavioral characteristics rather than the subject or object of the attitude. A generalized set is a basic orientation which enables the individual to reduce and order the complex world about him and to act consistently and effectively in it.

Readiness to revise judgments and to change behavior in the light of evidence.
Judges problems and issues in terms of situation, issues, purposes, and consequences involved rather than in terms fixed, dogmatic precepts or emotionally wishful thinking.

5.2 Characterization

This, the peak of the internalization process, includes those objectives which are broadest with respect both to the phenomena covered and to the range of behavior which they comprise. Thus, here are found those objectives which concern one's view of the universe, one's philosophy of life, one's Weltanschauung-a value system having as its object the whole of what is known or knowable.

Objectives categorized here are more than generalized sets in the sense that they involve a greater inclusiveness and, within the group of attitudes, behaviors, beliefs, or ideas, an emphasis on internal consistence. Though this internal consistency may not always be exhibited behaviorally by the students toward whom the objective is directed, since we are categorizing teachers' objectives, this consistency feature will always be a component of Characterization objectives.

As the title of the category implies, these objectives are so encompassing that they tend to characterize the individual almost completely.

Develops for regulation of one's personal and civic life a code of behavior based on ethical principles consistent with democratic ideals
Develops a consistent philosophy of life.

(1) Bloom, David R., et al., *Taxonomy of Educational Objectives*, Longman, 1964, p. 176 - 185.
(2). Illustrative objectives selected from the literature follow the description of each sub category.

Formulate-Share-Listen-Create

Focus Question	Determine at least TWO issues illustrated in the tape which are relevant to the Engineering classroom.

Students do NOT enter our classes with a 'blank mind' but in fact have a considerable 'collage' of information; some of which is wrong !

1. **It is our responsibility to assist the student in identifying their incorrect knowledge (i.e., pre-assessment instruments)**

2. **It is in fact OUR responsibility to develop general methods and procedures which the student can use to correct their knowledge (at least until they can develop their own 'intervention' techniques) .**

Where Will Change Originate ?

The biggest and most long lasting reforms

of undergraduate education will come when

individual faculty or small groups of instructors

adopt the view of themselves as reformers

within their immediate sphere of influence,

the classes they teach every day.

K. Patricia Cross

University of Alabam Response to Formulate-Share-Listen-Create

- Recognize misconceptions, find commonality or criticality
- motivate reconsideration (in a timely fashion) using hands on techniques
- Students have preconceived notions of how things work and are always crating more.
- Students need to learn how to verify their ideas.
- Check for understanding
  - peer interaction
  - correct misconceptions
- Interact with models
  - sketches
  - terminology

Issues

- In overcoming preconceptions about subject material, rather brutally challenge their preconceptions.
- Knowledge level - do they understand
  - one on one instruction
  - hands on
  - sketching

Curriculum Development, Design, Specification and Assessment

Prepared by

Barry W. McNeill & Lynn Bellamy

Supplemental Materials

Innovation in Engineering Education Program
College of Engineering and Applied Sciences
Arizona State University

BELLAMY

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Science and Technology - Mt. Edgecumbe High School

Name:

Learning Activity: Engineering Design Project

Updated : 5/12/94 6:18 PM

Learning Outcome	Competency Category	Competencies	Number of Competencies 45	Knowledge	Understanding/ Comprehension	Application	Analysis	Synthesis	Appreciation/ Evaluation
Engineering Design	Engineering Method	Client Need	1						
		Problem Definition	2						
		Ideation \ Imagineering	3						
		Modelling	4						
		• Physical Models	5						
		• Visual / Graphical Models	6						
		• Conceptual Models	7						
		• Mathematical Models	8						
		Working Solution / Design (meets?)	9						
		Search for Better (methodology?)	10						
		Documentation (report?)	11						
		Measures of Goodness for the Design	12						
		Robustness of the Design (sensitivity?)	13						
	Analysis of a Mathematical Mode	Variables (all!)	14						
		Equations (meaning)	15						
		Data (nature)	16						
		Specifications (humans/customers	17						
		Parameters (shared)	18						
		Initial Conditions (include t0)	19						
		Remaining Unknowns	20						
		Design Variables	21						
		Constraints	22						
		Result Variables (equations?)	23						
	TK Solver Plus (v 1.1)	Rules (equations)	24						
		Variables (alphanumeric values)	25						
		Unit Conversion (SI, English, CGS, etc.)	26						
		Display Units (what you see!)	27						
		Calculation units (what you get!)	28						
		Tables (lists)	29						
		Interative Tables (Put / Get Variables)	30						
		Plots	31						
		Formats (variables, lists, tables, plots)	32						
		Examine Variables / Expressions	33						
		Direct Solver	34						
		Iterative Solver (initial guess?)	35						
		Logical Expressions (IF rules)	36						
		List Functions (interpolation?)	37						
			38						
	Experimental Parameter Estimatio	K single strand	39						
		K bungee	40						
		mean value	41						
		standard deviation (+ or - 3 sigma)	42						
			43						
			44						
			45						

Learning Outcomes	Competency Category	Competencies	Knowledge	Comprehension / Understanding	Application	Analysis	Synthesis	Appreciation / Evaluation
		Course 1 : Conservation Principles in Engineering						
		Conservation Principles and the Structure of Engineering ECE 394 A REVIEW						
	System Definition I Selection	Labeled Sketches						
		System or Free body Diagram						
		Surroundings						
		Time Period						
		Data (Nature)						
		Specifications (Human)						
		Parameters (Shared)						
		Coordinate System (Motion Easy?)						
		Required						
		Assumptions						
		Defining Relationships (Constraints)						
	Analysis of a Mathematical Model	Variables (All)						
		Equations						
		Data (Nature)						
		Specifications (Human)						
		Parameters (Shared)						
		Initial Conditions (Include t0)						
		Remaining Unknowns						
	Conservation Concepts	Total Mass						
		Elemental Mass						
		Total Charge						
		Linear Momentum						
		Angular Momentum						
		Total Energy						
		Entropy (Cosmos, A)						
	Accounting Concepts	Species Mass (A)						
		Moles (A)						
		Plus Charge						
		Minus Charge						
		Electrical Energy (A,D)						
		Mechanical Energy (A,D)						
		Mechanical Energy (Particles, A,D)						
		Mechanical Energy (Rigid Bodies, A,D)						
		Mechanical Energy (Fluid Flow, A, I)						
		Entropy (System, A)						
		Entropy (Surroundings, A)						
		Entropy Generation (Irreversibility)						
	Other	Extensive Properties						
		Intensive Properties						
		Tables for Extensive Properties						
		KCL						
		KVL						

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COURSE 2 : PROPERTIES THAT MATTER

Competency		Process Learning				
	Knowledge	Know-How	Wisdom			
	Information	Understanding	Application	Analysis	Synthesis	Evaluation
General						
Modeling						
Implicit Assumptions						
Occam's Razor						
Constraints						
Specifications						
Extensive Properties						
Intensive Properties						
Fundamental Structure: Molecular & Bonding Structure						
Atomic Orbitals						
LCAO-MO Model						
LCAO-MO Methodology						
Bonding MOs						
Non-bonding MOs						
Anti-bonding MOs						
Molecular Orbital Energies						
Molecular Orbital Waveforms						
Electronic Configurations						
Relative Stability						
Resonance						
Resonance Energy						
Symmetry Types						
Symmetry in LCAO-MO						
Excitation / De-excitation						
Lennard-Jones Model						
Energy Band Diagrams						

	Process Learning					
	Knowledge	Know-How	Wisdom			
Competency	Information	Understanding	Application	Analysis	Synthesis	Evaluation
Fundamental Structure II: Mechanical Structure						
Crystal Structure						
Crystal Lattice						
Basis						
Translation Vectors						
Unit Cell						
Primitive Unit Cell						
Symmetry in Solids						
Bravais Lattices						
Nearest Neighbors						
Packing Fraction						
Density						
Miller Indices						
X-ray Diffraction						
Metallic Bonding						
Ionic Bonding						
Covalent Bonding						
Vacancies						
Substitutional Impurities						
Interstitial Impurities						
Frenkel Defects						
Schottkey Defects						
Line Defects (dislocations)						
Solid Solutions						
Partial Miscibility						
Phase Diagrams						
Lever-rule vs. Conservation						
Eutectics						
Allotropism						

Competency	Process Learning					
	Knowledge	Know-How	Wisdom			
	Information	Understanding	Application	Analysis	Synthesis	Evaluation
Fundamental Structure III: Surface Structure						
Surface Structure						
Surface Lattice						
Basis						
Translation Vectors						
Unit Cell						
Primitive Unit Cell						
Nearest Neighbors						
Surface Packing Fraction						
Surface Density						
Miller Indices						
Surface Energy						
Dangling Bonds						
Bond Breaking Models						
Binding Energy						
Fundamental Structure IV: Thermal Structure						
Allowed Modes of Motion						
Translational Energies						
Rotational Energies						
Vibrational Energies						
Continuum *vs.* Discrete Models						
Electromagnetic Spectrum						
Hooke's Law Model						
Configurational Entropy						
Randomness						
Allowed Configurations						
Permutations						
Equilibrium Defect Concentrations						
Diffusion						
Diffusion Mechanisms						
Fick's 1st Law						
Fick's 2nd Law						
Microscopic Diffusivity Models						

Competency		Process Learning				
	Knowledge	Know-How	Wisdom			
	Information	Understanding	Application	Analysis	Synthesis	Evaluation
Mechanical Properties of Solids						
Mechanical Testing						
Stress						
Strain						
Engineering Stress-strain curves						
True Stress-strain curves						
Elastic Response						
Plastic Response						
Proportional Limit						
Young's Modulus						
Yield Point						
Yield Strength						
Ultimate Strength						
Fracture Strength						
Tension						
Stress						
Shear						
Poisson's Ratio						
Bulk Modulus						
Theoretical Models for Mechanical Properties						
Empirical Models for Mechanical Properties						
Semi-empirical Models for Mechanical Properties						

Competency		Process Learning				
	Knowledge	Know-How	Wisdom			
	Information	Understanding	Application	Analysis	Synthesis	Evaluation
Mechanical Properties of Fluids						
Kinetic Theory of Gases						
Molecular model for Pressure						
Mean molecular velocity						
Mean Free Path						
Collision Frequency						
Ideal Gas Equation of State						
Bulk Modulus for a fluid						
Viscosity						
Molecular model for Viscosity						
Newtonian fluids						
non-Newtonian fluids						
Turbulent flow						
Laminar flow						
Boundary layer						
Speed of sound through fluids						
Surface Tension						
Time - Dependent Mechanical Behavior: Solids and Fluids						
Visco-elastic behavior						
Temperature-dependent behavior						
Strain rate dependent behavior						
Dashpot-spring models for viscoelastic response						
Creep						
Fatigue						

		Process Learning				
	Knowledge	Know-How	Wisdom			
Competency	Information	Understanding	Application	Analysis	Synthesis	Evaluation
Electrical Properties of Materials						
Energy band models						
Energy band gap						
Fermi Energy						
Fermi distribution						
Conductors						
Insulators						
Semiconductors						
Free Electron Gas Model						
Resistivity & Conductivity						
Mobility						
Charge carriers						
Doping: acceptors & donors						
Carrier concentrations						
p-type and n-type semiconductors						
p-n junctions						
Diode performance						
Transistor performance						
Dielectrics						
Dielectric strength						
Superconductivity						

Learning Outcomes	Competency Category	Competencies	Knowledge	Comprehension / Understanding	Application	Analysis	Synthesis	Appreciation / Evaluation
Understanding Engineering Systems Via Conservation, ECE 394 C								
Conservation Principles and the Structure of Engineering ECE 394 A REVIEW								
	System Definition I Selection	Labeled Sketches						
		System or Free body Diagram						
		Surroundings						
		Time Period						
		Data (Nature)						
		Specifications (Human)						
		Parameters (Shared)						
		Coordinate System (Motion Easy?)						
		Required						
		Assumptions						
		Defining Relationships (Constraints)						
	Analysis of a Mathematical Model	Variables (All)						
		Equations						
		Data (Nature)						
		Specifications (Human)						
		Parameters (Shared)						
		Initial Conditions (Include t0)						
		Remaining Unknowns						
	Conservation Concepts	Total Mass						
		Elemental Mass						
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		Angular Momentum						
		Total Energy						
		Entropy (Cosmos, A)						
	Accounting Concepts	Species Mass (A)						
		Moles (A)						
		Plus Charge						
		Minus Charge						
		Electrical Energy (A,D)						
		Mechanical Energy (A,D)						
		Mechanical Energy (Particles, A,D)						
		Mechanical Energy (Rigid Bodies, A,D)						
		Mechanical Energy (Fluid Flow, A, I)						
		Entropy (System, A)						
		Entropy (Surroundings, A)						
		Entropy Generation (Irreversibility)						
	Other	Extensive Properties						
		Intensive Properties						
		Tables for Extensive Properties						
		KCL						
		KVL						
	Knowledge Types	Content (Concepts)						
		Procedural (Know-How)						
		Conditional (Decisions)						
	Mathematical Models I Variable Types	Inputs						
		Outputs						
		Disturbances						
		Degrees of Freedom						
		Order						
		Auxillary Variables (DOF-Order)						
		Constraints						
	Mathematical Model I System Variables	Effort						
		Flow						
		Impedance						
		Interrelationships (Independence)						
		Power						
		State						

Learning Outcomes	Competency Category	Competencies	Knowledge	Comprehension / Understanding	Application	Analysis	Synthesis	Appreciation / Evaluation
Understanding Engineering Systems Via Conservation, ECE 394 C								
	Friction	Freebody Diagrams						
		* Single Body						
		* Multiple Bodies						
		Static (Dry)						
		* Limits						
		* Impending Motion						
		* Known Direction (Magnitude?)						
		* Known Force (Direction?)						
		Dynamic (Dry?)						
		* Known Direction (Magnitude?)						
		* Known Force (Direction?)						
		Viscous (Fluid)						
		* Rigid Body Motion						
		* Bearings, etc.						
		* Dampers or Dashpots						
		Springs (Force, Mechanical Energy)						
	Static Analysis of Structures: Trusses and Frames Only	System or Freebody Diagram						
		* Joint (Truss and LM Only)						
		* Member						
		* Section						
		* Structure						
		Attachments and Connections						
		Friction						
		Ropes and Pulleys						
		Springs (Force Only)						
		Tension / Compression (3rd Law)						
	Rigid Body Motion	Freebody diagram						
		Dynamic Friction (Dry)						
		Viscous Friction						
		Springs (Force, Mech. Energy)						
		Specifying Motion (Function of t)						
		* Acceleration, Velocity, Pos.						
		Method of Special Points						
		* Known and Unknown Points						
		* Contact Points						
		** Permanent						
		** Temporary, No Slip						
		** Temporary, With Slip						
		* Number of Constraints						
		Method of Vector Loops						
		Angular Velocity						
		* Inertial Reference						
		* Painted Line on Body						
		* Right Hand Rule						
		* Adding Angular Velocities						
		Angular Momentum Conservation						
		* Intertial Reference Frame						
		* Moving Point (Fixed W/CG)						
		* About the Center of Gravity						
		* Moments (RHR, Cross Product)						
		Multiple Rigid Bodies (Additive)						
		Linear Momentum, Mech. Energy						

Learning Outcomes	Competency Category	Competencies	Knowledge	Comprehension / Understanding	Application	Analysis	Synthesis	Appreciation / Evaluation
Understanding Engineering Systems Via Conservation, ECE 394 C								
	Electrical Circuits / Electrical Energy Accounting	Degrees of Freedom						
		Order						
		Circuit Elements						
		Resistors						
		* Two Possible Flows						
		* Defining Relationship						
		* Energy Dissipation (to?)						
		* Time Response, V and I						
		* Impedance Relationship						
		**High/Low Frequency						
		Capacitors						
		* Defining Relationship						
		* Energy Storage/Release						
		* Time Response, V and I						
		* Switching Capacitive Loads						
		* Steady State Response						
		* Impedance Relationship						
		** High/Low Frequency						
		Inductors						
		* Defining Relationship						
		* Energy Storage/Release						
		* Time Response, V and I						
		* Switching Inductive Loads						
		* Steady State Response						
		* Impedance Relationship						
		** High/Low Frequency						
		* External/Internal Magnetic Fields						
		** Vector Representation, RHR						
		** Magnetic Fluxes						
		** External Forces						
		* Self Induction						
		* Mutual Induction						
		** Modeling Induced Voltage						
		* Transformers						
		* DC Induction Machines						
		** External Forces						
		** External Torques						
		** Torque/Current Relationships						
		** Induced Volt./Angular Velocity						
		** Total Energy Equation						
		Equivalent Impedances						
		Voltage Sources						
		Current Sources						
		Equivalent Sources (Transformation)						
		Diodes						
		Photodiodes						
		Transistors						
		Switches						
		Operational Amplifiers						
		* Function (Reality-Reality)						
		* Circuit Isolation						
		* Open Loop Response						
		* Feedback Elements						
		* Summer						
		* Integrator						
		* Differentiator						
		Sensors						
		* Function (Reality-Reality)						
		* Types						

Learning Outcomes	Competency Category	Competencies	Knowledge	Comprehension / Understanding	Application	Analysis	Synthesis	Appreciation / Evaluation
Understanding Engineering Systems Via Conservation, ECE 394 C								
	Fluid Systems	Fluid Statics/Hydraulics						
		Fluid Dynamics						
		* Mechanical Energy Accounting						
		Steady State Flow						
		* Turbulent						
		* Laminar						
		* Conservation of Mass						
		Power Sources						
		* Pumps (liquids)						
		Compressors (gasses)						
		* Other						
		Friction Losses						
		* Conduit						
		** Equivalent Diameter						
		** Contraction						
		** Expansion						
		** Elbows						
		** Tees						
		** Pumps/Compressors						
		Flow Measurement						
		* Orifices						
		* Venturi						
		* Level Measurement						
		* Other Devices/Methods						
		Hydraulic Actuators						

Learning Outcomes	Competency Category	Competencies	Knowledge	Comprehension / Understanding	Application	Analysis	Synthesis	Appreciation / Evaluation
Understanding Engineering Systems Via Conservation, ECE 394 C								
	Thermal Systems / Thermodynamics	State						
		State Functions						
		Gibbs Phase Rule						
		Paths						
		* Isothermal						
		* Isobaric						
		* Isometric						
		* Adiabatic						
		* Isentropic						
		* Polytropic						
		* Reversible						
		* Irreversible						
		** Causes of Irreversibility						
		* Other Paths						
		Path Functions						
		* Work						
		* Heat						
		* Entropy Generation						
		Equilibrium						
		Phase Diagrams (Liquid/Vapor)						
		* P - T						
		* P - V						
		* Other						
		Pure Component Property Determination						
		* Graphical						
		* Tabular						
		** Single Interpolation						
		** Double Interpolation						
		* Equation of State						
		** Perfect Gas						
		** Ideal Gas						
		** Incompressible Liquid						
		** Real Fluids						
		* Two Phase Mixtures						
		Thermodynamic Cycles						
		* Carnot						
		** Essential Elements (6)						
		** Power						
		** Refrigeration						
		** Heat Pump						
		* Other Cycles						
		Thermodynamic Efficiency						
		*Theoretical Maximum						
		* Thermal						
		* Isentropic						
		* Mechanical						
		* Other Efficiencies						
		Availability						
		* Property						
		* Closed System						
		* Open System						

Competency Matrix ECE 294

Entry State ■ Exit State

Concepts	Competencies	Before Knowledge	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Self Assessment	Competency Matrix							
	Levels of Learning							
	Portfolio							
Levels of Learning	Knowledge							
	Know-How							
	Application							
	Analysis							
	Synthesis							
	Evaluation							
Character	Run Charts							

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Competency Matrix ECE 294

Entry State | Exit State

Concepts	Competencies	Before Knowledge	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Team Tasks	Additive							
	Conjunctive							
	Disjunctive							
Team Tools	Affinity Process							
	Code of Cooperation							
	Process Checks							
Teaming Process	Forming							
	Functioning Team							
	Norming							
	Performing							
	Storming							
	Team Maintenance							
Team Roles	Facilitator							
	Leader							
	Member							

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Competency Matrix ECE 294

Entry State ■ Exit State

Concepts	Competencies	Before Knowledge	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Design	DESIGN							
	Design Process							
	Planning							
	Process							
Design Process Tasks	Problem Definition							
	Idea Generation / Germination							
	Modeling							
	Finding Workable DESIGNs							
	Searching for Better DESIGNs							
	Documentation							
Problem Definition	Constraints							
	Customer							
	Feasibility							
	Performance							
	Quality / Customer							

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Competency Matrix ECE 294

Entry State | Exit State

Concepts	Competencies	Before Knowledge	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Idea Generation	Brainstorming							
	Random Idea Generator Brain							
	Reptilian Brain							
	Right Brain / Left Brain							
	Short Term / Long Term Memory							
Modeling	Backward Chaining							
	Cash Flow Diagram							
	Component Models							
	Data							
	Degrees of Freedom							
	Deterministic Model							
	Dimensions							
	Forward Chaining							
	Gaussian Distribution							
	Histogram							

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Competency Matrix ECE 294

Entry State | Exit State

Concepts	Competencies	Before Knowledge	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Modeling Continued	MARR							
	a Model							
	P given A Factor							
	P given F Factor							
	Parameter							
	Probabilistic Models							
	System Models							
	Units							
	Variable							
Commun-ication	DESIGN							
	Desired Outcome from Report							
	Diagrams							
	Graphs							
	Process Documentation							
	Reader Analysis							
	Reports							
	Sketches							

Competency Matrix ECE 294

Entry State ■ Exit State

Concepts	Competencies	Before Knowledge	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
TK Solver	Calculation/Display Units							
	Examine Command (/E)							
	Direct Solver							
	Global Sheet							
	Import / Export Data (/S)							
	Iterative Solver							
	List Function							
	List Solving							
	Lists							
	Plots							
	Presentation View							
	Rule Function							
	Rule Sheet							
	Tables							
	Variable Sheet							

Competency Matrix ECE 294

Entry State ■ Exit State

Concepts	Competencies	Before Knowledge	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
	Absolute Cell Address							
	Calculate							
	Cell Address							
SC5	Circular Reference							
	Copy (/C)							
	Format (/F)							
	Import / Export of Data							
	Plots							
	Relative Cell Address							
	Sort (/A)							
	Spreadsheet Good Practice							

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Competency Matrix ECE 294

Entry State ■ Exit State

Concepts	Competencies	Before Knowledge	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation

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Competency Matrix MAE 443

Level of Learning

Before Class ■ After Class

Learning Outcomes	Competency Categories	Understanding		Thinking			
		Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Conceptual Design Phase	alternatives						
	appropriate models						
	constraints						
	the customer						
	measures of quality						
	required performance						
Embodiment Design Phase	appropriate models						
	the design						
	feasibility - performance						
	feasibility - constriants						
	feasibility - intra component consistency						
	product quality considerations						
	system optimization (not required for team grades of B or less)						

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Competency Matrix MAE 443

Level of Learning

Before Class ■ After Class

Learning Outcomes	Competency Categories	Understanding		Thinking			
		Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Teams	forming						
	norming						
	storming						
	performing						
	maintenance						
	roles						
Meetings	agendas						
	discussion tools						
	process checks						
Prcess Improvement	plan						
	do						
	check						
	act						
The Design Notebook	complete design section						
	design process documentation						
	task documentation						

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Competency Matrix MAE 443

Project / Evaluation Milestones - Affective Traits

Project Requirements	Requested Date	Completion Date
Oral Preliminary Design Review	2/14, 16	
Draft Design Proposal	2/25	
Design Proposal Signed (last day)	3/11	
Oral Feasibility Design Review	4/4, 6	
Design Feasibility Certificate Signed	4/18	
Written Final Design Report	5/5	
Oral Final Design Presentation	5/9, 10	

Learning Outcome or Comp etency Category	Completion Date	Completion Date
Meetings (Knowlwdge & Know-How)	3/4	
task documentation (Knowledge & Know - How)	3/11	
Conceptual Design	3/20	
omplete design section (Knowledge & Know - How)	3/25	
Teams (Knowlwdge & Know-How)	4/1	

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Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
	Analysis						
	Application						
	Character						
	Charting						
	Competencies						
Assessment	Competency Matrix						
	Evaluation						
	Know-How						
	Knowledge						
	Levels of Learning						
	Portfolio						
	Self Assessment						
	Synthesis						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Heat Exchanger	Baffle						
	Cmax						
	Cmin						
	Compact Heat						
	Condenser						
	Cross Flow						
	Effectiveness						
	Evaporator						
	Flow Area						
	Flow Arrangement						
	Fouling						
	Heat Exchanger						
	Heat Transfer Area						
	j Factor						

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Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Heat Exch (continued)	LMTD						
	Mass Flux (G)						
	NTU						
	Nusselt Number (Nu)						
	Number of Passes						
	Periodic Flow						
	qmax						
	Recuperator						
	Regenerator						
	Reynolds Number (Re)						
	Shell & Tube						
	Stanton Number (St)						
	Thermal Flux						
	Tube Sheet						
	Tube Vibration						
	UA Product						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Variables	Analysis						
	Context						
	Data						
	Degrees of Freedom						
	Dependent						
	Design						
	Environmental Parameter						
	Independent						
	Instantiate						
	Performance						
	Role Reversal						
	System Parameters						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Design	A Design						
	A Design Process						
	Concept Space						
	Constraints						
	Design Features						
	Design Space						
	Design Trees						
	Feasibility						
	Leaf Features						
	Levels of Abstraction						
	Quality						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
System	Air Liquefaction						
	Component						
	Component Block Diagram						
	Gas Turbine						
	Information Flow Diagram (IFD)						
	Liquid Networks						
	Thermal System						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Models & Modeling	Backward Chaining						
	Forward Chaining						
	Rate of Creation of Energy						
	Rate of Creation of Entropy						
	Rate of Creation of Mass						
	Rate of Inflow (Outflow) of Mechanical Energy						
	Rate of Inflow (Outflow) of Momentum						
	Rate of Inflow (Outflow) of Thermal Energy						
	Selection						
	Simulation						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Fluid Components	Bernoulli's Equation						
	Duct						
	Friction Factor (Darcey Weishback)						
	Friction Factor (Fanning)						
	Frictional Head Loss						
	Pipe						
	Pipe Fixture						
	Relative Roughness						
Mechanical Energy Components	Compressor						
	Compressor Model						
	Fan						
	Pump						
	Pump Model						
	Turbine						
	Turbine Model						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Fluid Properties	Models						
Design Teams	Division of Work						
Feasible Design Space	Design Space & Equality Constraints						
	Design Space & Inequality Constraints						
	Dimension						
	Inequality Design Variable Constraints						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
Numerical Methods	Bi-Quadratic Function						
	Equation Solvers (e.g., TK Solver)						
	Hybrid Solution Methods for Sets of Non-Linear Equations						
	Interpolation						
	Jacobian						
	Least Squares Curve Fit						
	Sequential Solution of Set of Non-Linear Equations						
	Simultaneous Solution of Sets of Non-Linear Equations (e.g., Newton-Raphson)						

Competency Matrix
MAE 446

Concepts	Competencies	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation
	Constrained Derivatives						
	Golden Section Search						
	Gradient Search						
	mini-max Strategy						
Optimization	Minimum						
	Multi-Variable Search						
	Objective Function						
	Pattern Search						
	Uni-Variable Search						

A Guide
to
Self Evaluation and Documentation of Educational States

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Self Evaluation and Documentation of Educational States

Evaluation

In today's work environment it is essential that you strive to improve processes, products and yourself. However, before you can make suggestions for improvements, you must know the current status of the processes, products and yourself. Evaluation allows you to know where to make improvements, where the weak areas are which need to be improved. When you graduate you will find that the self evaluation process presented in this guide will be as useful as the engineering science knowledge you have gained in your course work.

Your education is the end product of an educational process and it is important to know the status of this education (product). Traditionally the evaluation of the status of your education has been done by course instructors who assign a grade to indicate the **state** of your education. While it may be relatively easy to let instructors do this evaluation of your work (i.e., you do the assigned work, submit the work and wait to see what the instructor reports), in the long term you will need to be the person doing the evaluation. You cannot continually rely on someone else to tell you how you are doing; you must learn how to evaluate your own educational state so you can make the required improvements. You must take responsibility for your education.

Before describing a method that can be used in self evaluation and documentation of educational states, it is necessary to more fully define what is meant by educational states.

Educational States

How can educational states be defined or characterized? While there are many ways to do this one possible way is to characterize your educational state by the activities and actions of you and your teacher. Reflect back over your time in school; you should be able to recognize the gross changes which have taken place in your activities. Early on you learned facts and worked **simple** , single concept problems; towards the end you worked problems which combined many different concepts and skills.

In the early 1950's a group of educational psychologists considered the problem of defining educational and developed a taxonomy of educational objectives[1] . To quote from the Foreword of this work:

> It (the taxonomy) is intended to provide for classification of the goals of our educational system. It is expected to be of general help to all teachers, administrators, professionals specialists, and research workers who deal with curricular and evaluation problems. It is especially intended to help them discuss these problems with greater precision.

These psychologists divided the problem up into three behavioral domains: the **cognitive**, dealing with the *recall or recognition of knowledge and the development of intellectual abilities and skills*; the **affective**, dealing with *changes in interest, attitudes, and values, and the development of appreciation and adequate adjustment*; and the **psychomotor**, dealing with the *manipulative or motor-skill area.*.

The taxonomy (a handbook) published in the mid 50's dealt only with the cognitive domain (a second handbook dealing with the affective domain was published in 1964). The

1 *Taxonomy of Educational Objectives*, Bloom et al, 1956, Longmans, Green and Co.

taxonomy for the cognitive domain had six major categories. In order of increasing complexity they were: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. Each of these categories was characterized by a different set of abilities (behaviors) exhibited by a person operating in the category.

In the late 80's and early 90's David Langford, in attempting to implement an important aspect of the quality culture (empowerment) into the classroom, recognized that this taxonomy could be used by the students as well as the teachers to determine where they were relative to these various objectives. Thus Langford proposed having the students use these educational objectives to do self evaluation. Langford renamed the objectives Levels of Learning, changed the name of Comprehension to Know - How, and developed summaries of the types of activities a student and teacher would do when they, the students, were operating at these various Levels of Learning[2].

A modification to Langford's material on typical activities can be found in the first six pages of Appendix A. This material consists of answers to a set of six standard questions. The answers to the questions change as the Level of Learning changes. For example, the answer to the question of *How do I know I have reached this level?* is answered as, *I recall information*, at the Knowledge Level but is answered as, *I have the ability to put together parts and elements into a unified organization or whole which requires original, creative thinking*, at the Synthesis Level. Read these answers over carefully, paying especially close attention to the first two and last two questions for each of the levels.

As the psychologists pointed out in the 50's there is a bit more to defining an educational state than is covered by the Levels of Learning. The Levels of Learning concern only the cognitive domain of the educational state; they do not concern the affective domain, a domain which must also be assessed. Affective behavior is indicated by your willingness to take responsibility for your education, to put in the needed effort, to be interested in what is being learned, to help others. Myron Tribus in several essays[3] states that Character (which is in some ways a part of affective behavior) is one of the major categories of things which should be cultivated in a school or university.

The last page of the material in Appendix A addresses the affective or character issue. This material is no where near as complete as the Level of Learning material, containing only some general affective traits and a few self awareness questions.

The Self Evaluation Process

Two different process are used to evaluate your educational state: one for the cognitive domain and one for the affective domain.

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[2] *Total Quality Learning Handbook*, Langford Quality Education, 1992

[3] *Quality Management in Education*, and *Total Quality Management in Schools of Business and of Engineering*, Myron Tribus, Exergy, Inc., Hayward, CA

Cognitive Domain

For the cognitive domain the self evaluation process is reasonably simple:

1. compare your current abilities or activities to a set of Abilities or Activities Exemplars[4], exemplars defined by a hierarchy of learning,
2. pick out the Exemplar which best fit your current abilities or activities,
3. the selected Exemplar defines your current educational state.

For this class you are to use the activities defined for the various Levels of Learning in Appendix A as the Exemplars. For example, if you are in Statics working single concept problems located at the end of a Section, you would be at the Know-How Level of Learning for the current statics topic because what you are doing matches the type of activity a person at that Level of Learning would be doing. On the other hand, if you were writing reports on the design of a bridge you would probably be at the Synthesis Level of Learning for Statics because creation of evocative reports is an activity which is done by a person at that Level of Learning.

Affective Domain

It is much easier to be self aware of your cognitive abilities or states than it is to be aware of your affective state. It is difficult to be an expert in your own behavior. To help bridge this difficulty the following process is proposed:

1. Select a periodic timing sequence (e.g., each day, each week, each problem);
2. select a set of affective traits;
3. at the end of each timing sequence and for each selected affective trait ask your self whether you exhibited the characteristic during the previous time period.
4. If the answer for a particular trait is consistently yes then you are exhibiting that affective trait.

For example suppose you want to document your interest (an affective trait) in Statics. You decide to evaluate this trait once a week on Friday afternoon by asking yourself "how many times during this last week have I discussed Statics with someone not in Statics?". If the answer is consistently three or more then you could feel confident that you were showing interest in Statics.

Documentation of Educational States

While it may be possible for you to fairly and correctly evaluate your actual educational state with only internal (i.e., in your brain) evidence, that will not be acceptable for this class. In this class you must supply documentation that you have actually reached the educational states you are claiming. The documentation processes you are to use are modification of the processes suggested by Langford.

[4] Exemplar - that which serves as a pattern, especially an ideal pattern

Documentation Vehicles

The documentation process uses several different vehicles for recording and storing your work. You must understand what the each of these vehicles is used for and how you can generate and use them before you can effectively document the required documentation.

A Portfolio or Design Notebook

A portfolio is an organized collection of the personal technical work done in a class. It contains, in some logical sequence, all homework assignments, quizzes, tests, reports, projects, i.e., everything technical done during the semester. A student's portfolio becomes a collection of worked examples, examples the student can refer to in later classes (or when out of school) when he needs to review a topic done in the earlier class.

Physically, portfolios are three hole loose leaf binders although an accordion file can also be used. Non loose leaf binders are not too practical because it is not easy to remove or insert material. There are any number of ways to organize the work in the portfolio but two minimum requirements are that:

1. it must be possible to refer to any specific page or section (i.e., all pages must be uniquely numbered), and
2. if a reader opens the portfolio to a random location, it must be obvious which way she would go to get to a specified location (i.e., W follows M or 12 comes before 34).

These two requirements can generally be met by numbering all pages with some type of hierarchical page numbering scheme (e.g., II.2 is page two of section II which comes before section III and after section I).

A design notebook is a special type of portfolio, one containing all the technical work related to a design project. Since design projects are often done by teams the design notebook will include work from a variety of people.

All the technical work in the portfolio/notebook is expected to adhere to accepted standards for documentation of technical work (e.g., see *Documentation of Technical Work - The Process and the Product* by McNeill).

Reflection Log

The work contained in your portfolio documents all the activities you have undertaken during the semester. Some of these activities reflect Know-How, some reflect Evaluation. As previously mentioned, traditionally it was the course instructor's task to decide what Level of Learning the work reflected; however, in the self analysis mode, this task of matching work to Levels of Learning is to be done by you. You must reflect on the technical work you have done, analyzing it to determine what Level of Learning is documented (demonstrated) by the material.

Once you've completed this reflection you must write a paragraph (or more) explaining the reasons why some set of your technical work shows you are functioning at a claimed Level of Learning. This phase of the documentation is done using a Reflection Log (see Appendix B for a sample log).

The log need not look like the one shown in Appendix B but it must contain the same information. The log must have an identifying entry number; it must be clear which competency category (see the next section on the Competency Matrix) and Level of

Learning are being addressed; it must be clear where the technical work being discussed is located; and finally the log must contain the paragraphs of reflection. You will generally find that the reflection for the higher Levels of Learning requires more space than is given on the form, in which case you can append the necessary additional pages to the log entry.

Physically the log must follow the Competency Matrix.

Competency Matrix

In any class the instructor has a set of knowledge and skills (e.g., Engineering Design Process, Second Order Differential Equations, First Law of Thermodynamics, Teaming, etc.) which she wants to have the class learn. This set of knowledge and skills are know as the *learning outcomes* for the class. Learning outcomes are rather abstract and must be characterized by (i.e., defined in terms of) a number of more specific topics called *competency categories*. Depending on how specific the competency categories are, it may be possible (desirable) to further divide these competency categories.

However it is not enough to just define the learning outcomes and competency categories, the instructor must also decide what Level of Learning the students should reach for each of these items. This crazy quilt of things to be learned and the levels they are to be learned to can be organized and presented in a Competency Matrix.

The general design of the matrix is quite simple. Along the left side of the matrix are the general course Learning Outcomes along with each Outcomes' more specific Competency Categories (and Sub-categories if they exist). Along the top of the matrix are the various Levels of Learning. Each cell in the matrix represents the intersection of a particular competency category or learning outcome and a particular Level of Learning. The Competency Matrix for this class is in Appendix B.

In looking at your Competency Matrix you will see black areas, gray areas, and white areas. The black areas reflect the Levels of Learning you are assumed to have reached when you start the class. The gray areas are the Levels of Learning that you are expected to achieve during the course of the semester. The white areas represent Levels of Learning which you may achieve but which are not ones explicitly desired to be achieved in the class.

As a vehicle for documenting your educational state you will find that the matrix serves two purposes.

1. It shows the Levels of Learning you have achieved in each of the course's competency categories, and
2. it shows where there is documentation that you have in fact mastered the competency category at the Level of Learning shown.

At the start of a semester, except for the black areas, your matrix is blank. During the semester you will make entries in each of the gray (and perhaps white) boxes in the matrix. These entries are pointers to the reflective discussion of the technical work which you feel supports your claim of being able to operate at some Level of Learning. What is actually put in these boxes will be explained in the next section.

The Competency Matrix belongs in the front of the portfolio followed by the Reflection Logs, Work Logs, and Run Charts. If you are using a design notebook all of this evaluation material (i.e., the matrix, logs, and run charts) belongs in a separate loose leaf binder called the Evaluation Notebook.

Work Logs

Work logs as the name implies, keep track of the work you have done. A sample, empty log, is shown in Appendix B. The log contains factual information related to your work. The log tells you when the work was done, how much time you spent on the work, where the work is located, and finally a very brief description of the work.

Work logs are generally found just behind the Reflection Logs in your Evaluation Notebook.

Run Charts

It is often necessary to keep track of a quantity whose value changes with time; it is also often necessary to keep track of the time averaged value of this quantity . The time averaged value is known as the running average for the quantity. While this data can be logged in tables, trends are hard to see in tables and, thus, this data is generally also shown on a graph. Such graphs are called Run Charts.

A sample Run Chart for class attendance is shown in Appendix B. The chart shows time along the horizontal axis (i.e., class number) and the value of attendance along the vertical axes (yes = 1, no = 0). The data for each class is shown by the height of the bar while the running average is shown by the line. In the example shown the person missed class on the 3rd, 5th, and 11th day (bar has zero height). For the third class the running average dropped from 1 (perfect attendance) to 0.67 (attendance for two of three classes). The running average drops for each class not attended and slowly rises when classes are attended. You can see that the running average after twenty classes is about .86.

The Documentation Process - Cognitive Domain

The basic documentation process is a three step process. However, once you get the feel for this basic process you will most likely want to consider adding a fourth step (step 0) which is discussed at the end of this section.

the basic process

The following three steps should be completed for each class assignment.

step 1

Read the assigned problem and decide what work must be done. Work the problem. Be sure to follow accepted standards for the documentation of technical work, (i.e., explain the process you followed or used, show the results of following the process, and discuss the results of the process). Once the work is done and documented, place the work in an appropriate location in the portfolio or design notebook.

step 2

Reflect on the work just completed:

a) decide what course competency categories are involved in the work (look at the matrix to see the list of competency categories), and

b) decide what Levels of Learning have been demonstrated (documented) in the work.

Once this reflection is complete, go to your Reflection Log and make a new entry or entries for the work you just entered into your portfolio. You must make separate log entries for each competency category / Level of Learning pair (i.e., for each box in the Competency Matrix). The one exception is when a piece of work covers a number of competency categories, all at the same Level of Learning in which case you may use a single log entry for all the categories. **You may never use a single log entry when different Levels of Learning are being claimed, even when there is only one competency category.**

step 3

Every competency category / Level of Learning pair in the Reflection Log corresponds to a box in the Competency Matrix. Starting with the first new log entry enter its Log Entry Number in the appropriate Competency Matrix box. Repeat this process until all of the new Reflection Log entries you just made in step 2 have been processed (i.e., logged in on the matrix).

a sample

For example, suppose you have been assigned to work problem 2.2 in Statics, which involves determining an unknown force acting on a simple beam. You work the problem (including all required documentation) and put it in your Design Notebook at pages 2.5-2.6. Upon reflection you decide that the work shows that you have Know-How in the competency categories of *free body diagrams* and *equilibrium.* You go to your Reflection Log and find that the next entry will be number 12 and so you fill out the log (Log Entry Number: *12*; Competency Category(s): *free body diagram, equilibrium*; Level of Learning: *Know How*; Location in Design Notebook: *pages 2.5 & 2.6*; Reflection: *Problem 2.2 requested a free body diagram and told me to use the idea of equilibrium of forces to determine the unknown force. Since the problem pretty much told me what to do and I was able to do it this is evidence of Know-How but not Application L of L.* The documentation process is finished by going to your Competency Matrix and putting 12 (the log entry number) in the box for (free body diagram,Know-How) and (equilibrium,Know-How).

an enhanced documentation process

As mentioned at the beginning of this section there is probably a fourth, initial, step which you will want to add to this process once you begin to see how the basic process works.

As currently proposed the documentation process has you work the problem before reflecting on what Levels of Learning have been demonstrated. Would it not make sense to think about the Levels of Learning before actually doing the work? If you did this wouldn't you produce technical work which more clearly showed evidence of the Level of Learning claimed? If the answers to these questions are yes then you will want to add Step 0 to your process.

step 0

Read the problem and look at your Competency Matrix. Based on the problem and on what competency categories have not yet been addressed in the matrix (i.e., which gray boxes are still empty) decide what competency category / Level of Learning pairs could be addressed by the problem. Before going to Step 1 consider how you can best show the Levels of Learning you are hoping to demonstrate with the completion of the assignment.

The Documentation Process - Affective Domain

You can document your affective traits as follows:

step 1

For each assignment or class related outside of class activity make an entry in your Work Log.

step 2

At the start of each class notes down (yes or no) whether you were on time, were at class, had done the assigned reading, and had done the assigned homework.

step 3

Each Sunday evening, using the data collected at the start of each class and the data in your Work Log update the following Run Charts:

1. Class Attendance
2. On Time to Class
3. Class Preparation (Reading)
4. Class Assignments
5. Average Hours per Week Outside of Class Spent on Class

When Can You Claim Mastery?

How many problems do you have to work to show you are at the Analysis Level of Learning; how many for Know-How? What value for the running averages on the Run Charts shows you consistently demonstrate the affective trait? When can you claim mastery?

The question of mastery has not been addressed up to this point but it is an important element in this evaluation process. Mastery means that not only have you reached an educational state for some competency category but that you will be able to operate at this level indefinitely (i.e., you will not slip back to some lower level). Mastery at the Application Level of Learning for Differential Calculus means that you routinely recognize when Differential Calculus is required in solving problems.

Mastery does not mean that you have instant recall or the ability to instantly solve the problem at the Level of Learning claimed. No one has everything they have mastered available instantaneously. Mastery does mean that you can, relatively easily, retrieve the necessary information (e.g., from your Portfolio) to solve the problem at the specified Level of Learning.

Further, mastery does not mean that you must be aware of what you are doing. Mr. House of Hewlett Packard Co. has suggested that as you gain mastery of a skill or subject area you pass through four stages of awareness: unconscious incompetent (you don't know that you don't know), conscious incompetent (you know that you don't know), conscious competent (you know that you know), and unconscious competent (you don't know that you know). You would like to get to the fourth state (i.e., be able to solve problems without thinking about how you are solving problems) but the third state is perfectly acceptable.

There is no pat or definitive answer to the questions posed in the first paragraph. In fact the answer generally changes from subject to subject. For this class the table below shows how many problems must be worked to *demonstrate* mastery.

Mastery Minimums

Educational State	Mastery Minimum Requirements
Knowledge	100 % correct on a quiz of at least three questions
Know-How	one example
Application	three examples
Analysis	two examples which between them cover all the competency areas covered by the Learning Outcome
Synthesis	same as Analysis
Evaluation	same as Analysis
Run Charts (except for hours per week)	the running average should be at or above 0.9
Run Chart (hours per week)	the running average should be at or above nine hours

If these minimums are followed then your matrix will show mastery of a category when the matrix box has one log entry for Knowledge, or Know-How; two log entries for Analysis, Synthesis, and Evaluation; three log entries for Application and your Run Charts show your running averages to be at or above 0.9 (9 hours for work per week).

Acknowledgments

The material presented in the Guide is a compilation of the thoughts and experiences of Drs. Lynn Bellamy, Don Evans, Mark Henderson, Darwyn Linder, Barry McNeill, Jack Pfster and Greg Raupp as they attempted to utilize the idea of a competency matrix in the evaluation of student performance in their classes during the last year and a half.

APPENDIX A
Activities at Various Levels of Learning
and
Affective Domain Traits

Printed May 12, 1994

APPENDIX B
Competency Matrix, Reflection Log, Work Log, and Run Charts

Printed May 12, 1994

Competency Matrix
XXX YYY

Level of Learning

Before Class ▮ After Class

		Understanding		Thinking			
Learning Outcomes	Competency Categories	Knowledge	Know-How	Application	Analysis	Synthesis	Evaluation

Reflection Log
XXX YYY

Log Entry Number:
Competency Category(s):
Level of Learning Claimed:
Location in Portfolio or Design Notebook of Supporting Work:
Reflection

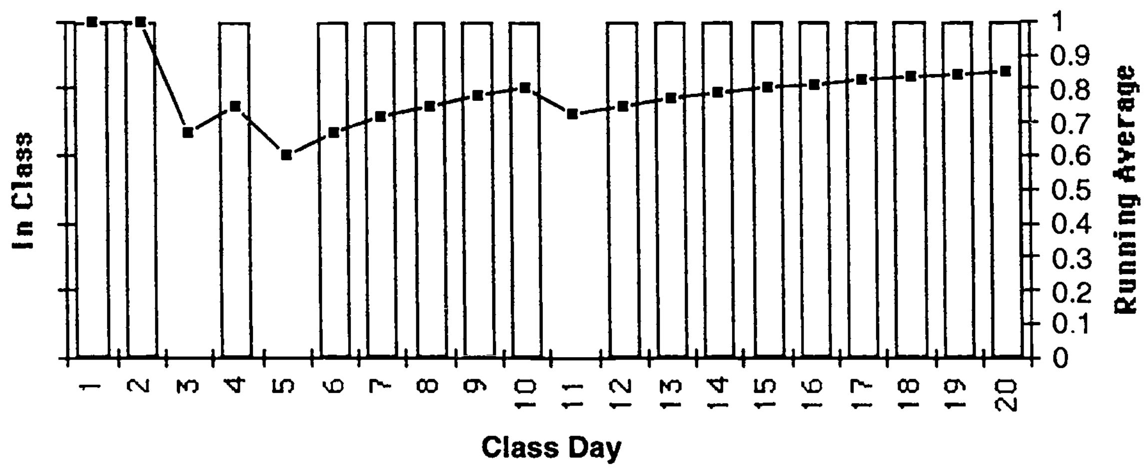
Log Entry Number:
Competency Category(s):
Level of Learning Claimed:
Location in Portfolio or Design Notebook of Supporting Work:
Reflection

Work Log
XXX YYY

Work Number	Name	Date	Time Spent (decimal hours)	Design Notebook Location:	Description of Work Task

Sample Run Chart
XXX YYY

Class Attendance



An Alternative Way to Fill Out Matrix

A number of you seem to be having difficulty in adding the discussion which explains why a certain piece of work documents some level of learning -- it does not seem to be a natural piece of the work. With this in mind let me suggest an alternative method of filling out the matrix.

step 1

Read the problem and decide what competency areas could be addressed by the problem and determine what level of learning is possible. Work the problem in a manner which shows you have mastered the competency area(s) at the level decided upon. Be sure to completely document the work, i.e., explain the process you followed, show the results of following the process, and discuss the results of the process (all three parts are required). Once the work is done and documented place it at some appropriate location in your portfolio.

step 2

Go to your list of work, a set of blank pages located just behind your matrix, and add an entry to this list of work, using the next consecutive number. The entry must include the following:

a) name of assignment just completed
b) page number in portfolio where assignment can be found
c) competency area(s) addressed along with level of learning claimed
d) a paragraph explaining why the work is proof of achieving the level of learning claimed

step 3

On you matrix, at the appropriate location(s) (competency area and level of learning) put the list number you used in step 2.

For example, if you did some work which you felt proved Know-How for j, you would put the work in your portfolio (say at page 45). Next you would update your list of work by adding a new entry. If the last entry were item 32 then this new entry would be item 33. You would enter in the required information and then go to the matrix and enter in 33 at all the places you have claimed by the work.

This indirect indexing scheme has the advantage of removing the discussion of why the work proves a certain level of learning from the work and concentrating all this material just behind the matrix.

If you remove an item from the list of work just remove it and its number; there is no need to change any of the following numbers.

Lesson Planner
MAE 443

Date: Learning Topic: Course Mechanics Learning Session Length (minutes): 25 min.

Learning Objective(s):	
Knowledge Level Material	course mechanics and schedule, teaming, process improvement, weekly design review meetings, project milestones, groups (all, a, b, any), code of cooperation
Know-How Level Material	
Application Level Material	
Analysis / Synthesis Level Material	
Evaluation Level Material	
Affective Objectives	interest in class
Classroom Organization & Equipment	
Table Arrangement	all tables facing forward
Audio - Visual Equipment:	overhead
Computer Equipment	none
Other Class Room Equipment	course syllabus and documentation material, code of cooperation
Classroom Management	
Learning Group Size	entire class
Learning Delivery Method	lecture and question
Discussion Tool(s)	

After Class Reflection
This seemed to go ok. The timing was fine. There not really a lot that makes much sense here. The class needs to take the material and read it and then ask quesitons. I forgot to put the required book on the handout material.

Lesson Planner
MAE 443

Date: Learning Topic: Course Evaluation Learning Session Length (minutes): 60 min

Learning Objective(s):	
Knowledge Level Material	levels of learning
Know-How Level Material	
Application Level Material	
Analysis / Synthesis Level Material	
Evaluation Level Material	
Affective Objectives	appreciate the evaluation exemplars
Classroom Organization & Equipment	
Table Arrangement	tables for groups of about 6
Audio - Visual Equipment:	overhead
Computer Equipment	none
Other Class Room Equipment	guide to self evaluation
Classroom Management	
Learning Group Size	6 expert groups of about 6 (maybe 7) with 6 learning groups of about 6 or 7
Learning Delivery Method	Jigsaw
Discussion Tool(s)	

After Class Reflection
All the groups seemed to keep working. There was little varying off task. This means we had the exercise timed out fairly well. I am not sure how well it worked in getting them to have a better understanding of the levels Do suggested that we use an example which they are more familar with, for example have them work with a learning outcome of driving and a category of shifting gears or maybe braking. They might be able to come up with examples of activites which relect the various levels of learning for this category where as they seem to have some difficulty with the dynamics suggestion. Need to make sure they focus on the actvity which shows the level of learning, i.e., for the example they are working with what activity would show the various levels.

Lesson Planner
MAE 443

Date:	Learning Topic: Project Selection Criteria — Learning Session Length (minutes): 60 min
Learning Objective(s):	
Knowledge Level Material	comparison matrix, criterion, NGT
Know-How Level Material	set relative weights, reduce number of options
Application Level Material	
Analysis / Synthesis Level Material	
Evaluation Level Material	
Affective Objectives	interest in group values of what makes projects interesting
Classroom Organization & Equipment	
Table Arrangement	tables for groups of 4 or 5
Audio - Visual Equipment:	overhead
Computer Equipment	none
Other Class Room Equipment	large sheets of paper, colored dots
Classroom Management	
Learning Group Size	groups of 4 and 5
Learning Delivery Method	group practice
Discussion Tool(s)	NGT, comparison matrix

After Class Reflection

The class did not have a good sense of what the criteria were. Many groups generated criteria which were more constriant based, e.g., sports flavor or thermal system or automobile. We did not do an adequate job of showing them the types of criteia which would be useful (interesting, which would include these specific sorts of things). I think we should probaly work out a very simepl example. They did not seem to be able to come up with generic criteria which could be used to evaluate a number of projects. Maybe if we asked them what type of project they would like and then had them generate criteria to evaluate projects which either all passed or all failed there go no-go switch. Need to get them focused on the idea of selection among acceptable alternatives, what is important when the most importar feature (i.e., project type) is ok.

AGENDA PLANNER

Time Block (minutes) From To Duration	Details
Topic	
Participants	
Purpose Cognitive Goals	
Affective Goals	
Discussion Tools or Activity	
Required Reading or Preparation	
Visual/Audio /Other Aids/Equipment	

Meeting Date

Meeting Location

Team Leader

Team Recorder

Team Facilitator

Team Time Keeper

Team Devil's Advocate

revised 3/7/94

McNeill

Knowledge (Information)

Process verbs:

define	memorize	record
label	name	relate
list	read	repeat
listen	recall	view

How do I know I have reached this level?
I recall information? I bring to mind the appropriate material at the appropriate time? I have been exposed to the information and I can respond to questions, tasks, etc.

What do I do at this level?
I read material, listen to lectures, watch videos, take notes and I am able to pass a test of knowledge on the subject area. I learn the vocabulary of the competency area, i.e., the terminology. I learn the conventions used.

How will the teacher know I am at this level?
The teacher will provide opportunities (either orally or in written tests), regardless of complexity, that can be answered through simple recall of previously learned material.

What does the teacher do at this level?
The teacher directs, tells, shows, identifies, examines the information necessary at this level.

What are typical ways I can demonstrate my knowledge?
1. Define technical terms by giving their attributes, properties or relations.
2. Recall the major facts about a particular subject.
3. List the characteristic ways of treating and presenting ideas (i.e., list conventions associated with the subject).
4. Name the classes, sets, divisions, and arrangements which are regarded as fundamental for a given subject field or problem.
5. List the criteria used to judge facts, principles, and ideas.
6. Describe the method(s) of inquiry or techniques and procedures used in a particular field of study.
7. List the relevant principles and generalizations.
8. Fill in the blank.

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

Comprehension / Understanding

Process verbs:			
describe	identify	report	tell
explain	locate	restate	work
express	recognize	review	

How do I know I have reached this level?
I comprehend and understand what is being communicated and make use of the ideas but without relating them to other ideas or material. I may not yet understand the fullest meaning. I understand what others are discussing concerning this idea. This level requires Knowledge.

What do I do at this level?
I successfully work assignments in which the appropriate approach is evident either because of material in the problem statement or because of the problem's relative location in the book to the appropriate method. I translate information into my own words (translation from one level of abstraction to another. I translate symbolic information (e.g., tables, commas, diagrams, graphs, mathematical formulas, etc.) into verbal forms, and vice versa. I interpret or summarize communications (written/graphical/oral). I determine implications, consequences, corollaries , effects, etc. which are extensions of trends or tendencies beyond the given data.

How will the teacher know I am at this level?
The teacher will often ask questions or give tests that can be answered by merely restating or reorganizing material in a rather literal (clearly stating the facts or primary meaning of the material) manner to show that I understand the essential meaning, e.g., give the ideas in your own words.

What does the teacher do at this level?
The teacher demonstrates, works problems, listens, questions, compares, contrasts, and examines the information and your knowledge of it.

What are typical ways I can demonstrate or can show on my own my comprehension and understanding.
1. Read Comprehension level problems, know what is being asked for, and successfully work the problems.
2. Clearly chronicle the process used in working the problem.
3. Clearly describe the results of working the problem.
4. Draw conclusions (interpret trends) from the results of solving the problem.
5. Compare/contrast two different problems (i.e., what things are the same? / what things are different?)
6. Restate and idea, theory, or principle in your own words.

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

Application (Thinking)

Process verbs:		
apply	illustrate	practice
demonstrate	interpret	recognize
employ	operate	

How do I know I have reached this level?

I have the ability to recognize the need to use an idea, method, concept, principle, or theory without being told to use it, i.e., I have the ability to use ideas, methods, concepts, principles and theories in new situations. I know and comprehend the information and can apply it to a new situation. I also have the ability to recognize when a certain task, project, theory or concept is beyond my current competency. Application requires having Knowledge and Comprehension.

What do I do at this level?

I work problems for which the solution method is not immediately evident or obvious. I take knowledge that has been learned at the Knowledge and Comprehension levels of learning and apply it to new situation. I solve problems on my own and make use of other techniques. This requires not only knowing and comprehending information, but deep thinking about the usefulness of this information and how it can be used to solve new problems that I create or identify.

How will the teacher know I am at this level?

I will show the teacher through my work that I am involved in problem solving in new situations with minimal identification or prompting of the appropriate rules, principles, or concepts by the teacher. The teacher will be able to ask general questions like, How much protection from the sun is enough? and I will know how to attack the problem.

What are the typical ways I can demonstrate or show, on my own, my application of Knowledge and Comprehension?

1. Solve problems which require recognition of the appropriate concepts, theories, solution techniques, etc.
2. Apply the laws of mathematics, chemistry, physics, and engineering to practical situations.
3. Work *project type* problems.

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

Analysis (Thinking)

Process verbs:

break apart	examine
break down	explain

<u>How do I know I have reached this level?</u>

I can explain *why*. I can examine, methodically, ideas, concepts, writing etc. and separate into parts or basic principles. I have the ability to break down information into component parts in order to make organization of the whole clear. Work at this level requires having Knowledge and Comprehension levels of learning (application is not required).

<u>What do I do at this level?</u>

I analyze results by breaking concepts, ideas, theories, equations, etc. apart. I can explain the logical interconnections of the parts and can develop detailed cause and effect chains.

<u>What does the teacher do at this level?</u>

The teacher probes, guides, observes, and acts as a resource.

<u>What are typical questions I can pose for myself to answer which will demonstrate or show my Analysis level of learning?</u>

1. Why did this (result) happen?
2. What reasons does she give for her conclusions?
3. Does the evidence given support the hypothesis, the conclusion?
4. Are the conclusions supported by facts, opinions, or analysis of the results?
5. What are the causal relationships between the results for the whole and the parts?
6. What are the unstated assumptions?

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

Synthesis (Thinking)

Process verbs:			
arrange	construct	manage	propose
assemble	create	organize	set up
collect	design	plan	write
compose	formulate	prepare	

<u>How do I know I have reached this level?</u>
I have the ability to put together parts and elements into a unified organization or whole which requires original, creative thinking. I recognize new problems and develop new tools to solve them. I create my own plans, models, and/or hypotheses for finding solutions to problems. This level of learning requires Knowledge, Comprehension, Application and Analysis levels of learning.

<u>What do I do at this level?</u>
put ideas together to create something. This could be a physical object, a process, a design method, a communication, or even a set of abstract relations (i.e., mathematical models). I produce reports, (written/oral) which create a desired effect (e.g., information acquisition, acceptance of a point of view, continued support, etc.) in the reader (listener). I generate project plans, I propose designs, I formulate hypotheses based on the analysis of pertinent factors. I am able to generalize from a set of axioms, principles.

<u>How will the teacher know I am at this level?</u>
I show that I can combine ideas into a statement, plan, product, etc., that is new for me; e.g., I can develop a program that includes the best parts of each of those ideas

<u>What does the teacher do as this level?</u>
The teacher reflects, extends, analyses, and evaluates.

<u>What are the typical questions I can answer which will demonstrate or show my Synthesis?</u>
1. Can I create a project plan?
2. Can I develop a model?
3. Can I propose a design?

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

Appreciation / Evaluation (Wisdom)

Process verbs:	
appraise	judge
choose	predict (quality)
compare	rate value
estimate (quality)	select
evaluate	

How do I know I have reached this level?

I have the ability to judge and appreciate the value of ideas, procedures and methods using appropriate criteria. To work at this level requires having achieved Knowledge, Comprehension, Application, Analysis and Synthesis levels of learning.

What do I do at this level?

I make value judgments based on certain considerations such as usefulness, effectiveness, and so on. Based on information gained through application, analysis ,and synthesis I can rationally select a process, a method, a model, a design, etc. from among a set of possible processes, methods, models, designs, etc. I evaluate competing plans of action before actually starting the planned work. I evaluate work based on internal standards of consistency, logical accuracy and the absence of internal flaws (e.g., I can certify if design feasibility has been demonstrated in a report). I evaluate work based on external standards of efficiency, cost, utility to meet particular ends (e.g., I can certify that design quality has been demonstrated in a report).

How will the teacher know I am at this level?

I can demonstrate that I can make a judgment about something using some criteria or standard for making the judgment.

What does the teacher do at this level?

The teacher clarifies, accepts, harmonizes, aligns, and guides.

What are typical statements and questions I can respond to which will demonstrate or show my appreciation/evaluation?

1. I can evaluate an idea in terms of ...
2. For what reasons do I favor...
3. Which policy do I think would result in the greatest good for the greatest number?
4. Which of these models i.e., modeling approaches is the best for my current needs. How does this report show that the design is feasible? How does this report show the quality of the design?

Modifications by B. McNeill of David Langford's definitions of Levels of Learning in *Total Quality Learning Handbook*, Langford Quality Education and B. Bloom et al. *Taxonomy of Educational Objectives*, Longmans, Green and Co. 1956.

Affective (Character) Traits

What are some affective traits?

Ability to work alone	Curiosity	Interest
Ability to work in teams	Honesty	Self Esteem
Attention	Initiative	Truthfulness
Cooperativeness	Integrity	

What questions can I ask myself to determine if I am exhibiting these characteristics?

1. Do I come to class (meetings) prepared?
2. Do I come to class (meetings) on time?
3. Do I seek out material on a subject beyond what is suggested by the instructor?
4. Do I admit when I do not know something?
5. Do I talk about class subjects with my friends during informal gatherings.
6. Do I help others when they are having difficulties?
7. Do I invest the time expected working on the class (meetings)?
8. Do I do the work I say I will do and have it done when I say I will have it done?
9. Do I know I can solve problems?

Documentation of Technical Work - The Process and the Product

printed May 12, 1994

DocumentationThe material presented here has been developed over the last seventeen years at Arizona State University in the cou

The goal of any documentation effort is to present the work that has been done in a form that makes it clearly understandable to other people. As an engineer, you spend many hours growing the design. Concepts are developed and compared, models are created and run, information is sought out from various resources, etc. All of this work needs to be recorded in a way that will permit you, or any technically competent person, to recreate the process that was followed or understand why the design is as it is. You will want to document both the process as well as the product (i.e., the design).

Without adequate documentation it is difficult to:

1. make the design,
2. convince other people that the design is worthwhile or will work,
3. explain what it is you plan or hope to do,
4. recreate the design process used when it is necessary to determine why the design does not work,
5. use a successful design process as the starting point for a new design,
6. have someone else pickup and continue the project.

Documentation, as a task, consumes much of an engineer's time. Documentation is not limited to design drawings but also includes written work, graphical work, computer codes, and oral presentations, as well as much of the effort spent on model development. While each of these areas requires its own special approach, the common thread is the desire to present the information in a form that is understandable to the reader.

After a brief discussion of the differences between engineering and classroom documentation needs, this material discusses general documentation requirements, then addresses the documentation needs of modeling and finishes with some material related to preparing reports. The material should provide you with some general attitudes and strategies as well as some specific methods you can use. While there are no universally agreed-upon "correct" formats for documentation, the formats suggested here can be used as starting points and are acceptable for the work done in your design courses.

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[1] The material presented here has been developed over the last seventeen years at Arizona State University in the course of teaching senior capstone classes, MAE 443, thermal system classes, MAE 446, the principles of design classes, MAE 441, and the introduction to engineering class, ECE 106. The ideas and formats are a blend of the opinions and thoughts of the class faculty which include Drs. Neil Cooperrider, Bob Fries, David Laananen, Mark Henderson, E. Dan Hirleman, Barry McNeill, Jami Shah, Joe Davidson, Jim Blechschmidt, and Don Evans.

Engineering vs. Homework Documentation

It is not as if you have had no experience in documenting your work. During your years in high school and the engineering program you have *learned* how to document (i.e., write up) homework problems and by the time you graduate you will have become quite proficient at homework documentation. Unfortunately, what you will soon discover after graduation is that the documentation effort which was adequate for homework problems is seldom adequate for engineering work. There are several reasons why more extensive documentation is needed for engineering problems.

First, work and school environments are significantly different, particularly in terms of what information is known and need not be stated and what information is not known and must be stated. For example, in homework problems most of the information contained in the problem itself (i.e., Problem Definition sort of material) need not be explicitly stated as part of the homework write up. Your instructor knows what problems she has assigned. Even material related to the method of modeling would generally not appear in your homework write up; the method is assumed to be some derivative of the material presented in the text or given in class. In an engineering work environment, however, you rarely have this built-in pre-knowledge about the problem and, unless it is provided in the documentation, it remains unknown to the reader.

Second, the reasons for doing the work differ significantly in the two environments. In school the reason for doing the work is implicitly clear and need not be addressed, i.e., the reason for the work is to demonstrate the expertise needed to solve the problem. In an engineering environment the reasons for doing the work may or may not be clear. What is obvious to you may not be obvious to the reader. Unless you provide this information (i.e., context) in the documentation, the reasons for doing the work are lost.

Finally, for homework problems there are generally no consequences or follow-up work required once an answer has been determined. The answer is boxed and turned in; just doing the problem is the end unto itself. This is clearly not the case for in an engineering environment. Merely doing the task is not sufficient unto itself. The results you obtain influence what you do next and this must be covered (explained) in the documentation.

The sooner you recognize the differences between adequate homework documentation and adequate engineering problem documentation, the sooner you will start documenting your engineering design work well.

Technical Work - General Comments

Any work that is undertaken as part of the design process is classified as technical work. Work related to Problem Definition, Conceptual Design, "research", as well as Model Development and Use, all fall under the category of technical work. Buried, but hopefully not hidden, in this mass of technical work are the reasons why the design developed as it did. If the documentation effort is successful, then these reasons will not be hidden. This Section discusses general traits of good documentation and then addresses a number of specific documentation requirements.

traits of good documentation

While specific methods of documentation vary depending on what sort of task you are documenting, there are some general, philosophical guidelines, which can help you achieve good documentation. When documenting your work, you should strive to do the following:

1. impart a sense of organization
   You should clearly show how the current work is related to the other tasks that are being or will be done; this ties the work together. You should strive to make it very clear where information comes from and where the reader can find information about other related tasks. It should be possible to quickly locate any desired task or piece of information contained within a task. For extensive work the use of page numbers and table and plot numbers helps add to an overall sense of organization.
2. explain what is going on
   You should attempt to let the reader know, at all times, what is going on. This means explaining what is being attempted, why it is being attempted, and what method is going to be used. This also means that at the conclusion of a task you explain what you are going to do next as a consequence of the work just completed.
3. make it readable
   Anything you can do to make the work easier to read will help improve the documentation. Imparting a sense of organization and explaining what is going on are two ways to improve readability. Other traits include doing neat work, having clean sketches, having the material bound so that it does not fall apart and yet is easy to access, etc.
4. make it clear whose work it is
   It should always be clear who did the work and when the work was done. This is usually done by dating and initialing each sheet of work done.

You need to strive to incorporate all of the above guidelines into your documentation effort; failure to include one of the characteristics reduces your chance of having adequate documentation.

graphical material presentation

Much information is contained in pictures and hence your work will contain significant amounts of graphic information. This graphic material is generally either pictures of the design or plots showing the relationship between a performance variable and one or more design variables. Because pictures concisely contain so much information, i.e., pictures capture the essence of the material, graphic material is frequently copied and distributed, often without the accompanying text. Since this practice is so ubiquitous, it is critical, when preparing graphic material, that you

1. add enough annotation to the material that the picture makes sense standing alone,
2. make the pictures with pencils or pens on paper that permits the making of good looking copies.

The first of these items means you put titles and labels on all your graphic material while the second item means that you do not put your drawings on green grid graph paper using a number 3 pencil.

There are some *standards* for the presentation of plots that you should be aware of.

1. Both axes must be labeled, including units when appropriate.
2. The plot must have a descriptive title
3. The dependent variable is always plotted on the vertical (y) axis.
4. A concise legend must be added if the plot has more than one independent variable.
5. Data points used in generating the plot are generally shown.
6. Smooth curves are generally drawn through or near the data points to show the trend.

The above standards are true for any plot, whether it is hand or computer drawn. You may find that computer drawn plots do not meet some of these annotation standards. In such cases it is entirely permissible to add the annotation after the plot has been generated. Whether you choose to add it by hand or with a typewriter or transfers depends on who is likely to see the work. The greater the chance that the work, or more likely a copy of the work, will be viewed by your supervisor or someone higher than your supervisor, the nicer you want the plot to look.

Technical Work - The Modeling Tasks

While the complete collection of technical work covers a number of different tasks, much of the technical work is concerned with developing and using models. Not only do the general requirements listed above apply to modeling, but there are some additional or more specific documentation requirements. The next three sections address the additional documentation needs for model development, computer models, and model use.

who is the reader?

How you document your technical work is heavily influenced by who is expected to be the reader. For these modeling tasks there are two potential readers and you must aim for the lowest common denominator when preparing the documentation. The primary reader will be you. You will need and want to refer to what you have done. The second reader will be a technically competent peer who may be expected to review the technical merits of the work or even be asked to take up the project and continue on from where you have stopped.

documentation goals for analytical model development

Model development work covers all aspects of assembling the set of equations which can be used to predict the performance of the design. The documentation of this task, i.e., the way you present the work, comes very close to how you have been doing homework preparation. After reading the model development material, if the material is well documented, the reader will have a sense that the work is complete and correct. This sense can be generated, if during the development, you are careful to:

1. Define the Model Limitations,
2. Define the Model Variables,
3. Establish the Correctness of the Model.

The first two items are requirements you've addressed in every homework assignment you've ever had. You are continually reminded to list all assumptions and to show all your variables on a sketch. There should never be a question as to what a model variable represents. Defining the modeling variables includes defining the units associated with the variable.

The third item is one that is often not explicitly part of your homework documentation. The correctness of the modeling method is generally implied and no real effort is needed to prove this. This is not the case for model development. As part of an engineering task you will need to impart a sense of correctness. There are several things you can do to demonstrate model correctness ranging from citing references, starting from a set of fundamental principles and logically developing the model, running a test case for which the answer is known, to proving that the assumptions used are reasonable. You may do all of these things. It is up to you to make sure that the reader comes away with a sense that the model and modeling method are correct. If you fail to do this, the reader will have grave doubts about the correctness of any decisions related to the use of the model.

documentation goals for computer models

The above discussion applies to any model that is developed, independent of the method or tools used in running the model. When developing computer models there are yet some additional documentation requirements which help assure that the computer model is understandable and correct.

<u>high level languages</u>

If the model is developed using a high level language such as FORTRAN or C, the computer code must include comments and a variable dictionary. A listing of the program must be included with the work. The listing should be in an appendix like location and should be easy to read (i.e., not bound into the documentation in such a manner as to make reading impossible). Any model which exceeds several hundred lines of code should be broken up into a set of smaller subroutines or procedures.

<u>formula solvers</u>

If the model is developed using a formula solving program such as TK!SOLVER[2] then the documentation must include a completed Variable Sheet[3] including the Units and Comments Columns. The Variable Sheet must show a consistent set of values for all variables. You must also supply a copy of the Rule (Equation) Sheet. The Rule Sheet should contain some general comments to tie major sets of equations together. If the model uses any special user defined functions these should also be included in the

[2] TK!SOLVER is a registered trademark of Universal Technical Systems, Inc., Rockford Illinois

[3] Equation solving programs have a variety of input and output screens which they call sheets. Some of these programs can solve multiple cases by running in what is called *List Solving*.

material submitted. User functions should be documented in the same fashion as the equations on the Rule Sheet.

spreadsheets

Documenting a model when a spreadsheet is used is a bit more difficult than when high level languages or formula solvers are used because spreadsheet equations use cell addresses rather than variable names. About the best thing you can do when spreadsheets are used to make sure each column and row of the sheet has a clearly defined title or heading. If the sheet's equations are not intuitively obvious then you will probably have to append a report which explains what calculation is being done in each cell.

documenting the use of models

Using a model implies running the model for a variety of different cases, in some instances a very large number of cases. It is easy to be overwhelmed by the enormity of data that can be generated with a model, and the documentation of this work needs careful consideration.

displaying the results

The important results of any case, such as those used to substantiate a conclusion, can be displayed using plots and or tables. Tables are required for any plot shown but there is no need to generate plots for all the tabular data, only the most important relationships need to be plotted. Each plot and table must have a figure or table number, e.g., Figure 1 or Table IV. The data from all cases which are run using the same model (i.e., the equations are not changed from run to run; only the input data are changed) should be grouped together in chronological order.

It is very important that for each case run, the values of the variables which were constant as well as the values of the variables which changed be known. The constants can be shown by including a complete Variable Sheet or table of values. For each case that you run you will generate a set of lists, probably collected into a table, showing how the other variables changed. For each case, you must annotate the lists (tables) with information explaining what has changed from the previous case. If you do use a general table with numerous variables, only some of which are of interest for each case, you must mark the variables of interest. This can be done using a highlighting marker.

One last point, you should not include results from runs made but not discussed (i.e., not used). Filling a report or homework assignment with pages and pages of tables and plots, none of which are discussed (used), is not conducive to a good documentation effort. Work filled with such material, suggests an unorganized, haphazard approach to the problem, i.e., run a bunch of cases and hope something turns up.

discussing the results

When you present the results of your work you always want to discuss the results (i.e., you never just submit a plot or a table without some discussion of the table or plot). Look at the data and tell the reader what **YOU,** the writer, want the reader to notice; do not make the reader figure out what is important or interesting about the data. Explain what decisions you have made or will make based on the data. Try to explain why the presented plot looks like it does (i.e., try to explain the fundamental laws and theories which are at work). If the data has any anomalies do not just ignore them; either attempt to explain why they are there or admit that after consideration you cannot really explain the unusual (unexpected) shape. The discussion must refer to the plots and tables by their names or numbers, e.g., Figure 1.

Technical Work - An Entire Project

The material up to this point has addressed the documentation requirements for individual models and not an entire project. The documentation for the entire project requires collecting and organizing all the individual tasks in one central location - the design notebook.

the design notebook

The design notebook is the complete record of the work done by your team on the project. The notebook is the source of all documentation required to establish that your design is feasible, that you considered a reasonable number of alternatives, that system optimization was done, etc. It includes the early high level of abstraction concepts as well as the final low level of abstraction variables.

design notebook organization

There are two important guiding principles you want to keep in mind as you develop and create your notebook.

1. It must be easy to find work in the notebook. The page numbering scheme you use must make it easy to find work referenced to or to find material related to topics of interest (i.e., if suspension systems are part of the project, it must be easy to find the technical work related to suspension systems).
2. It must be easy to insert new material into the notebook. By easy I mean that when pages are added to existing work you do not have to spend hours renumbering the notebook and revising all the internal references.

There are several ways to accomplish these goals but most methods boil down to dividing the notebook up into a large set of technical sections which page numbers starting from 1 in each section. For example, if the third section concerns heat exchanger work, the tenth page of this work would be 3.10. You could have tasks within sections have sequential numbering (e.g., A, B) and the work of each task start at page 1. Thus for example in the previous case a page number of 3.B.2 would indicate that the heat exchanger work (i.e., 3) was in the second task (i.e., B) and on page 2 of that task. (note: organizing a notebook according to who has done the work is generally not a good practice, focus on the tasks not the people)

<u>the design section</u>

While each notebook will be unique in terms of what technical sections are present, each notebook will not be unique in the sense that **all notebooks must have a design section.** The design section of the notebook contains the latest version of the team's design. It will be an ever changing section, growing during the semester as more and more information about the design is known. An important point about the design section: **The design section of a notebook contains only the design (i.e., the description) and not any justification of the design.**

product and process

Remember, one of the goals of technical documentation is to document the process as well as the product. This means that the notebook must do both and cannot be just a record of the current work or thinking. The only section of the notebook which is revised to show only current thinking is the design section. All other sections must clearly show process and product. Successful execution of this goal requires some thought about overall and section organization.

The overall organization of the notebook generally includes: a Table of Contents up front, an Introduction to the project, the design section and all the technical sections. The organization of the material within each technical section needs to be such that it is easy for the notebook reader to tell what is going on, what the current state of the design process is and what are you currently working on (i.e., product and process).

Reports of Technical Work

While the documentation of your technical work is critical if you or anyone else is going to understand exactly what was done and why, the people who generally make decisions about whether the project should be continued are not going to spend the time (do not have the time to spend) reading all this technical documentation. Instead you must prepare reports which serve the purpose of summarizing all your work and presenting the results in a format which is persuasive and able to convince a reader of the merits of the work. The ability to write and/or give good reports is critical if you want people to respond favorably to your efforts.

There are a vast variety of report types, ranging from short memo-type progress reports, up to extensive multi-volume reports. Many of the required reports are oral, with only limited written material to accompany the presentations. There are progress reports, conceptual design reports, final design reports, and documents (proposals) requesting money. At some time in your career you will have to prepare all or portions of all of these reports.

before writing your report

Good reports do not just spring into existence; good reports take a conscious effort. Writing a report is a process just as creating a design is a process and there is no one, *correct* way to do this process. Each person eventually determines which process best suits them. But as with the design process there are some guidelines which will help you learn to develop a report writing process you feel comfortable with. Following are some general tips which should ameliorate learning this process.

know your audience

You must determine who you are writing the report for. Is it for your technical peers, your parents, your technically wise supervisor, the vice-president of research, the nightly news, your prime contractor, a sub-contractor, a vendor, etc. As is the case in design you must know who your customer is, i.e., who is going to read the material or listen to the talk.

Once you know your customer you then know what level of detail must be included in the report. You know what vocabulary you can use. You know what ideas need explanation and what ideas the reader already understands. You don't want to waste the reader's time by telling her stuff she already knows but you also don't want to loose the reader because they haven't a clue as to what is going on.

know your purpose

You must know explicitly the reason for the report. What do you hope will happen after the customer has read the report? When you know this then you know exactly what things to put in the report (things which will make the desired result happen) and what things to leave out (things which either have no bearing on the desired outcome or worse yet will cause the customer to not perform the desired outcome).

design briefs

Design briefs, as the name implies, are relatively short documents which are meant to initiate some work. While a brief can be written during every stage of the design process, all design briefs contain three common elements. The brief must contain the goal(s), constraints, and measures of merit (quality, goodness) which are appropriate for the task at hand. Writing a good brief takes some effort; it is a balancing act. The brief must be as detailed and specific as possible so that the work and potential solution match your desires while at the same time the brief must not be too restrictive (i.e., implied solutions, solutions which you are not wedded to) or you run the risk of unduly biasing or limiting the person who is to do the work. Within this balancing act the brief should be as quantitative as possible (e.g., *last at least five years* rather than *have a long life* if in fact you really desire a five year life). You should try to clearly define concepts which may have alternate or multiple meanings (e.g., *low specific fuel consumption* or *time to process* rather than *high efficiency*). A well written design brief would be one where you gave it to the person to do the work, left for a month, and came back to find the task done to your satisfaction (i.e., no surprises).

design proposal

A Design Proposal presents a proposed solution (i.e., a possible concept) along with details of how the design will be developed. The purpose of a Design Proposal is to convince decision makers, i.e., the people who are responsible for deciding whether the project should proceed, that you understand the nature of the problem and know how to solve it. It is often the only document read by these decision makers and thus it must be very persuasive. If the project proceeds, the Design Proposal becomes a contract, defining what will be done and what will be supplied when the work is finished. Depending on who the decision maker is (i.e., is he/she your immediate supervisor or a person outside your company), Design Proposals can range from short memos to extensive reports. A written Design Proposal should always be developed, even if the initial approval is the result of conversations or a meeting.

A Design Proposal can only be written after some significant preliminary work has been done. Only after the problem has been defined, only after significant numbers of high level of abstraction design alternatives have been developed and evaluated, and only after a detailed plan of attack (i.e., a detailed design strategy) has been developed is it possible to write a Design Proposal. Only then can you expect to be able to develop a document which will be convincing.

Without a significant effort spent on *problem definition*, you cannot expect to convince the reader that you are working on the correct problem and that you are considering all the important, and not just the "obvious," aspects to the problem. Without a serious effort spent in *conceptual design*, you cannot expect to propose a solution that seems promising. Without quantitative based decisions for selection of the proposed alternative you cannot expect the reader to appreciate your technical skills. And finally, without a well defined design process you cannot expect to convince the decision makers that you can successfully accomplish the complex task.

design proposal format - senior design projects

There are many formats possible for a Design Proposal and you will need to determine the *correct* format. The following format is the one to be used for the senior design project classes (i.e., MAE 443/468). The proposal has several required major written sections which are discussed below.

1. Title Page
   Each Design Proposal must have a Title Page. This page must include the project title, the team number, the date the Design Proposal is submitted, the team members' names, and the names of the course faculty. Leave a blank, signature line to the right of each name.
2. Introduction
   This material sets the context and helps to define the boundaries of the problem. Who is the customer; why is your team working on this project? The context portion of this material will require a little imagination on your part. Since this problem is an *assigned* class problem there is no clearly defined context, i.e., work environr.ent. It is up to the team to define a context (i.e., work environment within which the proposed project makes sense). Defining this context helps define the boundaries of the problem; it establishes what things will be fixed and cannot change, e.g., environmental and system parameters, and what things can and will be varied, e.g., design and system variables. The team must define how their work fits into the larger problem solving process.
3. Problem Definition
   This material defines and explains the design objectives and all the relevant performance requirements, other constraints, and goals (i.e., discuss all the factors which must be considered in establishing design feasibility and quality). Any known restrictions on design variables must be explained. This section of the report will be used by the course faculty in deciding whether the team is planing to consider all the important performance and failure mechanisms in their up coming work. The Design Proposal will not be signed until this section is deemed reasonable.
4. Concept Generation and Selection
   This section needs to give a sense of what alternative concepts were considered and how these altematives were winnowed down to the final

concept to be developed during the semester. All the important, high level of abstraction alternatives should be described. The decision process should be, as much as possible, based on sound technical (i.e., read hard quantitative) reasons rather than intuitive (i.e., read soft qualitative) reasons. It is not necessary to develop (i.e., describe) all the alternatives in equal detail; it is important that the concept of choice be fully, at the level of abstraction appropriate, described.

5. Design Process
   This can be a very important section of the proposal. This section can convey mastery of the design strategy generation and show how the team might monitor and control the design process. It is here that the global approach is explained. A context for the work has been defined in an earlier section as has a possible design. The design process has proceeded to the point where the design contains some generic components, defined by some initial geometric and materials information for the various components Given this scenario and assuming that each team member will be assigned a certain set of the components to work on, this section describes the design process to be used by your team to work on this problem. Develop the process in enough detail that each member of your team understands her role within both the team and the *company* (context consistency) and knows what the appropriate set of design variables would be. Try to use the terminology used throughout your system design class (e.g., design variables, system parameters, system variables, components, design space, etc.) in defining and describing the proposed design process. Feel free to define the role of the team within the entire project; just make sure this role is clearly explained to your team members and that the role is consistent with the general role outlined in the Introduction.

   This section lets the team define the system aspects of the proposed artifact (solution). The specific technical models and methods are defined in the Statement of Work section, assuming this section is part of the report. In this section a picture is painted showing how all the work blends together into an organized coherent approach.

6. Statement of Work
   It is here that the technical details of the proposed plan of attack are given and discussed. Based on how the team has broken the problem down there will be a number of components that must be developed where the development will require the execution of a variety of tasks (e.g., predict component/system performance). This section of the report defines all these tasks which must be done. The more detail that is included in this section , i.e., the more tasks that are included, the better the chances are of convincing the reader that the team has a complete, technically sound plan. For example, in the design of an airplane, a team could include a task called "Design of the Wing;" or they could rather break the task down into a number of tasks (e.g., "Aerodynamic Wing Loads", "Wing Material Selection", "Wing Structural Stresses", etc.).

   Each proposed task should be a separate paragraph and should address:

   1. the goal or purpose of the task,
   2. how the task will be done, i.e., describe what modelling techniques will be used, what generic models will be used (e.g., Bernoulli, FEM), what resources used, etc.,
   3. who is going to do the work.

7. Deliverables
   This is the section of the report which is primarily used to judge whether the proposed level of effort is reasonable. This material describes what things are going to be turned in (i.e., delivered). There should be an item for everything that is turned in during the semester, including Notebook reviews, outlines, etc. The date that each of these items is delivered should be shown on the Schedule (see next section) as a milestone. Except for the final design specification contained in the final Notebook submittal, there needs only be a very briefly description of what is being delivered (i.e., the name of the document and a sentence or two is sufficient).

   The exception to this brevity is the description of the detail contained in the Design Section of your last Notebook. This report must describe, as best possible, the level of detail to be contained in the final design the team eventually plans to submit. List as many of the design variables as possible (just their names not their values). This large set of variables will need to be organized is some fashion (e.g., by component or function or system). Try to indicate the number of significant figures that will be presented. If the design variable value is something other than a number, indicate whether the variable value will be generic or specific (e.g., if the design variable is a type of pump, will its value be "gear pump" (generic) or Goulds Pumps, number G23-a45 (specific)). In addition to listing the design variables this section must also describe what set of design drawings (i.e., assembly, isometric with cutaways, layout, etc.) the team plan to develop and submit. Try to indicate what parts of these drawings will have dimensional information explicitly shown.

8. Schedule
   Because there are several mastery areas related to schedules (C4 & G2) the report must have a schedule showing when all the proposed tasks will be done. Any format is possible; a Gantt Chart format is acceptable (dates across the top, tasks down along the side, and bars showing when each task starts and ends). If the report has a Statement of Work Section there should be a one to one correspondence between the tasks shown on this schedule and the tasks discussed in the Statement of Work. In the Gantt Chart the thickness of the bars should indicate the level of effort (i.e., how many team members assigned), thicker bars implying more effort. The schedule should also include all required milestones (e.g., design notebook due for review)

final design report

The purpose of a final design report is to document and justify the final design. As is true for any report, this report must be convincing. Some general traits of good documentation were given earlier; some more specific suggestions for this report are discussed below.

1. present numerical results
The use of a specific numerical value or result instead of a general term always implies a greater level of known detail in the work. For example, stating that the temperature was 120 C, rather than that the temperature was high makes it much easier to convince the reader that some decision, based on this temperature, is reasonable. The presence of numbers implies the existence of models which again adds credibility to the report.

2. present specific facts
This is very similar to the above item but is not limited to numerical data. The more specific you can be, the stronger your arguments become. For example, the reader gets a much better feeling when he/she reads "The critical column load was found using a modified Euler, slender column, buckling analysis;" rather than, "The maximum column load was determined.

3. present a feeling of completeness
If the reader believes that you have covered all the necessary topics he/she will be more receptive to accept the work and results presented. This sense of completeness can be fostered by, early on, listing what you feel are the important topics and then discussing each of them completely in the body of the report. This is standard good report writing, i.e., tell the reader what you are going to discuss and then discuss the items.

4. present an organized feeling
The more organized your report; the more organized your project or at least that is the implication. If conclusions arise naturally as a consequence of a series of arguments, the reader gets the feeling that the writer of the report has truly mastered a complex subject because he/she is able to present the myriad of facts in a meaningful, organized manner.

5. present a readable report
If a report is easy to read, the reader is likely to accept the arguments presented more easily than if the report is hard to read. Report readability can be enhanced by using transition paragraphs to tie major sections of the report together.

   The need to be readable and the desire to use specific numerical facts can lead to a conflict. The presence of too much numerical data and too little text can make the reading very dry ("wooden" as Zonker remarked on the style of the Zip Code directory he was reading) and not very readable. You have to walk (write) a fine line between presenting too much or too little numerical work.

define your audience

For your final report you may select your audience to be either the course instructors or the MAE faculty. You must make it clear to the course instructors which audience you have selected.

state your purpose - select a theme

At the time you tell the course instructors who your audience is you must also tell them what your theme is. The quality and completeness of this final report will be judged based on your success at achieving your state purpose or theme.

final design report format - senior design projects

The following format is the one to be used for the senior design project classes (i.e., MAE 443/468). The report has six major written sections: Executive Summary, Introduction, The Design Process, The Design, Design Justification, and Conclusions. Each of these, along with some other topics, is discussed in the material to follow. As you write each section, be sure to keep the guidelines for good report writing in mind.

Before writing the report you should develop an outline. Since the report is limited in size and there are many topics which **must** be covered, an outline is almost mandatory. Further, since the report will have material written by different people, the outline is one way to define exactly what material should be covered by each person. An outline helps organize the report and eliminate redundancies.

1. title page
   The Title Page is the first page of the report and must include the project title, the class name, the submittal date, the group number, the members' names, and the instructors' names.

2. design picture
   This page is your concept presentation page. This page is a picture, sketch, or set of pictures on the page, that shows the essence of your artifact. The more you capture the sense of the entire proposed artifact the better this page becomes. It can range from an artists rendition to an engineering drawing; however, the more it is a rendering the more successful the picture will be. Be creative in developing this picture.

3. executive summary
   The Executive Summary is a summary of the report. This summary must included introductory background material as well as a synopsis of the design. In addition, you must cover the reasons behind several of the more important design decisions. The Executive Summary, along with the design Picture must be able to stand alone.

   Note: the title page, design picture, and executive summary should form a package which could stand along (i.e., make sense with no other material). These three pieces of a report are often removed, copied and distributed to other people. This means that the audience for the executive summary is larger and potentially less informed than the audience for the report itself.

4. table of contents
   Following the Executive Summary comes the Table of Contents. All major sections of the report should appear here, including the Executive Summary and all Appendices. You should have a separate Figure Table of Contents following the first Table of Contents. Every Figure (i.e., every plot and table) must be entered with a page number.

5. introduction
   This material is very similar to the material contained in the Problem Definition Section of your *Design Proposal.* This section establishes the context of the problem as well as presenting a brief description of the concept you propose as a solution. The discussion of the concept is done in a general manner, explaining how the concept works and solves the stated problem. The discussion of the concept does not contain specific details about the particular artifact you eventually designed; this detail will be found in the Design Section of this report.

   This section gives reasons as to why the project is being worked on; it gives background material or technical information which gets the reader up to speed; and it contains material which establishes the important design constraints and selection criterion. This section could contain justification for the general concept (some sort of shortened version of what was in the design proposal) but **should not** contain justification of the design decisions you made after the Design Proposal was signed.

   This material may end with a transition paragraph which explains the organization of the rest of the report.

6. the design process
   In your *Design Proposal* you discussed the general approach you planned to use, i.e., you discussed the system aspects of your work. In this section of your report you should explain what general approach you actually used. Discuss the generic types of models that were developed and how they were used and integrated together. Specific details concerning the models are not of interest; how the models were used in the over all design process is of interest.

7. the design
   This section presents your final design, the best design you had time to find. This section summarizes the most important features of the design. This section is not meant to be a complete description of the design because that is found in the Notebook. This section will be a combination of text, tables, and drawings, organized and presented in a form that makes it easy for the reader to quickly grasp the important features and components of the proposed artifact. As is true with the Notebook design section, this section of the report should not contain any justification of the design. All justification for the selections will be found in the next section.

8. design justification
   This section will be the longest and most detailed section of the report. It is in this section that you attempt to convince the reader that, through sound technical work:

   1. the design is feasible and
   2. the design is good.

You need to present plots and tables which show that the design does not violate major constraints (i.e., it is feasible) and that the particular values of the design variables selected give a design which is better, according to the selection criterion outlined in the Introduction. This section can also be used to discuss the sensitivity of some of the environmental and performance variables on the design decisions made (e.g., how sensitive is the wing lift calculation to the value of air density used in the analysis). If your group has done redesign this is the place this work is discussed.

Be sure to completely discuss all the figures that you include as proof of design feasibility or goodness. Be sure to discuss the implications of the plots and do not simply report the shape of the plot. Try to explain why the plot looks like it does. This may require you to briefly discuss some of the modelling details (e.g., major assumptions, first principle approaches used, etc.). Discussion of specific model development should be kept to a minimum and only be presented if it helps explain the predicted results. You should emphasize how the results of the modelling, as shown in the figures, influenced your design decisions. The detailed information on how the tables and plots were generated is contained in the Notebook.

9. conclusions
This section ends the body of the report and lists the major conclusions reached concerning the design. It also gives any recommendations you may have reached concerning the need for additional work, the goodness of the design or the completeness of the modelling. This is an important, if not long, part of the report.

10. appendices
These are optional and contain information which you feel should accompany the report. Remember, however, the report must make sense without the Appendices.

11. general format notes
You should assemble your report in the following order, observing the page limits.

    1. Title Page - one page
    2. Design Picture - one page
    3. Executive Summary - two page maximum
    4. Table of Contents - no limit
    5. Body of Report - twenty pages maximum (exclusive of pictures, plots, tables, etc.)
    6. Appendixes - no limit

You may use any printer font you wish but it must not be smaller than 12 point. The report should have at least a one inch margin on all sides. The report should be stapled once in the upper left hand corner; no folders or binders are required or desired.

oral reports

Dog and Pony Shows, Informal Presentations -- whatever you call them -- oral presentations of your work are an important facet of your professional life. Lasting impressions are made during oral presentations, impressions which can be helpful or harmful. The long range implications are such that you should never just give one of these presentation "off the top of your head " (i.e., you must plan in advance what you want to cover and how to cover it).

Like all aspects of design, the only way to learn how to present good oral presentations is to give them. It takes practice. Here are a few do's and don'ts which may help you initially.

1. plan your talk
   Find out who the audience will be and how much time you will have, and plan your talk around those two constraints. If the audience is familiar with your work, you will not need much introductory material and vice versa. Make an ordered list of the topics you want to cover and then, starting with the first one, cover as many topics as you think you will have time for. Always cover the most important topics first.

2. use visual aids
   It is mandatory that you use visual aids, either overhead slides, 35 mm slides, video, etc. You can use the slides to estimate the length of your talk. On the average you can cover 1 to 2 slides per minute of presentation. It's possible to go through 45 slides in 15 minutes, but no one will understand what is on any of the slides and the presentation will have failed. Your slides must be kept simple. Do not attempt to put all the information possible on one slide, either remove the secondary information or present 2+ slides on the subject.

3. present report extemporaneously
   You should strive to present the material with few if any notes, using the slides to organize the talk and remind you of the key items you want to discuss. "Extemporaneous" does not mean "off the top of your head," it simply means that you are not reading a prepared script. If you gave the talk twice, each talk would be a little different. You should never just read the text of a report.

4. practice
   Especially when you are just beginning to give oral presentations, you need to practice delivering the talk. This helps you see if the timing is correct as well as developing a presentation pattern in your mind, a pattern you can subconsciously use when actually presenting the material.

5. present to the audience
   When giving the talk, look at the audience; this way you can judge the reception of the talk. It is fine to glance at the slides from time to time, but you should not spend you whole time talking to the screen or slide projector. (Very few projects have been funded by slide projectors.)

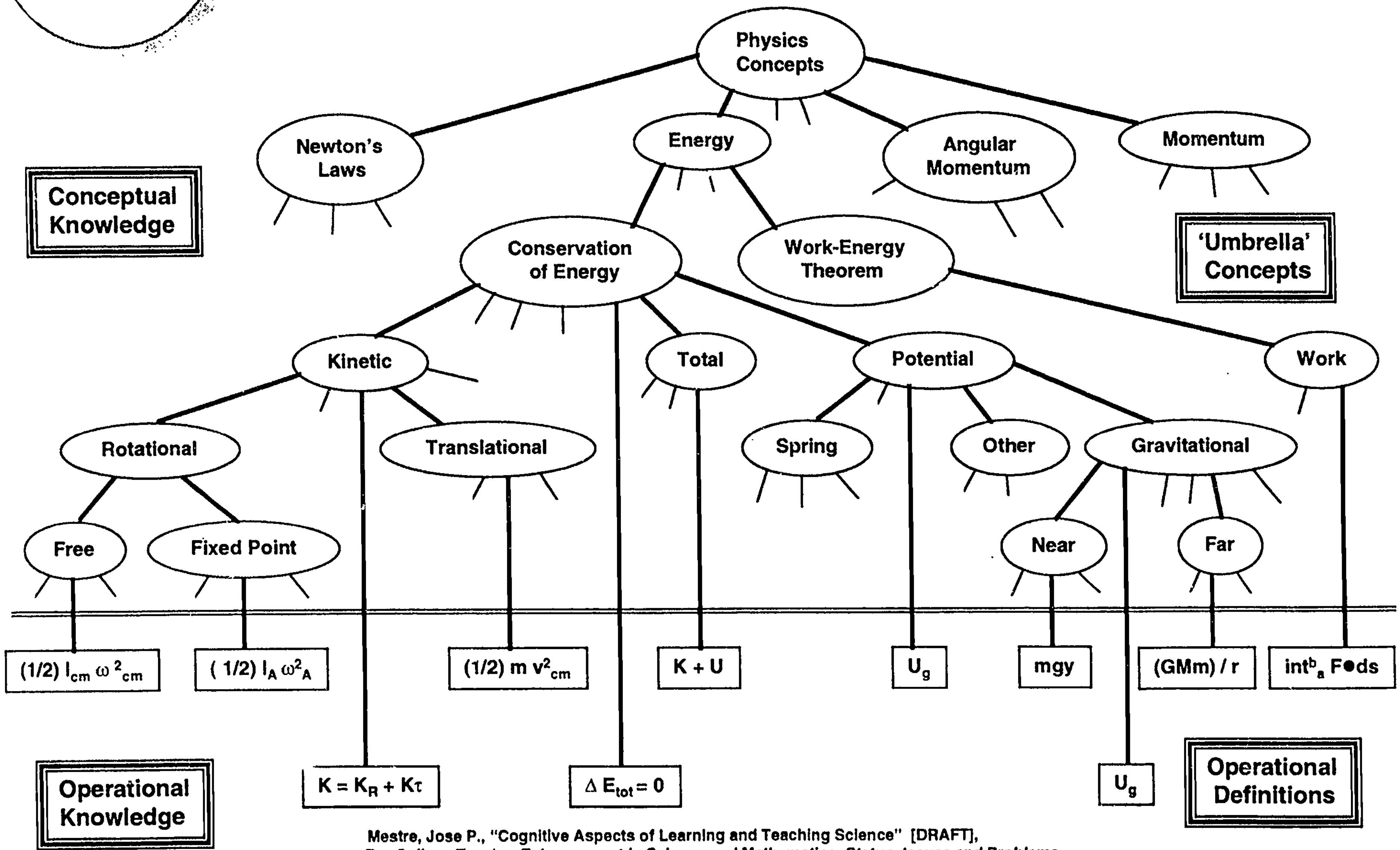
Hierarchical Structures for Students

Hypotheses :

- For lower level Engineering Science courses (and topics which are assigned primarily at the Knowledge, Comprehension and Analysis Levels of Learning in any course),
  - it is the responsibility of the teacher to develop and present hierarchical structures for the content.

- A reasonable and appropriate structure, both for the students and for active learning in general,
  - can be deduced from a reflective review of the teacher's original, lecture course notes.

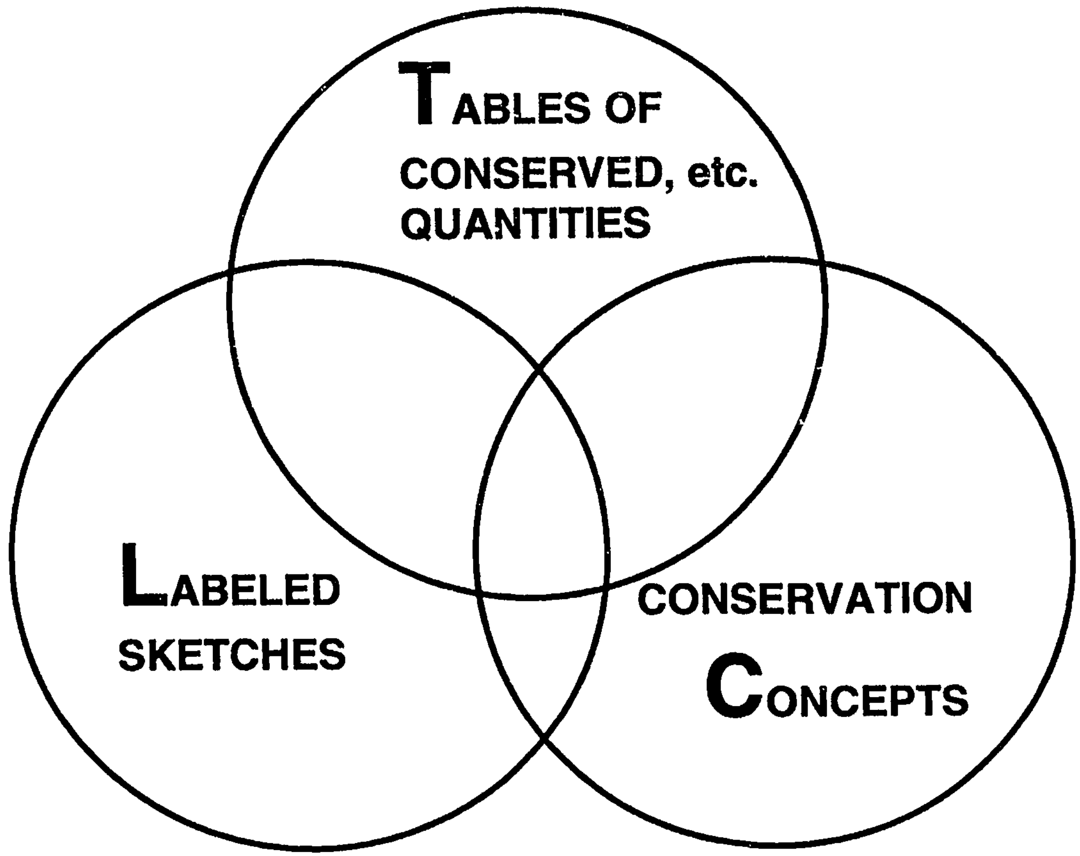
A Hierarchical Structure for Elementary Mechanics[16]



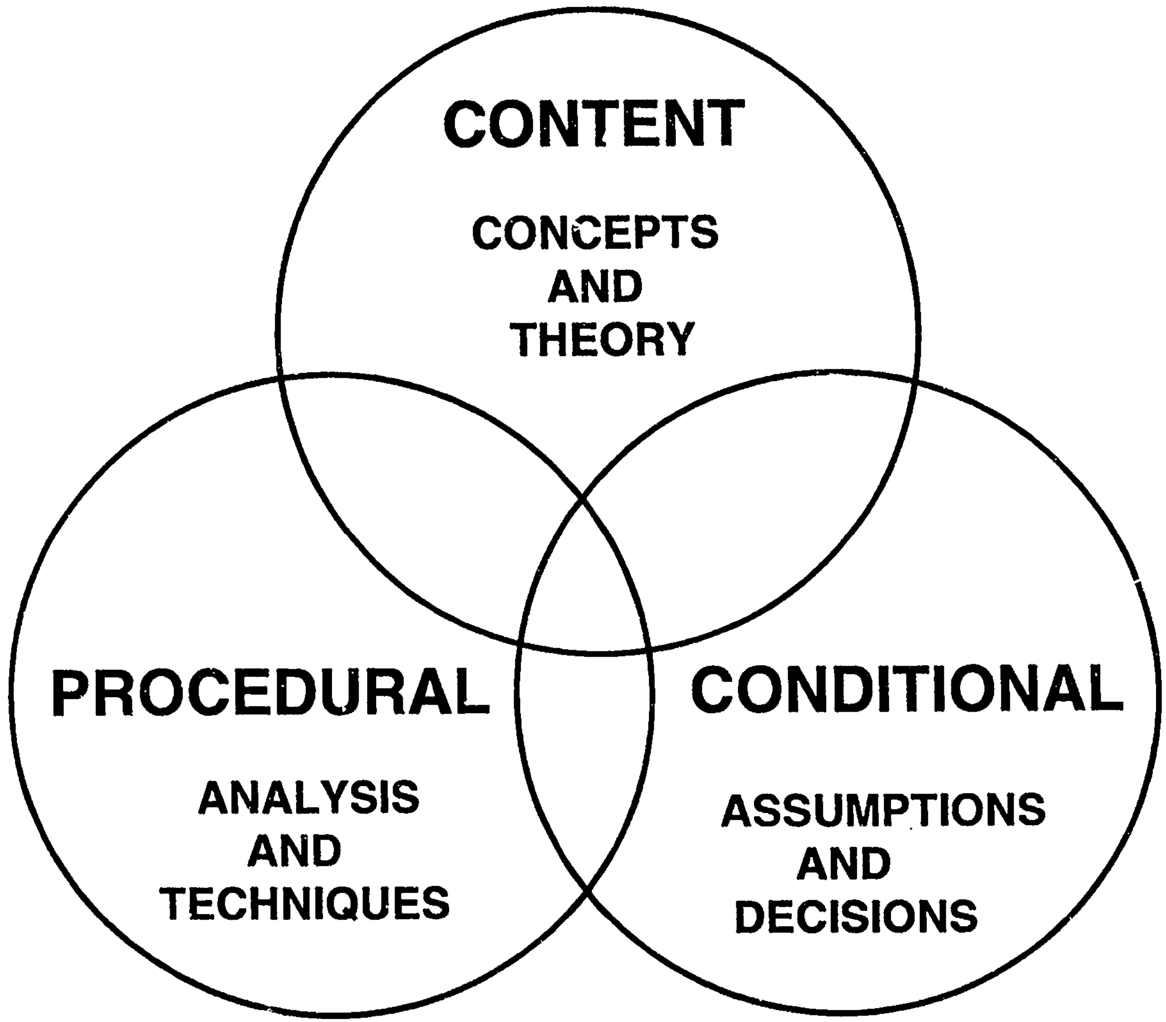
Mestre, Jose P., "Cognitive Aspects of Learning and Teaching Science" [DRAFT], *Pre-College Teacher Enhancement in Science and Mathematics: Status, Issues and Problems*

An Organizing Structure for :

Conservation Principles and the Structure of Engineering



Content, Procedural and Conditional



Knowledge Types (a structure)

The first type of knowledge (first in the sense of the order we choose to discuss it, not in its supremacy to other forms) is *content*. Content knowledge includes physics or basic principles of systems. For example, in a pendulum (as in all real systems) linear and angular momentum, and total energy can be accounted for. To do this, an understanding of what energy and momentum are, as well as an understanding of the forces of gravity and air resistance are needed. This knowledge might be labeled content. The content knowledge in this text will build on fundamentals established in your previous courses. The intent is not to introduce vast amounts of content.

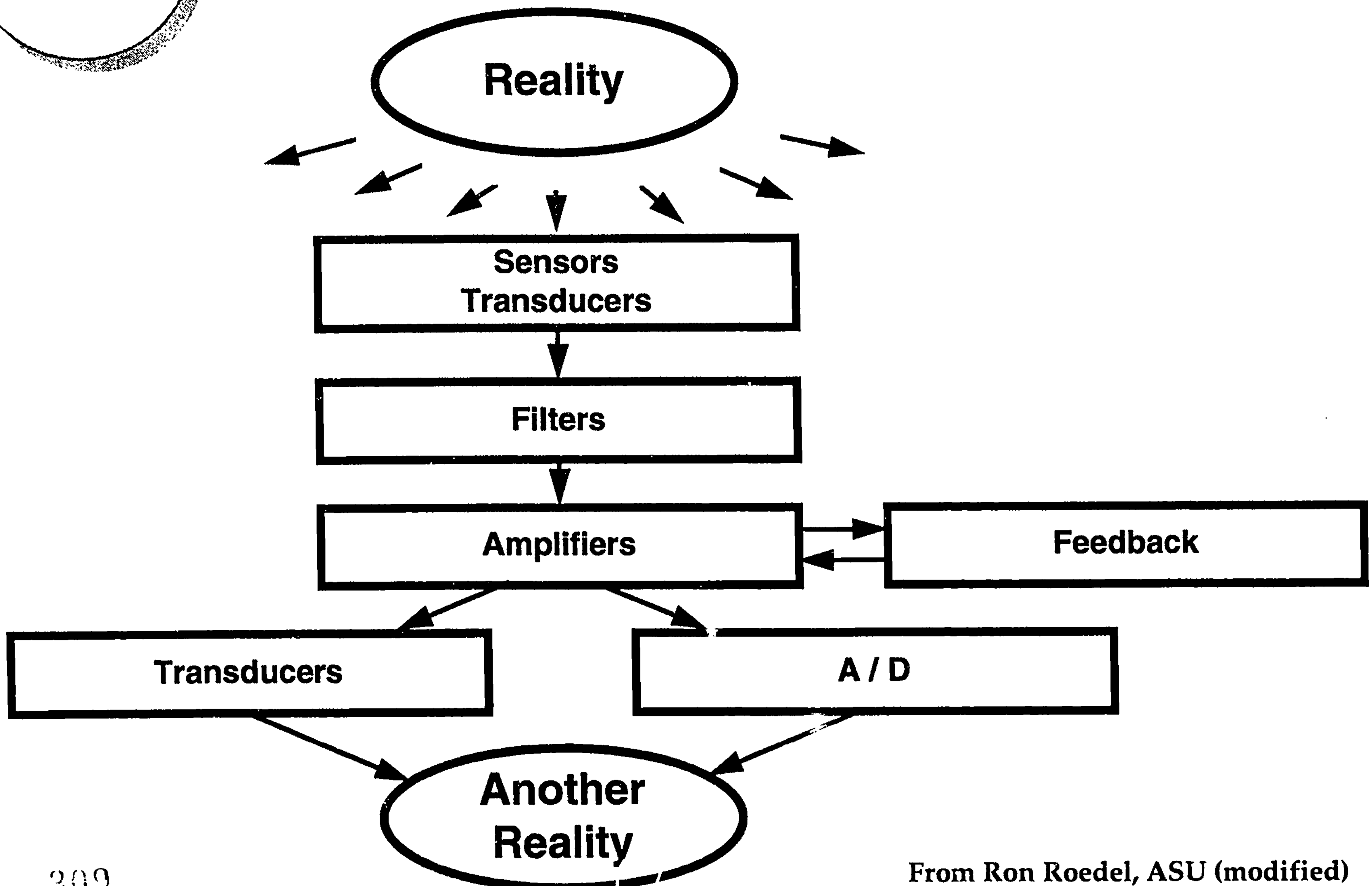
The second, and most common knowledge type in this text, is *procedural*. Procedural knowledge includes the process or methodology which you apply to understand systems. For example, to apply the *content* knowledge that angular momentum is conserved in the pendulum, you must determine the forces acting on the system. This can be done best by drawing a free-body diagram. There is a procedure, or correct way, to draw a free-body diagram, if one does not possess such procedural knowledge it will be difficult to apply content knowledge.

The third type of knowledge contained in this course is *conditional*. Conditional knowledge is used to decide when various methodologies are applicable. For example, if a point on the pendulum is fixed to the Earth, you must decide if the Earth should be assumed fixed, rotating about its axis, or hurling through space.

This course will emphasize te development of procedural and conditional knowledge by providing practice in the design and analysis of complex devices. The objective is to allow you to gain some of the experience necessary to make important engineering decisions about the design and analysis of complex processes. The text will also reinforce knowledge for understanding why a system behaves as it does, and to make design decisions based on desired behavior.

Everett, Louis J. ,
Understanding Engineering Systems Via Conservation, 1992, McGraw-Hill, New York

Another Structure

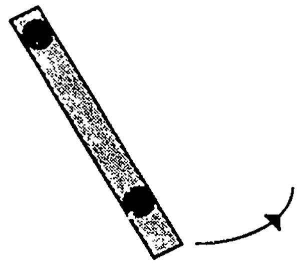


From Ron Roedel, ASU (modified)

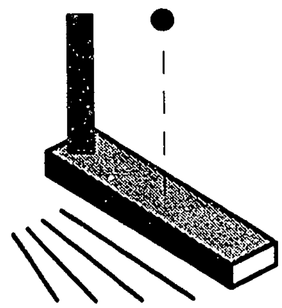
Expert-Novice Differences in Problem Solving
(From Mestre, 1991)

The following three physics problems can be used to illustrate differences in the problem solving behavior of experts and novices:

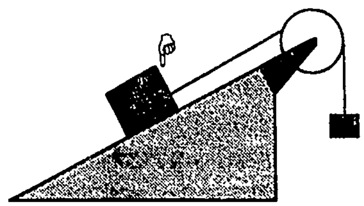
Problem 1 : A 1 kilogram stick of length 1 meter is placed on a frictionless horizontal surface and is free to rotate about a vertical axle through one end. A 50 gram lump of clay is attached 80 centimeters from the pivot. Find the net force between the stock and the clay when the angular velocity of the system is 3 radians per second.



Problem 2: A stick of length 1.5 meters and mass 0.2 kilograms is on a frictionless horizontal surface and is rotating about a pivot at one end with an angular velocity of 5 radians per second. A 35 gram lump of clay drops vertically onto the stick at its midpoint. If the clay remains attached to the stick, find the final angular velocity of the stick-clay system.



Problem 3: A 60 kilogram block is held in place in a frictionless inclined plan of angle 30 degrees. The block is attached to a hanging mass by a massless string over a frictionless pulley. Find the value of the hanging mass so that the block does not move when released.



Question: Which of problems 2 and 3 would be solved most like problem 1? Explain your answer.

Typical Expert's Response: Problem 3 would be solved most like problem 1 because both involve the application of Newton's Second Law.

Typical Novice's Response: Problem 2 would be solved most like problem 1 because both involve a rotating stick with a lump of clay attached.

Note that the expert cues on the underlying principle that could be applied to solve the problems, whereas the novice cues on the surface characteristics of the problems.

Question: Describe how you would go about solving problem 1.

Typical Expert's Response: The clay accelerates as it moves in a circular path. The net force needed to keep the clay going in a circle is provided by the horizontal force between the stick and the clay. Therefore, apply Newton's Second Law and set the net force on the clay equal to its mass times its centripetal acceleration. Then solve for the magnitude of the force.

Typical Novice's Response: The stick and the clay are both moving in a circular path so I would probably have to use $I\omega$ and $\frac{1}{2}I\omega^2$ for the stick, and mvR and $\frac{1}{2}mv^2$ for the clay. I am told values for the mass of the clay and the stick so I have m and I can find I by looking up the moment of inertia of a stick pivoted at one end in a table and plugging in to get a number for it. The force for something moving in a circle is $\frac{mv^2}{R}$ so I think that I have enough to get an answer.

Note that the expert performs a qualitative analysis during which the applicable principle is identified and a procedure for applying the principle is stated. In contrast, the novice immediately resorts to formulaic approaches, often writing down expressions that are irrelevant for solving the problem (e.g., $I\omega$, $\frac{1}{2}I\omega^2$). Principles and concepts are usually lacking from the novice's approach.

One approach for helping students overcome the "force of the hand" misconception (from Mestre, 1991)

Probe for Misconception: Toss a ball vertically up and ask students to enumerate the forces acting on it when the object is halfway to the top of its trajectory.

Ask questions to clarify students' beliefs: Does the "force of the hand" change in magnitude or direction? What happens to this force at the top of the trajectory and on the way down? Is this force active in other situations, such as rolling a ball on top of a horizontal surface? When does the "force of the hand" act on the ball?

Suggest discrepant events that contradict students' beliefs: Suppose I push on you - how do you know when I stop pushing on you? How does the object "know" that the "force of the hand" is still acting on it? If the object experiences the "force of the hand" after it leaves the hand, why can't one control this force while the ball is in the air?

Encourage discussion and debate: Promote fruitful, non-disparaging debate among students as they take different slides in the ensuing argument. Encourage students to apply physics arguments, concepts, and definitions.

Guide students toward constructing scientific concepts: How one guides students depends on their awareness to the teacher's questions and the issues raised during the discussion and debate. Once could involve students in:

- A synthesis of their responses to questions and situations, with a discussion of how consistent those responses are with the scientific concept or other observations.
- A discussion of "thought experiments" that in principle could measure the "force of the hand."
- A discussion of what the motion would be like with and without the "force of the hand" from the perspective of Newton's Second Law.
- The design and execution of experiments to test hypotheses.

Reevaluate students' understanding: Ask questions and pose situations that allow students to display whether or not they have acquired the appropriate understanding:

- When is the "force of the hand" acting on a ball that is thrown up in the air?
- What are the forces acting on a cannonball that was shot out of a cannon while it is airborne?
- What is the difference, if any, between the cannonball and the thrown ball?

A classroom dialogue for clarifying the concept of acceleration (From Mestre, 1991)

The teacher has previously introduced the concept of acceleration. The teacher now presents some simple situations in order to explore the students' understanding of the concept in concrete contexts.

Teacher	:	Suppose I toss a ball straight up in the air like this (demonstrates). What is the ball's acceleration at the top of the trajectory?
Student 1	:	Zero.
Student 2	:	Yeah, zero.
Teacher	:	Why is it zero?
Student 1	:	Well, at the top the ball stops moving, so the acceleration must be zero.
Teacher	:	OK. If I place the ball on the table so that it doesn't move, is it accelerating?
Student 2	:	No. It's not moving.
Teacher	:	What if I roll the ball across the table so that it moves at a constant velocity (demonstrates). Is the ball accelerating in that case?
Students 1 and 2	:	Yeah.
Student 3	:	No way! If the ball is rolling at a constant speed it doesn't have any acceleration because its speed doesn't change.
Student 2	:	No ... listen. The ball had to have an acceleration to get to the speed it had.
Student 3	:	Yeah, but once it rolls at a constant speed it can't have any acceleration, 'cause if it did it would roll faster and faster.
Student 2	:	I'm not sure. You're confusing me.
Teacher	:	What's the definition of acceleration?
Student 1	:	It's the change in speed over the change in time.

Teacher : Close but not quite. It is the change in *velocity* over the change in time. Speed doesn't care about direction but velocity does. At any rate, apply your definition to the ball rolling on the table.

Student 2 : Well, I guess since its speed - I mean, velocity - doesn't change when it rolls; it can't have an acceleration.

Teacher : Do we agree on this case?

Student 1 : Yeah.

Student 2 : I guess so.

Teacher : So it appears that an object can have a zero acceleration if it is standing still or if it is moving at a constant velocity. Let's reconsider the case where the ball is at the top of its trajectory (demonstrates again). What is the ball's acceleration when it is at the top?

Student 3 : It would be zero because the ball is standing still at the top. It's not moving - it has tot urn around.

Student 2 : It think it might be accelerating because it gets going faster and faster.

Student 1 : Yeah, but that doesn't happen until it gets going again. When it's standing still it's not accelerating.

The teacher could pursue various directions from here to attempt to get students to realize that the ball's acceleration is not zero at the top of the trajectory. One might be to pose a related situation. Another might be to revisit the definition of acceleration and ask students to apply it during the time interval just prior to the ball's reaching the top and just after the ball starts its descent.

Ernst von Glaserfeld on Constructivism

"...[constructivism] deliberately discards the notion that knowledge could or should be a representation of an observer-independent world-in-itself and replaces it with the demand that the conceptual constructs we call knowledge be *viable* in the experiential world of the knowing subject." (Synthese, 1989, p. 122)

"...knowledge cannot simply be transferred by means of words. Verbally explaining a problem does not lead to understanding, unless the concepts the listener has associated with the linguistic components of the explanation are compatible with those the explainer has in mind. Hence it is essential that the teacher have an adequate model of the conceptual network within which the student assimilates what he or she is being told. Without such a model as basis, teaching is likely to remain a hit-or-miss affair." (Synthese, 1989, p. 136)

"...the fact that scientific knowledge enables us to cope does not justify the belief that scientific knowledge provides a picture of the world that corresponds to an absolute reality." (Synthese, 1989, p. 135)

"...if I want to 'orient' the conceptual construction of others, I would do well to build up some idea as to what goes on in their heads. In other words, in order to teach, one must construct models of those "others' who happen to be the students. Only by operating on the basis of a more or less adequate model of the students' conceptual structures can one present the required 'knowledge' in ways that are accessible to the students. And students obviously do not come as blank slates. They have their own constructs, as well as theories of how and why their constructs work. Such constructs or theories may be considered 'misconceptions' from the teacher's point of view, because they are incompatible with the concepts and theories sanctioned by the particular discipline at the moment. Nevertheless they make good sense to the students, precisely because they have worked quite well in the context of the students' interests and activities. And because these concepts and theories make sense to the students, they also determine to a large extend what the students see. Hence it is often necessary to do a certain amount of dismantling before the building up can begin." (Bremen Proceedings, 1992)

Commentary on Hands-On Activities

"Unfortunately, the research evidence suggests that hands-on activities or instruction in process skills will not ensure meaningful learning, either alone or in combination with conventional fact-based instruction. One problem is that science processes do not seem to consist of unitary skills that can be transferred from one context to another. Observing cell cultures, for example, has little in common with observing geological formations or with observing chemical reactions. Furthermore, a major component of process skills seems to be content knowledge (e.g., a good observer of cell cultures must know a lot about cells.)" (Anderson, 1987)

Societies Problems : Root Cause ?

Root Cause	*Mechanism*
ESCAPISM	**AVOIDANCE AND DENIAL**

1. *The trivialization of public discourse.*

   Diversion of attention from serious discussion of public matters.

2. *The externalization of public responsibility.*

   Blaming malevolent forces outside the nation's borders for America's problems.

3. *The secession from the National Community.*

   Many of the more fortunate and economically successful members of american society have been quietly seceding from the rest.

Reich, Robert B. ,Of The People ... the 220-year history of the democratic party

Slide 2

Education's Problems : Root Cause ?

Root Cause	*Mechanism*
ESCAPISM	AVOIDANCE AND DENIAL

1. *The trivialization of faculty discourse.*

   Diversion of attention from serious discussion of academic matters.

2. *The externalization of faculty responsibility.*

   Blaming malevolent forces outside the faculty member's control for education's problems.

3. *The secession from the academic community.*

   Many of the experienced and economically secure members of the faculty have been quietly seceding from meaningful academic contact with other faculty as well as with the students they teach.

Where Will Change Originate ?

The biggest and most long lasting reforms of undergraduate education will come when individual faculty or small groups of instructors adopt the view of themselves as reformers within their immediate sphere of influence, the classes they teach every day.

K. Patricia Cross

Who Should Get Credit ?

The credit belongs to the [person] who is actually in the arena; whose face is marred by dust and sweat and blood; who strives valiantly; who errs and comes up short again and again; who knows the great enthusiasms, the great devotions and spend himself in a worthy cause; who, at the best, knows in the end the triumph of high achievement; and who, at the worst, if he fails, at least he fails while daring greatly; so that his place shall never be with those cold and timid souls who know neither defeat nor victory.

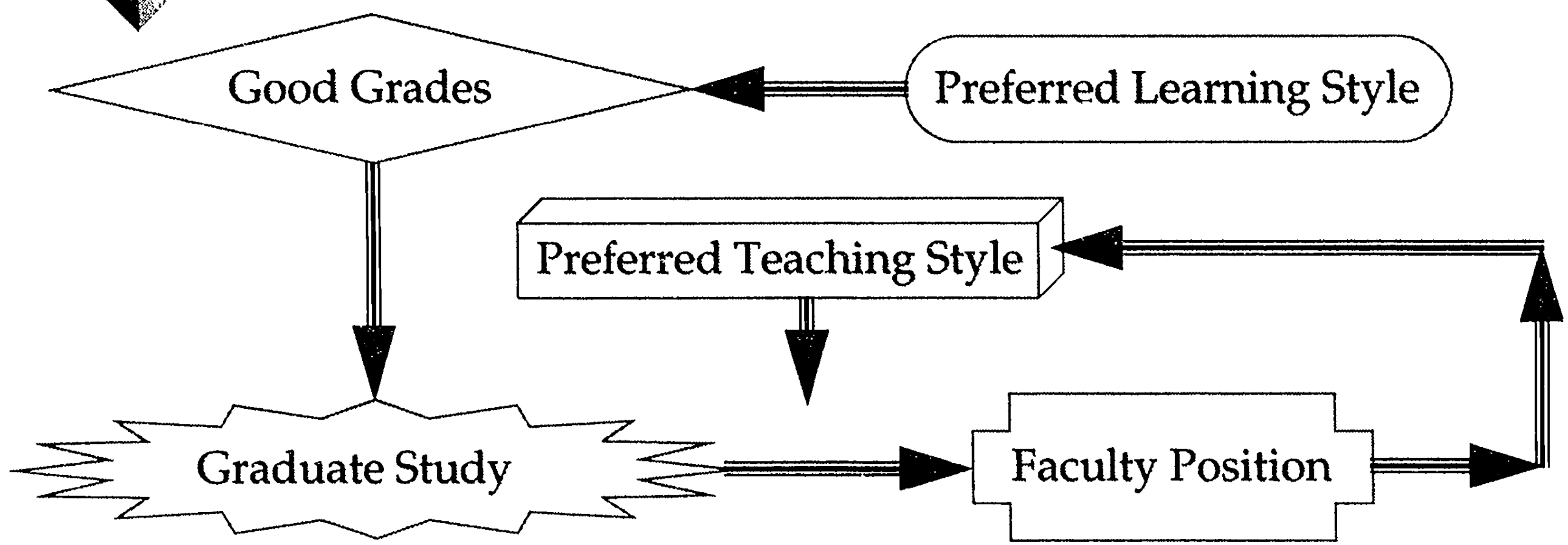
-- Theodore Roosevelt

Managing Change : R. S. Culver

The educational concepts proposed above are ambitious, perhaps even threatening to some, because they call for planned growth and change of both the student AND the professor. ...

However, if the educational program is going to improve, it must change. This will require change in the way we teach, and the change will involve risk. It is important, therefore, that the administration of the educational institution also assumes its responsibility for improvement of the program through innovative development. This can best be done by openly supporting faculty who are willing to risk learning new ways to teach.

The 'Vicious Cycle' of Preferred Learning Styles



'Students prefer to learn in a mode that is comfortable; the traditional lecture format is comfortable because it is familiar and responsibility for the learning rests primarily with the instructor. The professor prefers the traditional mode because he learned well that way. Otherwise he would not have made the grades to go to graduate school and on to a position on the faculty.', R. S. Culver

To Realize the Benefits of a Team Culture Requires a Change in Management Behavior

FROM	TO
Directing	Guiding
Competing	Collaborating
Relying on Rules	Focus on the Process
Using Organizational Hierarchy	Using a Network
Consistency/Sameness	Diversity/Flexibility
Secrecy	Openness/Sharing
Passive	Risk Taking
Isolated Decisions	Involvement of Others
People Costs	People Assets
Results Thinking	Process Thinking

Adaptability *

Engineering Careers in the '90s :

Adaptability is the watchword. The Department of Labor tells professionals to expect a lot of change. A new college graduate can expect to work 48 years in five careers and 12 jobs. Self-reliance, constant training, and flexibility are the keys to staying employed. Be ready to make lateral moves to build new skills. The only security is in your skills, experiences and successes.

* The Institute, *November/December 1992, Volume 16, Number 6,* *The Institute of Electrical and Electronics Engineers*.

Accomodation *

It is strange that we expect students to learn, yet seldom teach them anything about learning ...
(i.e., the process of learning).

We expect students to solve problems, yet seldom teach them about problem solving ...
(i.e., the process of problem solving).

And similarly, we sometimes require students to remember a considerable body of material , yet seldom teach them the art of memory ... (i.e., the process of remembering) .

It is time we made up for this lack ....

* Norman, Don A. (1980), Cognitive Engineering and Education, In D.T. Tuma and F.R. Reif (editors), Problem Solving and Education: Issues in Teaching and Research, Hillsdale, Lawrence Erlbaum

Emphasis

The mere formulation of a problem is often far more essential than its solution, which may be a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks a real advance in science.

Albert Einstein

Engineering: In School and Out

Engineering schools recognize the overlap in industry between engineering and science, and they design their curricula accordingly. Engineering education is strongly theoretical and geared toward math and science. This is partly because of the natural interests of people who are attracted to a professorial life and who set the curriculum. It is also because engineers can learn the more applied portions of their field on the job, while they are unlikely to learn math and science on the job. But because the activities of the engineering student have little relation to the activities of many practicing engineers, it is likely that engineering education discourages some students who would make excellent engineers and encourages others who will not. The mentality to do well in engineering schools emphasizes the ability to work problem sets and get right answers. In engineering, there are never right answers and few problem sets.

Adams. James L. 1991. *Flying* Buttresses, Entropy, and O-rings: The World of an Engineer. *Cambridge, MA : Harvard University Press.*

Restructuring

These problems are endemic to all institutions of education, regardless of level. Children sit for 12 years in classrooms where the implicit goal is to listen to the teacher and memorize the information in order to regurgitate it on a test. Little or no attention is paid to the learning process, even though much research exists documenting that real understanding is a case of active restructuring on the part of the learner. *Restructuring occurs through engagement in problem posing as well as problem solving, inference making and investigation, resolving of contradictions, and reflecting*. These processes all mandate far more active learners, as well as a different model of education than the one subscribed to at present by most institutions. Rather than being powerless and dependent on the institution, learners need to be empowered to think and to learn for themselves. Thus, learning needs to be conceived of as something a learner does, not something that is done to a learner.

Fosnot, C.T. (1989). Enquiring Teachers, Enquiring Learners. NY: Teachers College Press.

Seven Styles of Learning [11]

TYPE	LIKES TO	IS GOOD AT	LEARNS BEST BY
LINGUISTIC LEARNER "The Word Player"	read write tell stories	memorizing names, places, dates and trivia	saying, hearing and seeing words
LOGICAL/ MATHEMATICAL LEARNER "The Questioner"	do experiments figure things out work with numbers ask questions explore patterns and relationships	math reasoning logic problem solving	categorizing classifying working with abstract patterns/relationships
SPATIAL LEARNER "The Visualizer"	draw, build, design and create things daydream look at pictures/slides watch movies play with machines	imagining things sensing changes mazes/puzzles reading maps, charts	visualizing dreaming using the mind's eye working with colors / pictures
MUSICAL LEARNER "The Music Lover"	sing, hum tunes listen to music play an instrument respond to music	picking up sounds remembering melodies noticing pitches / rhythms keeping time	rhythm melody music
BODILY/KINESTHETIC LEARNER "The Mover"	move around touch and talk use body language	physical activities (sports/dance/acting) crafts	touching moving interacting with space processing knowledge through bodily sensations
INTERPERSONAL LEARNER "The Socializer"	have lots of friends talk to people join groups	understanding people leading others organizing communicating manipulating mediating conflicts	sharing comparing relating cooperating interviewing
INTRAPERSONAL LEARNER "The Individual"	work alone pursue own interests	understanding self focusing inward on feelings / dreams following instincts pursuing interests/goals being original	working alone individualized projects self-paced instruction having own space

[11] Based on material presented in Howard Gardner's *The Unschooled Mind; How Children Think and How Schools Should Teach.* Basic Books, 1991.

Stages of Concern in Change *

0 -	AWARENESS	(I don't know anything about this.)
1 -	INFORMATION	(I've heard a little about this and am actively seeking more information.)
2 -	PERSONAL	(How will this affect my life?)
3 -	MANAGEMENT	(I'm having trouble managing time, materials.)
4 -	CONSEQUENCES	(How is this affecting my customers?)
5 -	COLLABORATION	(I want to work with others who are using this.)
6 -	REFOCUSING	(I can think of some modifications that would make this work even better.)

Conclusions About Change *

① Change is a process, *not* an event.

② Individuals, *not* organization, change -- one by one

③ Change is highly personal -- each individual sees it in terms of how it affects him/her and job.

④ People go through phases, or stages, when trying to adopt a change.

⑤ Stages can be predicted and planned for.

Cautions About Change *

1. Not everyone in an organization will change, no matter what!

2. Very few will reach the Refocusing stage.

3. People tend to backslide when top level attention drifts away.

4. IT'S PERFECTLY OK TO BE AT ANY STAGE.

5. It's OK to move through stages at different rates.

Intervention Strategies for Change *

1. What kinds of support (interventions) might enable a person to move from one stage to the next?

2. What support, activities, or interventions exist at this institution that might help people in the stages previously discussed.

* Hall, G.E. & Hord, S.M. (1987), Change in Schools: Facilitating the Process, Albany, NY, State Univeristy of New York Press

Character : The Data

What we have learned so far :

With the caveat that the present research base is small, disparate, and inconsistent, we can offer the following observations.

Leming, James S., *Synthesis of Research: In Search of Effective Character Education,* Educational Leadership, 1993, Vol. 51, No. 3, pp. 63 - 71.

Character : The Findings

- *Didactic methods - codes, pledges, teacher exhortation, and the like - are unlikely to have any significant or lasting effect on character.*
- *The development of students' capacity to reason about questions of moral conduct does not result in a related change in conduct. Apparently, one cannot reason one's way to virtuous conduct.*
- *Character develops within a social web or environment. The nature of that environment, the messages it sends to individuals, and the behaviors it encourages and discourages are important factors to consider in character education. Clear rules of conduct, student ownership of those rules, a supportive environment, and satisfaction resulting from complying with the norms of the environment shape behavior*

Character : Levels of Development

1. ***The rules are external to the student and behavioral conformity is assured through discipline and self-interest.***

2. ***The rules are embodied in social groups, and compliance with the rules is the result of the students' desire to gain acceptance within that group.***

3. ***The rules are interpreted in terms of self-chosen principles***

(N.B. positive rules, principles or social norms assumed)

Character : Cooperative Learning

One of the major educational success stories over the past decade is the use of cooperative learning strategies. In cooperative learning, students are placed in small groups where the group learning assumes central importance and students are responsible not only for their own learning but also for the learning of others.

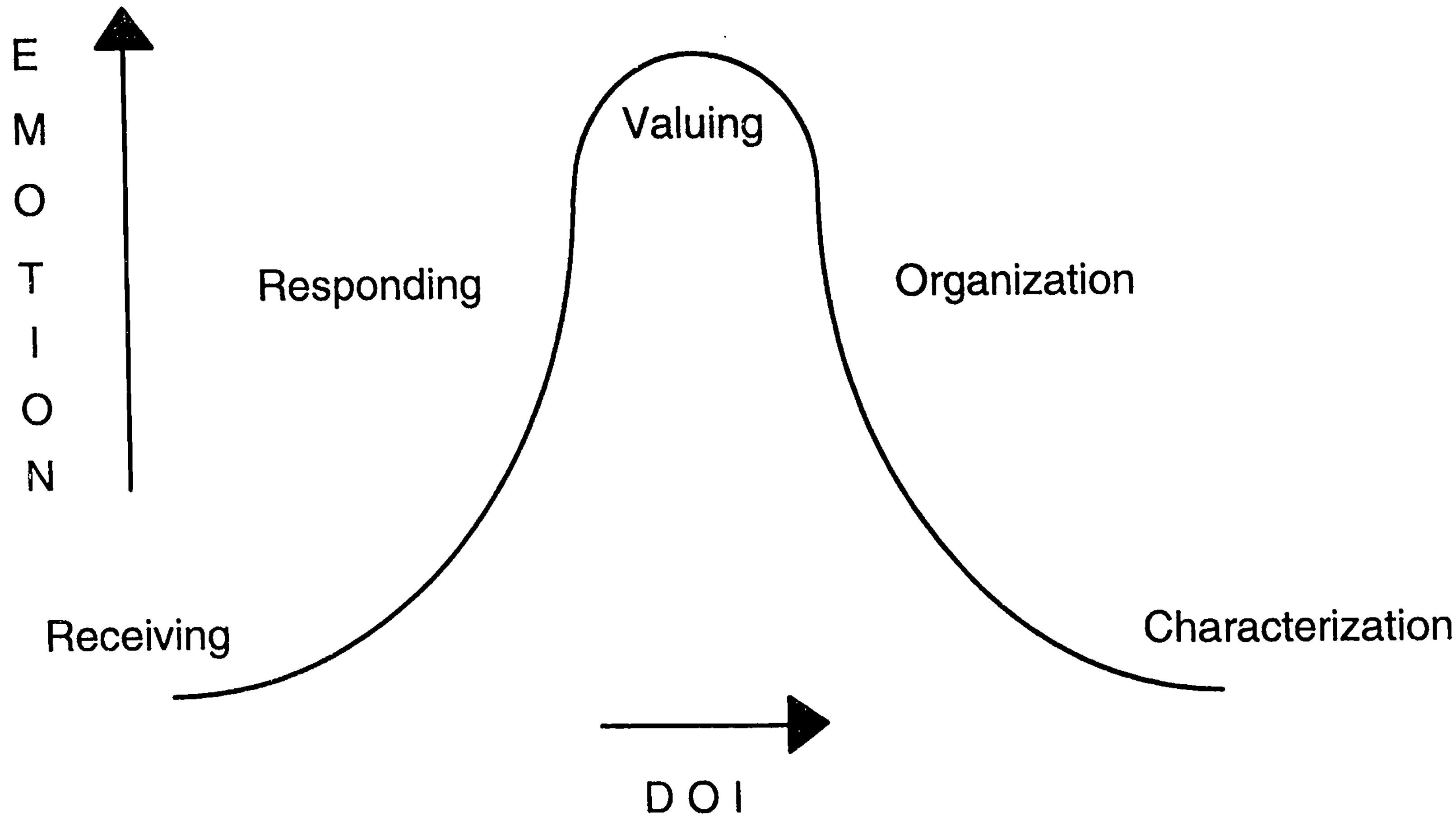
... The influence of cooperative learning methods and just community environments on student character suggests mechanisms by which schools can utilize the dynamics of attachment to groups in a positive pro-character manner.

Leming, James S., *Synthesis of Research: In Search of Effective Character Education*, Educational Leadership, 1993, Vol. 51, No. 3, pp. 63 - 71.

Character : Just Community

Another approach that emphasizes student responsibility is the just community approach developed by Lawrence Kohlberg and his associates. In the late 1970's, Kohlberg revised his perspective on moral education, emphasizing collectively derived social norms rather than individual values as goal of moral education. ... In the just community approach, students confront real problems related to the social organization of the institution. Within a democratic context, students discuss group problems and develop norms by which group life is organized. While the just community research is based on an atypical educational setting, there are encouraging data from research on school climate in more typical institutional settings. Several studies have shown that institutions that seem to have an impact on student character respected students, encourage student participation in the life of the school, expect students to behave responsibly, and give them the opportunity to do so. Discipline is not always imposed, but within the framework of shared group norms, students accept discipline as legitimate and change their behavior accordingly. (pp. 67).

Affective Domain and Emotion Levels



DUMMY

Incorporating Assessment Into Classroom Activities

Richard S. Culver
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"A is for assessment. Assessment is the most powerful tool you have for influencing the learning process. Change the assessment and you change what students give their attention to. Keep control of the assessment and you keep control of learning. If you want students to take some responsibility for their learning, then you probably have to hand over aspects of assessment too."[1]

Graham Gibbs

INTRODUCTION

Gibbs' quote reflects an often overlooked truism in modern education - Grades are the coin of the realm in the classroom. For most students, assessment is synonymous with grades. But assessment should accomplish more than just providing a basis for assigning grades. It should also provide feedback to improve performance by the student and course effectiveness by the instructor.

There is an interesting parallel between the "Quality" movement in industry and the role of assessment in education. The marked improvements in production efficiency and product quality achieved in the past five years have resulted primarily from a change in management philosophy. Responsibility for product quality has been shifted to the workers, along with mechanisms for obtaining direct feedback on the production process. Through quality circles, workers have joined the team which manages the production process, contributing to solutions of problems and new innovations.

The conventional approach to engineering education is similar to traditional management philosophy. Students, like workers on the assembly line, are assigned tasks to complete, including homework assignments, lab reports, and examinations. The instructor grades these to determine the quality of student performance and provides a numerical evaluation of the result back to the student. The primary purpose for the evaluation is to assign a grade. The student is given little opportunity to provide feedback on the educational process. The end-of-term student course evaluation can be accepted or rejected as a basis for future course/instructor improvement. For meaningful improvement in the quality of education, we need to design much more sophisticated and effective classroom assessment systems. In this paper, a model of incorporating a broad-based assessment program into a course is presented.

K. Patricia Cross, the 1991 Distinguished Lecturer, states, "We will not make effective progress in reducing the gap between what is taught and what is learned until the classroom instructor is more actively involved in the assessment process."[2] She distinguishes between assessment-for-accountability, in which the feedback is public, normative, comparative, and competitive, and assessment-for-improvement, which provides a continuous flow of information to aid in shaping teaching and learning while in process. Assessment-for-improvement, which parallels the industrial "quality" philosophy, is typically formative, is most effective if not made public and emphasizes competencies rather than comparisons.

COURSE OBJECTIVES AND ASSESSMENT

As in industry, quality must be defined in terms of outcome specifications. Without performance objectives, which define what the student should know and be able to do, it is difficult to design an effective assessment system. Professor John Heywood, author of Assessment in Higher Education[3], describes efforts to improve assessment in English universities in this way: "If learning is to be enhanced, then the design of comprehensive examinations becomes a complex activity which has to take into account the effects of instruction on learning and the attainment of objectives."[4] He illustrated various components in the design of curriculum in the cycle shown in Figure 1. It should be noted that, while the syllabus drives the learning strategies, the syllabus itself works in interaction with aims, student assessment, program evaluation, and materials.

In response to Heywood's premise, I have found it helpful to write three independent, but complementary, sets of objectives for a course, which define what the student should know (knowledge), be able to do (skills), and how he should feel about it (attitudes). The objectives form a living which will change as the course develops and in response to the personality of each class.

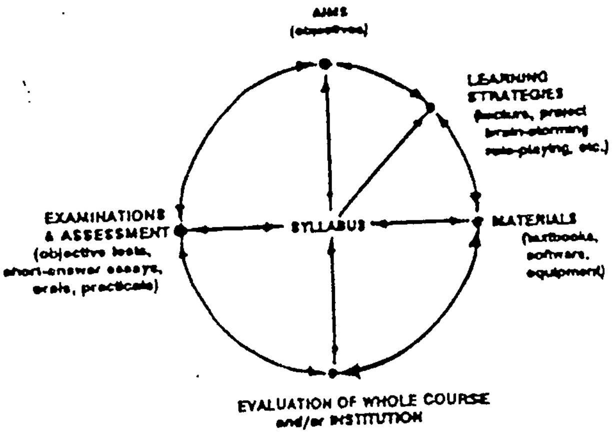

Figure 1 - Assessment-Curriculum-Instruction Process

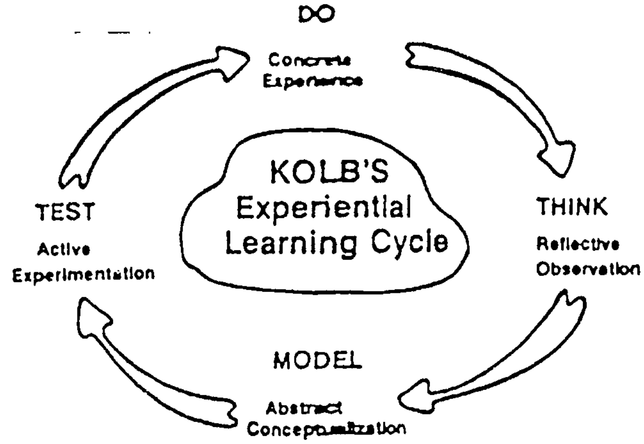

Figure 2 - Kolb's Experimential Learning Cycle

For the objectives to be of value, they must be used before, during, and after the course as part of an ongoing evaluation of student learning effectiveness. Students should be provided with a copy of the objectives at the beginning of the term and have their importance emphasized. The objectives will define the level of mastery required in each topic and suggest methods of evaluation which will determine if the objectives have been met.

KOLB'S EXPERIENTIAL LEARNING CYCLE APPLIED TO A TECHNICAL CONCEPT

In previous papers, I have described the stages of intellectual development of college students as defined by Perry.[5] It is assumed that such development is desirable and that properly designed educational programs can stimulate intellectual growth, in contrast to the lack of growth exhibited by students in conventional programs. As previously mentioned, assessment is perhaps the most powerful tool for encouraging students to stretch beyond their current level. For growth to occur, the students must be stretched in a manner which is not always comfortable, to reach for a goal that they think is beyond them. In conventional courses, intellectual challenge is almost entirely based on increasingly difficult analysis of more advanced material, but not synthesis or evaluation. It does not provide alternative methods of learning the material or for demonstrating that knowledge. Combining Perry's scheme with Kolb's Experiential Learning Cycle, along with the assessment methods which are available at each stage, provides a model for building mastery of a subject while stimulating intellectual development.

The Learning Cycle - David Kolb describes a logical sequence of events through which an individual will pass in learning a new concept: concrete experience, reflective observation, abstract conceptualization, and active experimentation.[6] As shown in Figure 2, these can be described for learning in a technical course in terms of the action verbs: Do, Think, Model, and Test.

The Curriculum Cycle - The first step in designing a course to teach a new concept is to write a series of learning objectives. Next, a series of activities which follow Kolb's stages of learning are selected that represent an increasing level of knowledge and a corresponding increasing level of intellectual functioning.

Figure 3 provides an example of such a curriculum cycle. It starts with a concrete experience such as a demonstration of the concept to be taught. At this entry level, it is critical to stimulate the student's curiosity for the topic, it's importance, it's validity, and it's intrinsic beauty. This can be done through such activities as a physical demonstration, graphical modeling on the computer, and/or videotapes of its application in the real world. If the student isn't interested in the subject, she will learn it to the level needed to pass the examination, but her psychic energy will be directed elsewhere.

The second step, reflective observation, can be accomplished by getting the student to learn the vocabulary and become aware of the basic concepts, formulas, etc. which undergird the concept. This is where the text book comes in. Most students only read the text book to copy out the homework problems or look at sample problems for hints on the solution procedure. But if the student does not know the vocabulary for the topic under discussion, much of the value of the lecture will be lost because it won't be understood. A list of vocabulary words or questions to be answered helps direct the students' reading and heightens the "reflection" on what is found. This activity is also helps build the skills of reading and information retrieval critical for life-long learning.

The third step, abstract conceptualization, is where most instructors start, with derivation of the mathematical formulas which describe the physical phenomena under discussion. While most instructors do this through a

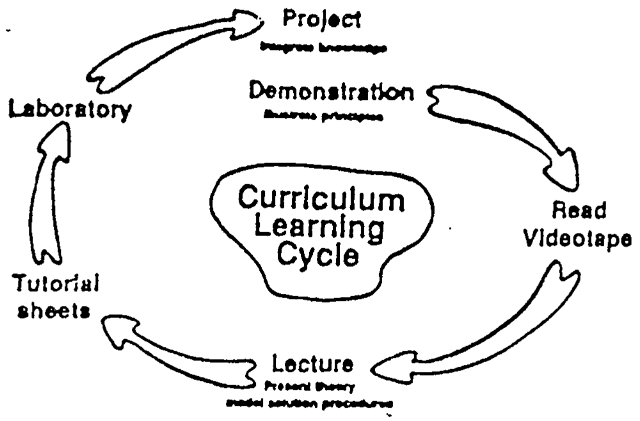

Figure 3 - The Curriculum Learning Cycle

formal lecture, Karl Smith uses an alternative delivery model based on cooperative learning.[7] In either case, the goal is to model for the student the method by which professionals use theory to describe the physical world.

The fourth step, active experimentation, could entail two forms of learning, practice problems and laboratory experiments. Each has its role to play. The practice problems require the student to review class notes and the text to understand the concepts and use mathematical analysis to apply them in a variety of situations. The laboratory provides an alternative, more concrete, method of understanding the concepts and provides an opportunity to explore the approximate nature of the mathematical models used in engineering analysis. It also develops skill in using technical equipment, making physical measurements, and performing data analysis.

The learning cycle starts over again with application of the concept being learned to a design problem and/or project in which it is tied to other concepts; a new concrete experience but at a much higher level than the original demonstration. The project should require the student to deal with the concept under study at the synthesis/evaluation level. It can also provide practice in the skills of project management, time management, oral and written presentation, and open-ended problem solving.

The Assessment Cycle - In parallel with these activities is the assessment that can be used at each stage of the cycle and the objectives which are being measured by each. (Figure 4) Some of these assessment activities will be primarily formative, providing feedback to the student and the instructor on what is known and the rate of progress. Others will be primarily for the purpose of measuring student competence and assigning a grade. It is implicit that each assessment activity also serves as a potential source of feedback to the instructor on the effectiveness of the learning activity.

The assessment activity in support of step two, the reading phase, could be a check list of definitions and equations which the student should locate in the reading. If additional structure is needed in order to insure that the student does the reading, the instructor could give a short quiz at the beginning of the class period. This might be done in order to meet the objective of building skill in reading technical literature.

During a lecture, step three, a possible form of feedback is a discussion question or problem handed out to the students to be worked in pairs. Ostermann proposes that this be done after about 20 minutes, at the point where student attention tends to drift.[8] Five to 10 minutes spent on this activity is rewarded by increased attention, better understanding of the material just covered, and feedback to both the student and instructor on the level of understanding of the topic. The discussion question also gives a means of taking role in a large class and stimulates cooperative learning between students.

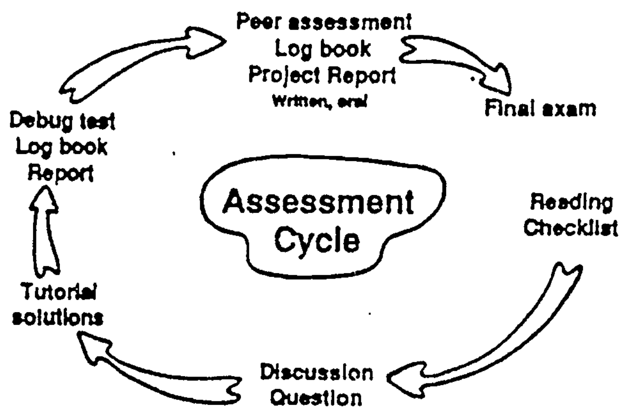

Figure 4 - The Assessment Cycle

Use of homework for assessing learning, step four, is common in engineering courses. To improve the level of feedback to the students, one might have the students grade one problem on each other's homework, using a grading scheme provided by the instructor. This reinforces the importance of doing the problems, and provides students with a model for effective solutions and examples of a variety of approaches. This technique was used at the University of Strathclyde, with a significant improvement in student test performance.[9]

Peer marking can also be used on midterm examinations for the same reasons. While additional time is required in preparing the examination and the solution marking procedures, instructor time is saved on marking the examinations and students benefit from the more effective feedback.[10]

The laboratory report is a logical means of obtaining feedback on student learning. However, the conventional report provides little insight on student knowledge. Most students can complete the laboratory assignment and meet the course requirements, given enough time. If the students are working in pairs then it is possible that one student is carrying the other. This is an area where the skill objectives should be clear and distinct from the knowledge objectives and should be measured separately. Skill in using equipment, taking accurate measurements, precision in calculations, and effective writing are all required for effective laboratory performance. Understanding of the physical concepts is equally important but quite separate. An appreciation of safety regulations, responsibility for ones own experimental results, and the importance of experimental work for creative engineering practice are attitudinal objectives which require separate attention.

Two other activities besides the lab report which can help in measuring these skills and attitudes are the log book and the debug test. A log book provides an opportunity for the student to keep track of his progress in learning the topic under study, particularly in the laboratory. But it should be a record of all learning that is going on. Optimally, the instructor will read the log book and discuss its contents with each student. Practically, there is little time for this. However, someone besides the student should read it and should make comments on the entries, both in order to improve the use of the log book and to help the student appreciate the progress that is being made. Donald Woods makes use of the logbook to help students develop self assessment skills.[11]

The debug test, or lab practical, is an attempt to determine whether the student really understands how to use the equipment. It can involve nothing more that setting all the dials on an oscilloscope to zero and asking the student to set it up to accomplish a particular sweep and gain. Or, at a more sophisticated level, the instructor can introduce a bug into a piece of equipment and ask the student to determine what is wrong. This activity will separate the students who understand the equipment from those who rely on others for help in the lab. If students understand that this is an objective of the lab and that they will be tested on it, they will take a different approach to using the lab equipment.

The design problem/project step provides an opportunity for a much wider range of assessment. Too often in project courses, the objectives and methods of assessment are poorly defined, so the student is working in the dark. Frequently, the instructor is also unsure of how to assess design/ project work. Approaching the assignment from a professional perspective can help. If this were an assignment to a junior engineer in industry, what would be measured? How would the assignment be made? What would be considered an acceptable outcome? How would the engineer be expected to report the results of his work? To whom? The assessment should be framed such that it measures performance at the synthesis/evaluation level. Many design projects only require analysis. Problem definition should be a major part of the assignment.

As in the laboratory assignment, the assessment can measure skills in a variety of areas, such as: group participation and leadership, project management, time management, oral presentation, report writing, and professional attitudes. Some of these may be measured purely for feedback and to support skill development, particularly the first time they are measured. Without some form of assessment, they may not be taken seriously. Furthermore, many students will not see them as skills which can be developed with practice.

If the other forms of assessment listed above are used during the course, the final examination can be purely for the purpose of accreditation. The formative assessment included in the other activities will provide adequate feedback to the student.

The curriculum and assessment activities selected above are purely illustrative. The types of assessment activities, as well as their scope, will depend upon the learning objectives set for the course. Careful analysis of the results of each assessment activity can provide the instructor with valuable information on how to improve the course and which forms of assessment are most useful to student and instructor.

FEEDBACK FOR COURSE DEVELOPMENT

While it is implicit in the description of the curriculum/assessment cycle given above that the instructor is obtaining feedback on the effectiveness of learning activities, there are two specific means of obtaining feedback that should be mentioned. I have found the use of class representatives and midterm course evaluation sheets to be simple and effective ways of obtaining feedback during the semester which permits me to adjust the course to meet the needs of a particular class.

Class Representatives - Most students are reluctant to inform the instructor if there is a problem with the way a course is organized or is being taught. There is always the assumption that if a student complains, that part of the fault is with the student, not the course. To circumvent this problem, I ask for three student volunteers to serve as class representatives at the first or second class period. Class election of representatives proved burdensome.

I meet with these students about once a month, starting about two weeks after the beginning of the semester. Because they are representing the class, they do not have to assume personal responsibility for their comments. It is important to report back to the class on their comments after the first meeting, and any changes in schedule, etc., should be attributed to the student input. After the first meeting, other students in the class will begin to seek out a representative if they have problems. By the end of term, if there is a problem, the representatives will come to see me on their own initiative.

The class representatives frequently become the instructor's advocate with the rest of the class. Because they have taken the time to get to know the instructor personally, and have learned about the rationale behind the course, they can answer many student concerns before they become a problem.

Midterm Course Evaluation - A single sheet questionnaire with room for short answers in response to questions on course organization, presentation, etc., permits the students to identify what they like and don't like about a course. A Likert Scale (1 to 5) does not provide useful feedback in this case. The midterm evaluation identifies ways that the course can be modified to improve student learning in that particular class. It is important to give students time in class to fill out this form. If they are rushed, or if they complete it out of class, the answers will not be as informative.

CLOSURE

How much assessment is enough? Look at your research and ask yourself the same question concerning the level and magnitude of results required to support your publications. We should be able to defend what we are doing in the class to the same level that we can defend our research. Otherwise, we are not meeting our professional responsibilities.

RICHARD S. CULVER

Dick Culver is Professor of Mechanical Engineering at the State University of New York at Binghamton and Visiting Professor at the University of Salford, Manchester, England. Formerly Associate Dean for Academic Affairs, he helped develop the engineering program at Binghamton which started in 1983. Prior to coming to Binghamton, Dr. Culver was director of the EPICS Program at Colorado School of Mines, where he served on the faculty over a period of twenty years. He has also served on the faculties of Ahmadu Bello University in Nigeria and the University of Calgary, in Canada.

Active in ASEE, Dr. Culver is past chair of the ERM Division, and was general chairman for FIE'89. With Peggy Fitch, he has presented workshops in the US, Canada, and England, dealing with intellectual development and rational curriculum design.

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Educating for Maturity: Perry's Model for Intellectual Development*

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Modern engineering education programs are very effective at teaching students the technical material of the engineering profession. They are less effective at preparing them for the practice of engineering, where the problems are typically complex and ill-defined, and have critical, nontechnical components. Effective engineering practice calls for a professional who is intellectually and ethically mature, who can deal with complex issues, make effective use of authority, and assume responsibility for his/her decisions. Perry's model for intellectual development provides an effective description of intellectual maturity and suggests the types of instructional activities which will stimulate intellectual growth. In this paper, the author compares the challenges faced by the student in a traditional engineering education program with those faced by the professional and shows that, since the challenges are different, the students are not being encouraged to develop the critical skills and attitudes required by the professional. With Perry's model as a theoretical basis, he then describes educational activities which can stimulate such development and lists some engineering programs which have incorporated these activities into their curricula.

MATURITY; "The state of being fully developed in body and mind"— *Webster's Dictionary.*

INTRODUCTION

WHEN asked what attributes he would seek in a new graduate, a practicing engineer started the list with:

> "He, or she, must be able to mature rapidly. We give new graduates responsibility much more rapidly than in the past."

As I explored the characteristics of the effective professional, this attribute seemed to encapsulate the others.

Accepting this as a goal presents a significant challenge to engineering schools, as it suggests that we should build an emphasis into our programs that currently seldom exists. Since there is far more to teach than can possibly be covered, we must carefully assess what is the optimum use of our 4-year window of opportunity when preparing our students for professional practice.

In particular, it challenges the professor to expand his role in the education of the student. On most counts, we do a good job of mentoring the full-time graduate students, serving as professional role models, and engaging them in the learning process. But only a small percentage of our students go on to graduate school and most who do are preparing themselves for that narrow portion of the engineering profession dealing with research. For most undergraduate students, contact with the professor is superficial, constrained by the boundaries of the class period and format.

What are the characteristics of the mature professional engineer? Innumerable studies have addressed this question. For the purposes of this paper, I will use the following: The effective professional:

(1) has mastered a body of knowledge and the corresponding skills central to his field of practice,
(2) exercises good judgement in making decisions,
(3) uses authority as source of expertise,
(4) assumes responsibility for decisions,
(5) is capable of thinking critically and complexly,
(6) deals with problems in their total complexity,
(7) uses reflective thinking and self-evaluation,
(8) has an effective and socially responsible value system.

In earlier papers, Culver [1, 2] has contended that a person with these characteristics is capable of a high level of intellectual functioning, as defined by Perry [3]. In this paper, I will compare the similarities and differences between the effective student and effective professional with Perry's model, propose some goals for the educational program, and look at the role of the professor in achieving them.

PERRY'S MODEL

In the 1950s, William Perry, Director of the Bureau of Study Counsel at Harvard College, undertook a longitudinal study to determine "what

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happens to a student exposed to four years of liberal arts education?" The research occurred within the framework of an educational philosophy which claims that education should nourish the process by which a student approaches complex issues. This increasing sophistication occurs in part as the individual matures, but also in response to stimuli in his environment. Thus, college students will mature intellectually when exposed to an environment which fosters critical thinking.

Perry's study, based on the cognitive-development views of Piaget [4], started from an empirical base. He began by focusing on how college students respond to the intellectual and moral atmosphere at Harvard College, an atmosphere that appears to present constant challenges to the students' unexamined assumptions about the world around them. After 4 years and 98 recorded interviews, Perry and his colleagues observed that there appeared to be "... a common sequence of challenges to which each student addressed himself in his own particular way." This led Perry to formulate a model for the sequence of intellectual development. He then expanded the study to test his hypothetical model under better controls.

The following is a paraphrase of the stages, or 'positions', of intellectual development identified by Perry:

Dualism

Position 1. Students see the world in polar terms of we–right–good vs other–wrong–bad. Absolute right answers exist for everything; the answers are known by Authorities whose role is to mediate (teach) them to students. Problems are solved by following the word of an Authority, rules, tradition or the norm. Knowledge and goodness are perceived as quantitative accumulations of right answers that are collected by hard work and obedience.

Position 2. Students begin to perceive alternative views as well as uncertainty among Authorities, but account for them as unwarranted confusion among poorly qualified Authorities. They may decide that uncertainty is simply a game devised by Authority 'so we can learn to find the Answer for ourselves.' Their arguments are often illogical, and they do not understand the use of evidence.

Multiplicity

Position 3. Students see diversity and uncertainty as legitimate, but still temporary, in areas where Authority 'hasn't found the Answer yet.' They begin to see Authority as 'biased' or arbitrary in that they are graded for 'good expression.' The apparent lack of standards is puzzling, and many students begin to view all arguments as equally correct or biased, or both, with decisions based predominantly on personal belief. The hard sciences and mathematics seem better understood by Authority than humanities or social sciences.

Position 4. (a) Students perceive legitimate uncertainty (and therefore diversity of opinion) to be pervasive and raise it to a realm of its own in which 'anyone has a right to his own opinion,' as opposed to Authority's realm, where right and wrong still prevail. Or (b) students discover qualitative, relativistic reasoning as a special case of 'what They want' within Authority's realm. In either case, students are suspicious of the 'truth' of any evidence or an authority's opinion, and often deny that opinions can be objectively evaluated.

Relativism

Position 5. Students perceive all knowledge and value (including authority's) as contextual and relativistic. They subordinate right–wrong problems to the status of special cases, in a frame of reference. They begin to recognize that all points of view are not equally correct and may argue on the basis of evidence that one is more likely.

Position 6. Students recognize the need to orient themselves in a relativistic world through personal Commitment (as distinct from unquestioned or unevaluated commitment). While they can rely on evidence, they still may not synthesize that evidence for themselves but rely on the synthesis of others.

Commitment in relativism

Position 7. Students make an initial Commitment in some area, such as career selection, values, religious belief etc. However, they examine the views they endorse based on logical evaluation of evidence, the opinions of experts, as well as reasoned conjecture about 'what appears to be true.'

Position 8. Students experience the implications of Commitment, and explore the subjective and stylistic issues of responsibility.

Position 9. Students experience an affirmation of identity among multiple responsibilities and realize Commitment is an ongoing, unfolding activity and that their own views may be incorrect and may need to be reformulated in the future in light of additional evidence.

According to Perry, one of the major accomplishments of college students is to progress from a simple, dualistic view of life and knowledge to a more complex, mature view which is also relativistic. Until this transfer occurs, students are not 'their own people' in the sense that their values, attitudes and life goals are borrowed from the influential Authority figures in their earlier development. Note that when the transition occurs the 'Authority' in the upper case (unchallenged) becomes the 'authority' in the lower case, who the student has evaluated and accepted as having the best answer at the present time.

While Perry found that most Harvard students had reached position 6 by the time of graduation, subsequent studies have indicated that, in the academic environment prevalent on most modern campuses, there is relatively little intellectual development in the college years [5]. Most students enter the university in position 2, or 3, and leave in position 4, which probably is not what most educators would prefer. This position is characterized by:

(1) a tendency to treat all opinions as equally good,
(2) little evaluation of alternative views of an issue,
(3) a tendency to hold one's opinions largely on the basis of whim and unsubstantiated belief,
(4) a hesitancy to take a stand or commitment based on evidence and reason [6].

Interestingly, position 5, where the transition from multiplicity to relativism occurs, was rarely identified by the students while they were in that position. Only in retrospect could they identify this fundamental change in their way of thinking.

Apparently, the transition process from concrete to abstract thinking is perilous, requiring concerned challenge and reinforcement by the instructor. Newell recognized that during this transition, the students commitment is noticeably reduced. At the lower stages of Perry's model, commitment is based upon 'faith' in Authority and the rightness of Authority's positions on key issues. As the student grows, that faith is slowly eroded by unreconcilable conflicts. Only when the student gradually rebuilds commitment through a process of personal analysis will he be able to convert what was faith into personal and self-committed belief [7].

This process is illustrated schematically in Fig. 1 where, at the lower stages, everything is black or white and a dominant Authority figure has all the right answers. As diversity increases, commitment declines until the transition at position 5 creates a new, more open viewpoint. A need for commitment is realized at position 6, initially attempted at position 7, evaluated at position 8, and established as a process of continual revision and development at position 9.

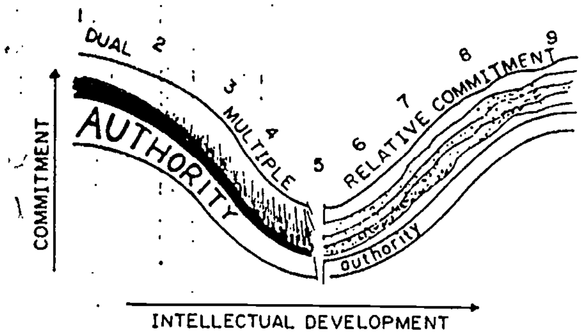

Fig. 1. Perry's model of intellectual development.

EFFECTIVE PERFORMANCE IN AN ENGINEERING ENVIRONMENT

Perry's model provides a tool for looking at how we prepare engineering students for professional practice. Let us approach this task by comparing the challenges and performance of the successful student with the successful practicing engineer, on the premise that professional preparation is best accomplished by having the student model professional behavior. Table 1 presents a comparison of the measures of success for the student and the professional. It shows that the student is expected to learn prescribed solutions to classes of problems. He is measured by the professor in his ability to perform these procedures quickly and correctly. By contrast, the major challenge for the professional is determining what problem needs to be solved. Speed is not as important as insuring that the problem is properly defined before solution proceeds. The problems faced by the professional

Table 1. Criteria for effective performance

	Engineering student	Professional engineer
(1) View of knowledge	Discrete facts, procedures, subjects	Connected concepts and facts
(2) Critical knowledge	Algorithms and facts	Heuristics for decision making
(3) View of instructor/ supervisor	Source of knowledge, authority	Source of expertise, support
(4) Source of Evaluation	Instructor	Self and peers
(5) Approach to learning	Responsive	Proactive
(6) Work/learning environment	Competitive	Cooperative
(7) Critical problem-solving skills	Efficient at solving structured problems	Effective at defining problems
(8) Goal of work	Good grades	Usable product or service

are typically complex and multifaceted, requiring cooperative input by other professionals and self-education in new areas as the solution progresses. While the student defers to the professor as the source of knowledge, right answers, and evaluation, the mature professional selects authorities on the basis of expertise, but assumes responsibility for evaluation of his own work.

While exceptional work has the hallmark of creative genius, whether produced by the student or the professional, it can be seen that, in virtually all the areas listed in Table 1, the approach and criteria are different. By comparing the lists in Table 1 with Perry's model, it is apparent that the challenges presented to the student reinforce the functioning in lower, dualistic positions, while the successful professional is called on to function in the higher, relativistic mode. If the academic challenge does not encourage performance at the higher levels, the student has no incentive for intellectual growth.

In his book, *The Reflective Practitioner*, Schon [8] describes how the effective professional uses reflective thinking during the critical phases of problem formulation. The reflection tends to be intuitive, nonlinear and, at times, nonrational. Through practice, he develops the judgement needed to expand the variety of problems addressed and the effectiveness of the solution. By contrast, the applied scientist uses a more elegant, rational approach to the development of analytical solutions. Schon distinguishes between the engineering professor, who he sees as an applied scientist, and the practicing engineer in terms of convergent and divergent thinking. Since it is the applied scientist that is recognized by the educational establishment, it is his approach to problem solving that is typically presented to the student in the classroom. While competence in analytical solutions is also a critical skill for the practicing engineer, it is but one of many skills needed for effective professional practice. I contend that our students also need practice in dealing with open-ended, ill-defined problems in order to start developing the art of the practitioner and the ability to handle complex systems.

RESTRUCTURING THE CURRICULUM

If we wish to improve our students' preparation for professional practice, we need to identify those skills and attitudes which are underdeveloped in our current graduates. The report of the Future Graduate Study at the Colorado School of Mines [9] acknowledged that the graduates were technically competent and hardworking. However, along with graduates from other engineering schools, most graduates "... lack good communication skills, even in writing. They are unfamiliar with working in interdisciplinary groups ... cannot investigate an unfamiliar problem starting from fundamentals, and impart only limited knowledge of, *and interest in*, their responsibilities to their social, political and natural surroundings ... the full (heavy) curriculum and insularity of departments leads to the 'credit syndrome', in which each course is seen as a hurdle to be jumped and left behind ... The narrow nature of their assignments leads to a cook-book approach to the solution of well-defined problems, at which the graduate is adept but also to a lack of curiosity and a reluctance to approach broader, unfamiliar, problems from a fundamental standpoint."

The reasons for these limitations are not hard to find. The growth of public education, with limited resources and increasing enrollments, has developed an approach to education which emphasizes memorizing answers and solutions to standard problems. Multiple-choice tests, lectures with 400 students, and depersonalization of the learning environment have led the students to see learning as a means to an end rather than an end to be valued in itself. Emphasis has been placed on fitting more subjects into less time and more details in a given course. We hear more about the student who finished the prescribed program in 3½ years than the student who chose to reduce the course load in order to learn the material more thoroughly or explore areas of interest outside those required for the degree.

What can we do? Some features of a professionally-oriented program are:

(1) give the student more *ownership* of his learning,
(2) reduce the prescribed *work load* and increase *project emphasis*,
(3) create '*marker events*' which can give meaning to the learning,
(4) have a *mentor* for each student,
(5) structure the educational activities to stimulate *increasingly 'mature'* performance,
(6) train the student in *performance evaluation*,
(7) involve students in *each other's learning*,
(8) provide projects for students with *professional context*,
(9) create activities that involve *risk taking* and assuming *responsibility* for the consequences,
(10) use '*developmental instruction*' concepts to design educational activities.

Ownership—Ownership of learning implies that the student sees himself in *control* of his educational program and, because of a positive attitude towards it, becomes actively *engaged* in the learning process. The other features listed below will suggest how this can be accomplished.

Reduce course workload—A common rule of thumb is that a student can be expected to work 55 h per week. Assignments need to be balanced throughout the program so that they can be completed within this time frame. If the workload is so heavy that the student cannot master one concept before passing onto the next, it leads to *superficial* *learning* which is unsatisfying and results in a *survival mode* of operation in which learning runs a poor second to passing the course.

Project emphasis—To combat the 'credit syndrome', students need to know how they will use the subjects being studied in math, science and humanities. This can best be illustrated by having them involved in 'doing engineering' at an early stage, even if the projects are technically trivial. In class discussions during the project, the instructor can explain the relevance of the other courses to the educational background of the professional, but in the context of the project.

Marker events—Students are more likely to retain a new procedure or concept if it is tied to an event which has personal significance to them, that stands out in their memories. This event frequently is the basis for new insight, a rearranging of thinking, and major jumps in growth. It can be positive or negative. (Failing a course is a marker event for most students.) Since the 'marker' is the student's response to a stimulus, not the stimulus itself, we cannot force our students to experience markers in our courses, but we can create an environment in which they can happen. The more intense the response, the longer the lesson will be remembered. Industrial tours, student design competitions, an impressive laboratory demonstration, or the completion of a major project are likely sources of marker events. A course designed to include two or three activities with marker potential is more likely to influence a student's career than one without.

Mentors—People recognized as successful uniformly identify the mentors who were critical in shaping their careers. The typical advising system used in engineering schools is not designed to develop a mentor relationship between student and faculty. Given prevalent student–teacher ratios, it is unrealistic to put this burden entirely on the shoulders of the faculty. But upperclassmen, properly trained, could start the process with freshmen. Professionals from industry could assist on a Big Brother basis. The student needs help in making meaning out of a collection of courses.

Professional projects—Left to pick their own projects, students tend to select something that is narrowly defined, using previously developed skills, or a project so broad that it can't be managed. Carefully selected projects, submitted by an external client, can provide real-life experience. These should have a social or economic context which the students are required to address as part of the solution. Project teams with students from different academic years can provide internal mentoring. The client-based project has strong marker potential.

Increasing maturity—It is unreasonable to expect a freshman to function as a self-managed learner. (For discussion of self-managed learning, see Culver [10, 11].) But since effective engineers MUST do so, the transition would ideally occur during the 4 years on campus. The process can start with a freshman project or design course. By the senior year, most courses should be structured to call on 'mature' performance, with the instructor as coach instead of manager and judge.

Performance evaluation—One of the marks of the mature professional is the ability to evaluate his own work and assume responsibility for it. Peer evaluation is important in developing the student's understanding of professional relationships. Students should start with quantitative evaluation and progress to qualitative evaluation of reports, oral presentations etc.

Cooperative learning—The academic environment is primarily competitive, but the critical phases of professional performance normally occur in design groups, which must work cooperatively. Competition between student project teams can give the students the opportunity to experience both concurrently.

Risk and responsibility—Risk taking and assuming responsibility for results are critical qualities of the professional. In most cases, the risk in an educational activity must be dissociated from the grade received or the students won't 'play the game.' Academic risks do not accurately model the risks faced by the professional. Projects, simulation games, and student competitions are good ways of exposing students to risk taking.

Developmental instruction—Based on Perry's intellectual development scheme, Cornfield and Knefelkamp's developmental instruction model provides a procedure for selecting and designing educational activities to achieve an optimum balance between *support* and *challenge*. Experience has shown that this approach to curriculum design can significantly increase the rate of student development. Fitch and Culver presented a workshop on Developmental Instruction at the 1985 Frontiers in Education Conference, which is reported in the Proceedings [12].

THE ROLE OF THE INSTRUCTOR

From the statements above, it is apparent that the professionally-oriented program envisaged would pose a different role for the professor. Instead of functioning as an 'independent subcontractor' who lectures on a given topic, with a student assistant to do the grading, the professor would be a member of a management team which supervises the student's learning. Some of the activities suggested could be built into an individual course, but since student growth to 'mature' professional functioning is a gradual process over the 4-year period, it will occur most effectively as the result of planned growth, rather than a series of disjointed efforts by individual professors. This calls for a redesign of the curriculum with the goal of producing a graduate prepared for professional practice, as well as for research-based graduate studies. It would be a program designed to emphasize general professional skill development, rather than the specific technical skills needed during the first year on the job, although some technical skills would be covered as practice in self-education.

In his role as a learning manager, the professor would work with the student through a learning contract, serving as coach and mentor. While a course in such a program might look similar to conventional courses from the outside, the interaction between student and professor and their expectations for the course would be different. If the student is to gain control over the learning, the instructor would have to give up some control. This would require more tolerance on the part of the instructor, since the student will make some mistakes as he explores the scope of his responsibility. It will also demand more of the professor's energy, since it takes more effort to manage a system that you do not completely control.

As control is gradually shifted to the students, evaluation should begin to look and feel more like that which occurs in a professional environment. The professor would be responsible for monitoring the quantity of work being assigned, as well as the amount and quality being produced. In the professional work place, the manager is responsible for insuring that assignments can be completed according to schedule, since he is evaluated on his ability to manage the projects in his charge. This type of accountability is alien to most higher education, but could be the basis for insuring responsible instruction, as well as effective learning.

SOME EXAMPLES OF PROFESSIONALLY-ORIENTED PROGRAMS

This may sound like an overwhelming job, but it has been achieved to varying degrees in some innovative engineering programs in the United States.

Worchester Polytechnic Institute (WPI) restructured its curriculum in 1971 [13]. The WPI PLAN, as it is known, emphasizes competencies, individual freedom within a student's curriculum, self-initiated investigation, and new instructional methods which join students and faculty in a learning partnership. The four major activities of the PLAN include:

(1) a competency evaluation of a major field of study,

(2) a major qualifying project (MQP) which integrates formal academic studies in the student's major field through an in-depth research project,

(3) an interactive qualifying project (IQP) which focuses on the interactions of technology with society and human values,

(4) a sufficiency in a minor area.

The MQP and IQP provide the practical experience required for professional preparation, while the procedure for selecting courses and minor give student ownership of his learning in a manner uncommon in undergraduate education.

Harvey Mudd College established the Engineering Clinic in 1960, where junior and senior undergraduates work with a master's candidate on a client-submitted project, on which the graduate student serves as a project leader [14]. As in the WPI program, the projects are carefully screened to provide appropriate learning opportunities. Since the institution guarantees completion of the project, students may leave the institution before the project is complete. Permitting students to work into increasingly responsible positions within the project team models professional development of the graduate engineer.

A similar Design Clinic was developed by Lee Harrisberger at the University of Alabama. Senior mechanical engineering students do individual projects and participate in exercises selected to teach professional skills during the fall semester and then participate as members of project teams to solve client-based problems in the spring semester [15].

The guided design principles developed by Wales and Stager are uniquely successful in teaching a process for problem solving and decision making [16]. Guided design exercises are particularly valuable as an introduction to open-ended problem solving.

The EPICS Program at Colorado School of Mines encompasses developmental instruction concepts into the first 2 years [17]. A four semester, 10 credit hour course sequence, EPICS integrates instruction in graphics, computer programming, technical writing, and open-ended problem solving in a manner which provides a context for upper-division engineering courses. The fact that the instruction is spread over four semesters is important because it paces the student's personal maturation.

In recent years, several other engineering schools in the United States have begun to adopt some of the ideas presented in the programs described above.

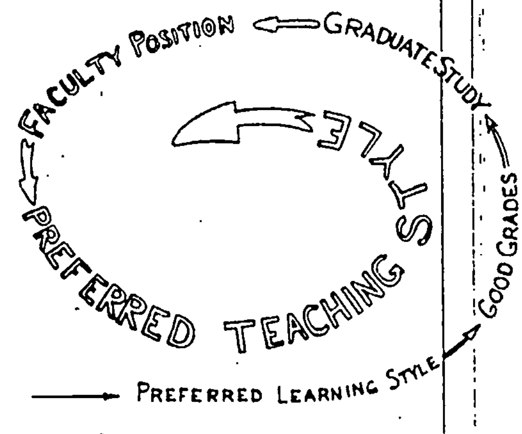

Fig. 2. Vicious cycle of preferred learning styles.

MANAGING CHANGE

The educational concepts proposed above are ambitious, perhaps even threatening to some, because they call for planned growth and change of both the student AND the professor. Students prefer to learn in a mode that is comfortable; the traditional lecture format is comfortable because it is familiar and responsibility for the learning rests primarily with the instructor. The professor prefers the traditional mode because he learned well that way. Otherwise he would not have made the grades to go to graduate school and on to a position on the faculty. This is the vicious cycle of preferred learning styles (Fig. 2).

However, if the educational program is going to improve, it must change. This will require change in the way we teach, and the change will involve risk. It is important, therefore, that the administration of the educational institution also assumes its responsibility for improvement of the program through innovative development. This can best be done by openly supporting faculty who are willing to risk learning new ways to teach.

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Educational Engineering: Heuristics for Improving Learning Effectiveness and Efficiency*

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The development of student skills can be improved by the application of cognitive learning procedures. Knowledge representation strategies are described in relation to the construction of knowledge bases for use with expert systems. Active involvement of students is stressed since meaningful learning is enhanced by talking with peers and preparing to teach others.

INTRODUCTION

"IT IS strange that we expect students to learn, yet seldom teach them anything about learning. We expect students to solve problems, yet seldom teach them anything about problem solving, and, similarly, we sometimes require students to remember a considerable body of material, yet seldom teach them the art of memory. It is time we made up for this lack . . ." [1, p. 97].

Educational engineering is based on recent developments in knowledge engineering and cognitive science. The contribution of knowledge engineering (and the broader field of cognitive science) for improving learning efficiency and effectiveness will be discussed along with the implications and importance of these considerations for engineering education.

Drucker coined the terms efficiency (doing the thing right) and effectiveness (doing the right thing) in reference to business management [2]. The terms apply equally appropriately to learning efficiency (enhancing the rate of learning) and learning effectiveness (enhancing the mastery and retention of facts, concepts and relationships). Students' learning effectiveness and efficiency can be enhanced by providing them with strategies that promote learning how to learn.

LEARNING HOW TO LEARN

The concept of "learning how to learn" was first articulated by Bateson [3] who termed it "Deutero-learning" and it was associated with the then new science of cybernetics. Also called "double-loop learning" this form of learning involves changes in the governing variables, in contrast to "single-loop learning", which involves learning of new strategies to achieve existing governing variables [4].

The process of "learning how to learn" is commonly referred to in the cognitive science literature as "metalearning". The prefix "meta-" in this usage is supposed to be analogous to its use in the term "metaphysics" and means "going beyond", "on a higher level", or 'transcendent'. In a like manner, "metaknowledge" is used to refer to the structuring of knowledge. Metalearning and metaknowledge are two different but interconnected concepts that characterize human understanding. Learning about the nature and structuring of knowledge helps students to understand how they learn, and helps to show them how humans construct new knowledge. Novak and Gowin [5] describe specific strategies—concept mapping and V-heuristic—for helping students learn about the structuring of knowledge and the process of knowledge production. Concept maps are intended to represent meaningful relationships between concepts in the form of propositions. They are overt, explicit representations of the concepts and propositions a person holds. The V-heuristic is an aid to help students understand the contribution of and the relationship between conceptual and methodological views in making sense of events or objects observed.

The approach of this paper will be to follow the engineering method, defined by Koen [6] as "the use of heuristics to cause the best change in a poorly understood situation within the available resources". Heuristics from cognitive science are reviewed that assist in making the best change in students' learning effectiveness and efficiency.

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ROLE OF HEURISTICS

Heuristics are essential for a discussion of learning how to learn since there are no clear-cut algorithms for second-order learning. The word "heuriskin", meaning "serving to discover". Heuristics have become very popular in the cognitive science literature, and interest is growing once again in the problem-solving literature [7, 8] and the engineering-method literature [9].

One of the most prolific promoters of heuristics was George Polya. Polya [10] proceeded from three assumptions: (1) "heuristic" means "guiding discovery"; (2) solving a problem certainly involves a bit of discovery, hence it involves an heuristic process; and (3) investigation into heuristic processes cannot aim at finding infallible rules of how to make discoveries. Polya's work in heuristics is aimed explicitly at teaching the young how to be better problem solvers [11]. The main usage of the word "heuristic" at present is as an adjective in the sense of "guiding discovery" or "improving problem solving". Although difficult to define, heuristics are easy to identify using the characteristics listed by Koen [6]: heuristics do not guarantee a solution; two heuristics may contradict or give different answers to the same question and still be useful; heuristics permit the solving of unsolvable problems or reduce the search time to a satisfactory solution; the heuristic depends on the immediate context instead of absolute truth as a standard of validity.

Learning to use heuristic strategies is necessary but not sufficient to ensure competent problem-solving performance. Schoenfeld asserts that these equivocal results have occurred because the complexity of heuristic strategies, and the amount of knowledge needed to implement them, have been underestimated in three ways [12]:

(1) Typical descriptions of heuristic strategies (examining special cases, for example) are really labels for categories of closely related strategies.
(2) The implementation of heuristic strategies is far more complex than at first appears.
(3) Although heuristic strategies can serve as guides to relatively unfamiliar domains, they do not replace subject matter knowledge or compensate easily for its absence.

Heuristics for learning how to learn are likely to be a promising area of research and development. If the teaching of heuristics is to be effective, however, it must focus not only on the heuristics themselves but on their application in a variety of contexts, that is, on when and where to apply them.

CONTRIBUTIONS OF KNOWLEDGE ENGINEERING

Some of the contributions of knowledge engineering (and of the broader field of cognitive science) to metalearning include models of the learner, expert–novice differences, acquisition of expertise, and knowledge structure and representation.

Models of the learner

Bruner [13] outlined five models of the learner that serve as a useful guide to gaining a perspective of the contribution of cognitive science to metalearning. The five models are Tabula rasa, Hypothesis generator, Nativism, Constructivism, and Novice-to-expert. The central notion of *Tabula rasa* "one learns from experience" rests on the premise that experience writes on the wax tablet of the mind. According to this model such order as there is in the mind is a reflection of the order that exists in the world. *Hypothesis generator* learner models react against the passive, tabula rasa models and propose that the learner, rather than being a creature of experience, selects what is to enter the mind. *Nativism* theories share one central concept: mind is inherently or innately shaped by a set of underlying categories, hypotheses, and forms of organizing experiences. The opportunities to use and exercise the innate powers of mind is all. The tenet of *Constructivism* is that the world is not found, but made, and made according to a set of structural rules that are imposed on the flow of experience. The recently developed *Novice-to-expert* view operates within domains and begins with the premise that, if you want to develop learning strategies, find an expert and examine him, then figure out how a novice can become one. Computer simulations are often used to attempt to identify transforms and heuristics that will allow a novice to become an expert.

Bruner [14] offered his synthesis of the general models that we store in our heads that guide our perception, thought and talk by saying that "they appear to be diverse, rich, local, extraordinarily generative". Bruner also discussed two modes of thought, two modes of cognitive functioning, each providing distinctive ways of ordering experience, and of constructing reality. One mode, the paradigmatic or logico-scientific one, is familiar to engineers and scientists. The other, the narrative mode, deals in human or human-like intention and action and the vicissitudes and consequences that mark their course. The importance of the narrative mode lies in Bruner's claim that "great fiction, like great mathematics, requires the transformation of intuitions into expressions in a symbolic system—natural language or some artificialized form of it (p. 15)".

Novice-to-expert

Enormous differences of degree and of type have been observed in the approach taken by experts, novices and uninstructed students in solving problems. Novices ask questions such as "What formula do I know that relates what's given with what I've been asked to find?" They quickly move to a calculation phase and seldom reflect (at least overtly) on what they're doing. Experts ask questions such as "What are the general principles that apply?" They spend more time thinking about the problem, asking themselves questions, and commenting on their understanding of the problem. Schoenfeld [15] mapped the mathematical problem solving activities of novices and experts on numerous problems and noted major differences as described above. Similar results to those noted by Schoenfeld were found for uninstructed students, novices and experts solving physics problems by Champagne *et al.* [16].

Modeling the problem-solving methods of experts and utilizing these models as instructional aids is a very attractive approach, but it is complicated by what experts are able to tell about what they know. Furthermore, although novice-to-expert models are the principal ones followed by cognitive-science researchers it is important to keep in mind that there are many other models of the learner.

Acquisition of expertise

Expertise appears to be acquired through a process consisting of three more or less distinct stages of learning [17]. In the first phase, often termed the stage of cognition or thought, students learn from instruction or observation what knowledge and actions are appropriate. In the second phase, often termed the associative phase of learning, students practice (with feedback) the relationships discovered or taught in phase one until they become smooth (fluent and efficient) and accurate (proficient). In the third phase, termed the stage of automaticity, relationships are "compiled" through overpractice to the point where they can be done without large amounts of cognitive resources.

Dreyfus and Dreyfus [18, 19] extended and elaborated on these distinct phases of skill acquisition and proposed five stages—novice, advanced beginner, competent performer, proficient performer, and expert. The novice knows basic facts about a subject and context-independent rules for using those facts. The advanced beginner can use examples to formulate rules for action and can take context into account. The competent performer is personally involved, goal-oriented, and is able to reason analytically and act without conscious thought about the rules. The proficient performer can recall whole situations and apply them without having to decompose them into smaller components. The expert makes little conscious use of analytical reasoning, has little awareness of the skill, is fully involved in the situation, and seems to operate by visualizing and manipulating whole objects and situations.

Performance on tasks at the expert level is usually smooth and proficient; however, the processes used by experts in their performance are generally not available to conscious awareness. Polanyi [20] refers to this type of knowledge as "tacit". Johnson [17] has termed this fact the "paradox of expertise"—the very knowledge we wish to represent in a computer program, as well as the knowledge we wish to teach others, often turns out to be the knowledge that individuals are least able to talk about.

Knowledge structure and representation

Research in cognitive science has contributed to our understanding of knowledge structure, representation and construction. Researchers have experimented with production systems. They have developed inference procedures that involve forward-chaining and backward-chaining to act on knowledge bases. The modeling of learning, however, turned out to be much more difficult than expected. For example, sequential readiness assumptions may hold for some simple tasks and for young children: however, adolescent and adult structures of knowledge and individual differences are often uneven and nonlinear [21].

CONSTRUCTING KNOWLEDGE BASES

Outlines and texts are the main methods that students use for organizing knowledge externally. These approaches appear to serve their purposes since the majority of student learning involves rote memorization. Meaningful learning, on the other hand, requires more powerful representation strategies. A concept map (type of spatial learning strategy) summarizing various forms of knowledge representation is shown in Fig. 1.

Concept maps require representation of relationships between concepts: they facilitate abstraction and deep processing. Unlike more content-dependent techniques (matrixing, flow-charting, constructing pictures or graphs, for example) these systems can be used in a wide variety of texts. Concept maps, according to Novak and Gowin [5], are intended to represent meaningful relationships between concepts in the form of propositions. In its simplest form, a concept map would be just two concepts connected by a linking word to form a proposition.

Outlines and concept maps differ in three main ways [5]: (1) concept maps show key concepts and propositions in very explicit and concise language whereas outlines usually intermix instructional examples, concepts and propositions in a matrix that may be hierarchical, but fails to show the superordinate–subordinate relationship between key concepts and propositions; (2) concept maps are concise and show the key ideational relationship in a simple visual representation; and (3) concept maps visually emphasize both hierarchical relationships between concepts and propositions and cross-links between sets of concepts and propositions.

The process of constructing knowledge bases (or representations) is very powerful for assisting students in learning how to learn as will be overtly) on what they're doing. Experts ask questions such as "What are the general principles that apply?" They spend more time thinking about the problem, asking themselves questions, and commenting on their understanding of the problem. Schoenfeld [15] mapped the mathematical problem solving activities of novices and experts on numerous problems and noted major differences as described above. Similar results to those noted by Schoenfeld were found for uninstructed students, novices and experts solving physics problems by Champagne *et al.* [16].

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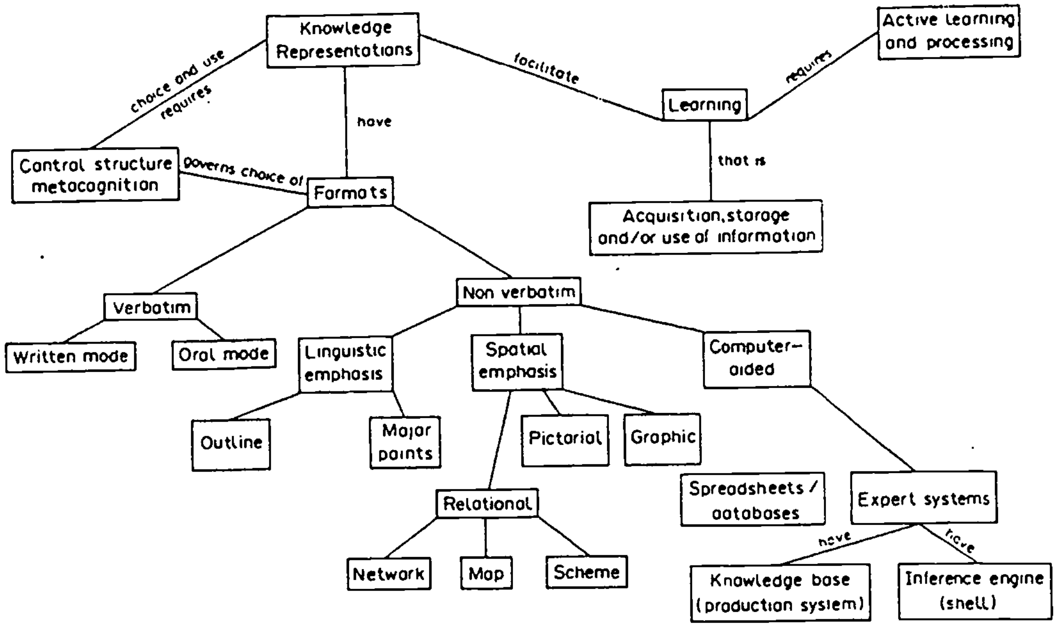

Fig. 1. Concept map for "constructing knowledge bases".

described later. Additional strategies for representing knowledge are described in Smith *et al.* [22].

Expert systems

Our work in the area of requiring students to construct explicit knowledge representations began when we introduced the idea of students building small expert systems. Our primary purpose was to familiarize them with this approach in a course on the application of operations research techniques in engineering. The introduction of this idea had several unanticipated side effects. One, the students were much more enthusiastic than we had expected. Two, they mastered content that we had not expected that they would master. Three, they formulated rules for design and decision-making that showed they had not only reviewed a large amount of information, but that they had reviewed it selectively and purposefully. The outcome of this procedure is described briefly below and is described in more detail in a recent article by Starfield *et al.* [23].

A small expert system shell has been an indispensable part of the way in which we have used knowledge bases as a teaching tool. The shell, described in Starfield *et al.* [24] is written in Pascal and runs on a personal computer with 128K memory. The knowledge bases constructed by the students are stored in text files, according to a simple and flexible format. These files are input data for the shell, which will read, parse, check and interpret the text. The shell then permits users to interact with the knowledge base.

The knowledge base itself is divided into three parts. First, there is a set of numbered decisions. The second part consists of a series of questions which aim to solicit the information necessary to select an appropriate decision; associated with each question is a limited number of answers. The third part consists of a set of production rules. Each rule has the formation

IF <condition> THEN <decision>,

where the condition is a Boolean expression relating to answers to the questions and perhaps to decisions.

In a typical project students built a knowledge base to select an urban transportation system. The decisions in that case consisted of a list of transportation alternatives, such as

Decision 1 buses
Decision 2 light rail.

The questions related to the range of lane capacity needed, the maximum possible investment, the speed required, the levels of acceptable noise and pollution, etc. A typical question might be

Question 3 "What is the range of lane capacity you need?"
Answer 1 "Between 15,000 and 20,000 spaces per hour"
2 "Between 8000 and 15,000".

An example of a production rule might be

If (Q2 Ans3) and (not Dec4) and (Q5 Ans1 or Q6 Ans2) THEN Dec2.

In the interaction between a user and the expert system shell, the shell will ask questions, record and remember the user's responses, and systematically test out the rules until it finds a rule that is valid. It will then print out the appropriate decision. An additional, and from the instructional point of view, important feature is that the user can at any stage ask the shell "why?". The knowledge base may contain reasons (text strings) that are associated with each question and each rule. These should explain, briefly, the reasoning behind the questions and rules, respectively. When a user asks "why?" he is first given the reason associated with the current question. If he asks "why?" again he is then given the reason associated with the rule that the shell is currently testing.

We have found the following sequence to be effective in the classroom:

(1) First we introduce the concept of an expert system and knowledge base, explain the structure of the production rules, and demonstrate a small system on the computer.

(2) We then divide the class into groups of two or three and ask them to suggest topics that would lend themselves to this kind of approach. The ensuing discussion highlights the differences between topics that are suitable and those that are not.

(3) Each group is then required to construct a knowledge base as a homework assignment over a period of 1 or 2 weeks. The students are told to pay particular care to the explanation facility and are required to implement and demonstrate their work, using the shell. This allows faculty and fellow students a chance to critique the assignments.

Our experience is that students adapt very quickly to this formal structure, learn to exploit it, and get a very real sense of achievement when they implement their work. The structure forces them to approach their problem in a pragmatic and purposeful manner. It guides them into thought processes that they may not have previously encountered in a structured environment and teaches them to think explicitly in ways that will be essential to them in their professional careers.

Databases and spreadsheets

The expert system described above is an example of "build/run" software. It enables students to construct a knowledge base, operate on it, and examine the results. Standard database and spreadsheet programs facilitate the same operations. Students can compare, merge and test information in a database; in addition, a spreadsheet allows them to introduce and simulate mathematical relationships. A successful spreadsheet application must be carefully constructed of knowledge and rules (i.e. values and formulae) in order that one might later observe a rippling effect of column by column output of the calculated values. Similarly, a database must be constructed before various sorting and merging functions can be invoked. These programs provide a means to represent and manipulate knowledge.

Spreadsheet programs are used increasingly outside the traditional business domain. For example, spreadsheets have been used by students in mine network analysis to simulate air flow, wherein known values of air pressure at selected network junctions (entered as real values) and physical laws (entered as formulae) express the interdependence of network junctions and network branches.

INSTRUCTIONAL USE OF KNOWLEDGE REPRESENTATIONS

The strategies described above are techniques for externalizing concepts and propositions. However, learning the meaning of a piece of knowledge requires dialog, exchange, sharing, and sometimes compromise. Meanings can be shared, discussed, negotiated and agreed upon. When spatial learning strategies are used in groups of two or three students, it can serve a useful social function and also lead to lively classroom discussion. Cooperative learning groups, an active learning technique described by Smith [25] and Smith *et al.* [26, 27] has shown similar positive outcomes. Preparing to teach or tutor another, whether or not any teaching is actually done, results in greater achievement and liking of the subject and other class members [28, 29]. Cognitive-psychology researchers have shown that the two principal contributors to the development of expertise are talking with peers and preparing to teach [30].

The learner must engage in active analysis of the structure in order to construct a spatial representation. Spatial strategies may be effective not because they provide an image, but rather because, by constructing a graphic representation, the learner carries out activities such as analysis, encoding and organization that are themselves effective regardless of whether or not they result in a spatial representation.

In addition to training and encouraging students to construct knowledge bases to assist in learning, instructors could incorporate a variety of forms of knowledge bases in their lectures or handout materials. Day [31] described modifying lecture materials to incorporate some of these ideas. The construction of knowledge bases can be incorporated in evaluation procedures with, for example, a scoring procedure developed for concept mapping. We have required students to build the knowledge representation for expert systems in exams.

Many recognize microcomputers as a revolution in education, not to supplant traditional educational processes, but rather to supplement them by allowing students to experiment with many different situations and to "instruct" the machine rather than be "instructed" [32, 33]. Programs which enable one to modify data and quickly recalculate are excellent tools for sensitivity analysis and encourage a deeper understanding of the behavior of the system being studied. Once a knowledge representation is constructed, one is free to operate on it with the tools of the particular package using a "WHAT IF?" approach.

SELECTION OF KNOWLEDGE REPRESENTATION STRATEGIES

Metalearning requires a capability for examining one's own knowledge and thoughts and then modifying them accordingly. The "control structure" that can accomplish this modification is called "metacognition" in the cognitive-science literature. Flavell's [34] generally accepted definition of metacognition is as follows:

> "Metacognition refers to one's knowledge concerning one's own cognitive processes and products or anything related to them, e.g., the learning-relevant properties of information or data. ... Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objectives on which they bear, usually in the service of some concrete goal or objective" (p. 232).

Metacognition has two separate but related aspects: (1) knowledge and beliefs about cognitive phenomena, and (2) the regulation and control of cognitive actions [34]. Since there are numerous strategies available to each learner, the approach that is needed is to help the student choose appropriate strategies for each learning task. Bruner argues against promoting only one model of the learner and suggests instead that the best approach is a reflective one that allows one to "go meta". He concludes:

> "Any learner has a host of learning strategies at command. The salvation is in learning how to go about learning before getting irreversibly beyond the point of no return. We would do well to equip learners with a menu of their possibilities and, in the course of their education, to arm them with procedures and sensibilities that would make it possible for them to use the menu wisely."

McKeachie [36] points out in a critique of spatial learning strategies that he has difficulty justifying the amount of time needed to teach students how to implement these strategies. In contrast, our experience is that it takes very little time for students to learn how to operate within the formalism of a rule-based knowledge system, or to exploit the facilities provided by a database or spreadsheet package. One might speculate that, if spatial learning strategies were automated, they would become a far more effective teaching tool. They would then share the advantages of the computer-aided representations discussed here, namely, that they provide a framework for the student, an intellectual "jungle jim" which encourages them: (1) to review (information or data) and select from it; (2) to think about what is important and what is secondary; (3) to hypothesize interconnections, consequences and relationships; (4) to test those hypotheses and explore sensitivity; and (5) to communicate what they learn.

IMPLICATIONS FOR ENGINEERING EDUCATION

In real-world engineering practice, problems do not present themselves to the practitioner as givens. Problem formulation, the process by which we define the decisions to be made, the ends to be achieved, and the alternative means which may be chosen, is neglected in much of engineering education. Problem formulation requires the capability to learn how to learn and to reflect-in-action. According to Schon [4] reflection-in-action exemplifies professional activity:

> "When someone reflects-in-action, he becomes a researcher in the practice context. He is not dependent on the categories of established theory and technique, but constructs a new theory of the unique case. His inquiry is not limited to a deliberation about means which depends on a prior agreement about ends. He does not keep means and ends separate, but defines them interactively as he frames a problematic situation. He does not separate thinking from doing, ratiocinating his way to a decision which he must later convert to action. Because his experimenting is a kind of action, implementation is built into his inquiry. Thus reflection-in-action can proceed, even in situations of uncertainty or uniqueness, because it is not bound by the dichotomies of Technical Rationality."

In *Educating the Reflective Practitioner* Schon [37] describes his approach to the development of professional practice skills. He writes:

> "Designing, both in its narrower architectural sense and in the broader sense in which all profession practice is designlike, must be learned by doing. However much students may learn about designing from lectures or readings, there is a substantial component of design competence—indeed, the heart of it—that they cannot learn in this way. A designlike practice is learnable but is not teachable by classroom methods. And when students are helped to learn design, the interventions most useful to them are more like coaching than teaching—as in a reflective practicum" (p. 157).

Champagne's [38] research on scientific knowledge and the mechanisms by which it is learned indicates that scientific knowledge is complex and often tacit, learners construct understanding; refinement of personal theories about the natural world is an important part of the learning of science, and social interaction is a powerful mechanism for producing cognitive change.

The cognitive-psychology research confirming the importance of peer interaction in the learning process has important implications for engineering education. Meaningful learning and especially learning how to learn is enhanced by talking with peers and preparing to teach others. They are essential aspects of learning. Social psychologists

(Lewin, Deutsch and the Johnsons) have been advocating this practice for over 40 years.

A key, therefore, to learning how to learn is to get students involved in the construction of knowledge representations [22, 39]. Getting students involved in meaningful problems is a powerful means for developing talent [34, 40]. We must, in addition, let students struggle with problems, especially at the formulation stage. We can provide them with some learning strategies to make their task a bit easier [42–44]. For example, Schoenfeld acts as a roving consultant while the class breaks into small groups to work on mathematics problems. He has found that asking the following three questions promotes the development of metacognitive skills [45]:

(1) What (exactly) are you doing?
(Can you describe it precisely?)
(2) Why are you doing it?
(How does it fit into the solution?)
(3) How does it help you?
(What will you do with the outcome when you obtain it?)

Heller and Hungate [46] conclude that students need to become better able to reason qualitatively about problems and to know when and how to perform the many component procedures. They suggest several ways students' attention could be turned to learning these particular activities, including: (1) make tacit processes explicit, (2) get students talking about processes (an idea proposed by Bloom and Broder in 1950 [47], (3) provide guided practice, (4) ensure that component procedures are learned well, (5) emphasize both qualitative understanding and specific procedures, and (6) test for understanding and reasoning processes.

CONCLUSION

The development of higher cognitive skills that enable students to be independent learners and independent, creative problem-solving users of their knowledge is a very important goal for educators. Providing students with an active learning environment where they can get involved with the material to be learned in a mutually supportive situation with other people and providing them with tools such as the ones described here will contribute to meaningful learning.

Even if learning, thinking and problem-solving strategies, whether general or specific, are shown to exist, it might not be possible to teach them directly. Perhaps they must spontaneously emerge as consequence of substantial experience. The current conception is that metacognition—conscious awareness of and control of cognitive processes—emerges only as knowledge and skills in a particular domain become quite well developed. At the very least, it should be possible to select and design experience to result in a more rapid and complete emergence of such skills. A key to the success of developing students' skill at using these strategies is for faculty to incorporate them in their handouts, exercises, lectures, assignments and exams. We must also be willing to accept that it may be the idiosyncratic, covert concept meanings that are the principal factors in most human learning [48, 49].

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Testing Intellectual Skills in Engineering; Test Design Methods for Learning*

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This study examines classroom testing from the perspective of psychological learning. Four intellectual skill levels are defined, based upon basic and classic research on human learning psychology. These intellectual skill levels can then serve as the foundation for designing test questions. Additional psychological learning variables are considered, and how testing interacts with these variables. Finally, the results of a survey on testing methods used by engineering faculty are presented.

TESTING in engineering courses is typically viewed by university faculty members as simply a method of measuring course content students acquire, and providing grades on academic achievement in an engineering major. However, testing can be much more than this. Since 1981, the College of Engineering at the Pennsylvania State University has conducted teaching seminars for engineering faculty, and a course on teaching effectiveness for engineering teaching assistants. One of the major topics during these seminars and course is test development. At the start of the test development seminar faculty members and teaching assistants are asked to write a sentence or two describing the major importance of classroom testing in engineering. Of the 805 faculty members and teaching assistants asked to respond over the years, 87% indicated that tests are for giving grades and evaluating the amount of information acquired. Other responses included: evaluating how effectively material was taught, motivating students, and providing feedback to students on skills learned. While sincere regarding their desire to be effective instructors, few engineering faculty members and teaching assistants understand the relationship between testing and psychological learning, and the overall value of testing for achieving specific intellectual outcomes.

This paper will further examine the fundamental relationships of testing and psychological learning. The issue of a test as an independent variable in the learning process was considered in our first paper on testing [1]. This issue will be elaborated upon here with a more detailed discussion of psychological learning, or intellectual skill levels, and classic research findings related to these topics from the research on concept learning and problem solving. A number of sample test problems will then be presented and analyzed in terms of intellectual skill levels. A number of references will then be provided on developing effective tests, from key researchers in the area of testing theory and test construction. Finally, survey results will be presented and discussed, from a survey evaluating the typical testing methods used by the engineering faculty. This survey examined testing methods, intellectual skills, and types of engineering courses.

RELATING TESTS TO PSYCHOLOGICAL LEARNING VARIABLES

A basic psychological variable (learning variable) that the test affects is the variable or motivation. Of course, motivation is a fundamental psychological variable in the learning process. Without motivation, little or no learning takes place. The variable of motivation can be considered a continuum, ranging from sleep to a high level of state anxiety. However, the type of motivation that is most related to classroom testing is achievement motivation [2, 3]. Achievement motivation research attempts to explain the basics of goal seeking behavior, and what causes various forms of this behavior. A detailed discussion of achievement motivation can be found in Atkinson and Feather [4]. Achievement motivation research results are complex, indicating that a great deal of environmental and subtle psychological factors stimulate the need to achieve certain goals, specifically academic goals, as Travers explains, p. 434:

> The students in a class may appear bored and listless, but this does not mean that they do not have potential for showing achievement motivation. Perhaps their specific needs are not being aroused [5].

The type of achievement motivation the classroom test seems to stimulate most often is the

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desire to acquire favorable grades. Unfortunately, grades are not the most appropriate type of achievement motivation, but students are highly motivated by grades on tests and major assignments. This level of motivation is known as external motivation, discussed in the locus of control research [6]. The overall outcome of a professional degree should be to lead to internal motivation [7], or the desire to be a productive and competent engineer for that reason alone. But, in reality, most undergraduate students are stimulated to learn because of grades. Therefore, the test directly affects motivation to learn, by stimulating achievement motivation, to acquire favorable grades. This relationship should be positive, and not a negative or punishing type of motivation. Students will tend to study more completely, and more seriously, close to the time of major tests [8]. The frequency of testing will then directly manipulate the amount of serious study students will engage in. So, the psychological variable of achievement motivation can be directly manipulated by frequency of testing. It is likely that giving only a mid-term and final examination is not appropriate since this contributes to a cramming study strategy by students. More frequent testing would lead to a distributed study strategy by students, and keep their motivation levels for learning new material at a constant, probably optimal level, rather than peaks of high and low motivation.

The second psychological variable tests can control is the level of intellectual skill at which students will acquire course content. It is not surprising to engineering faculty members to observe a wide variety of understanding levels in a class, on any given topic being presented. For example, some students seem to simply memorize new information, while others appear to have a much 'deeper' understanding of the material. This depth of learning phenomenon is in reality a manifestation of the intellectual skill level students are psychologically operating at with the new material. The test can be used to directly control this intellectual skill level students attempt to acquire. For example, if a test usually asks students to memorize basic facts, such as formulas, symbols, and definitions, chances are the majority of students will learn at the factual intellectual skill level with course material. If tests provide the facts, but then require students to apply new rules they should understand, chance are, students will master material at the rule application level. Of course, instruction must be at the appropriate intellectual skill level to effectively prepare the student for the testing situation [9].

There are a number of researchers who have attempted to define intellectual skill levels [10, 11, 12, 13]. For many teaching and learning situations, their definitions are useful. However, when explaining engineering course material a more classical approach to defining intellectual skill levels, based on research from learning psychology, seems to be applicable [5, 14, 15].

Most engineering course content seems to fit four basic intellectual skill levels identified as the psychological research related to learning. From a basic level to a more sophisticated level, these intellectual skill types are: factual learning, concept learning, rule learning, and problem solving. The key is to be able to define course material at these different intellectual skill levels, and then prepare test questions at the same level. Subsequently, this should stimulate students to learn material at the appropriate intellectual skill level, since tests require them to perform at that level.

The basic intellectual skill level is factual learning. All educated individuals must acquire a vast number of facts to be able to perform more complex intellectual tasks. Classic research on problem solving, indicated that more complex problem solving tasks required the acquisition of factual information. [16, 17, 18]. The early Gestalt Psychologists spent a good deal of effort explaining the differences between faculty memory and problem solving, which they sometimes called drill and practice versus meaningful apprehension [19], or reproductive versus productive thinking [20]. So, while facts are the most basic level of intellectual skill that can be acquired, they form the crux of much later and more complex intellectual skills. Students should be required to learn these basic facts in a given area, and test questions of a factual type can easily be developed to test this skill. The factual level test question can be designed to stress recall of information or recognition of information. Simple completion items are quite good for factual memory testing, as well as matching type test questions [1]. Of course, multiple choice items can be designed to test factual memory of a recognition type. It is more difficult, however to recall factual information than to recognize factual information stored in memory [21]. Therefore, if the facts are to be well learned for future use, a recall test question may be better, such as a completion type of item.

The second level of intellectual skill is concept learning. There is a good deal of history behind the research on concept learning beginning in 1920 by Hull. Similar to Hull [22], the work by Heidbreder [23] on concept learning and Bruner, Goodnow and Austin [24], indicated that concepts are classification systems humans use to categorize information in the environment. The concept is a definition, made up of a listing of attributes. This list of attributes forms the concept category and once these attributes are learned, classifying information into and out of the conceptual category is a simple task. Conceptual thinking is an innately human way of thinking, allowing us to deal with large quantities of information encountered in the environment without putting a burden on memory. In fact, without the ability to think in a conceptual way, human memory would probably have difficulty dealing with even the most simple recognition tasks. For example, the conceptual task of identifying and grouping dogs from other animals, and by dog type, is quite simple for normal adults, once the conceptual rule about dogs is learned. Simply stated the dog concept is: 'Has four legs, has a head, has a body, has a tail—usually, and barks.' Knowing this information at a conceptual intellectual level eliminates the problem of memorizing all images and features of all dogs encountered, to be able to recognize a dog, or dog type. Computers, on the other hand, are very poor conceptual thinkers, but have better memory capabilities than humans, so they can carry out pattern matching memory tasks better than we can. Young children often attempt memory methods to try and learn concepts and fail to think conceptually, and therefore, have difficulty with concept tasks [25]. It is common to observe students who attempt to use memory, instead of trying to learn conceptually [26]. We often say that these students don't seem to comprehend, or can't apply what we taught. The phenomenon being observed is simply the different intellectual skill levels of factual learning versus conceptual learning.

Concept tasks are common in most college level courses, and should be represented on tests. For example, a conceptual learning task in electrical engineering is the ability to classify basic electrical components for building circuits, such as resistors, capacitors, diodes, transistors, etc. There are a wide variety of resistors, of varying capabilities, shapes, sizes, and colors, but once the conceptual rule defining resistor is learned, classifying what is and what is not a resistor becomes a simple conceptual task. Similarly, many other types of concepts can be identified in most engineering courses at the college level. The first step in test design then, is to differentiate course content along the lines of what is a fact, concept, rule, and problem, and develop test items that will stimulate the appropriate type of thinking in students. However, it may be obvious at this stage, that differentiating course content and writing test items at certain intellectual skill levels and evaluating student thinking, is a hypothetical task at best. This is true, but after some practice and evaluating tests developed in this way, it becomes a viable method of test development. Since the test developer has only five test items to select from: completion/short answer, essay/long answer, multiple choice, true-false, and matching, most intellectual skill levels can be tested with these item types. Except for true-false items, all four intellectual skill levels can be addressed contingent upon how the test item is designed. For the concept learning level, test items should require students to be involved with concept identification [14], or classifying information into and out of conceptual categories. Conceptual thinking can be stimulated by requiring the student to: compare and contrast concepts, explain or identify attributes, identify correct from incorrect attributes, formulate and explain the conceptual category.

The next intellectual skill level is rule learning. While the definition of concept learning may seem awkward, rule learning is a little easier to deal with since engineering course content involves a wide array of rules. Rules can be either mathematical or verbal, and are usually a part of problem solving. The rule can be a logical rule, such as Kirchhoff's Voltage Law or the Periodic Law, or a mathematical rule, like the independent equations to solve an electrical circuit problem. The key, however, of the rule learning intellectual skill, is that the student cannot simply memorize the rule but must know when to apply the rule or when not to apply a rule; or in some cases, how the rule should be changed to fit a certain application. A common learning problem among engineering students is that of simply memorizing rules, and not fully comprehending how to apply rules. There is a great deal of difference in intellectual capability between memorizing the rule as opposed to being able to apply the rule, given the appropriate situation. Rule learning is similar to concept learning, and some educational researchers have indicated that complex rules used in problem solving can incorporate several lower-level concepts [27]. Rule learning test questions should attempt to get the learner to apply the rule and avoid simply recognizing or recalling the rule, since this would then become a factual intellectual skill. The crux of the rule learning test question is that it should deal with application. The student should be forced to apply the rule or rules in a realistic way, by demonstrating how the rule is used, or by explaining the application of the rule, and in some cases for mathematical rules generating the rule. Multiple choice questions can be developed to test this intellectual skill, but they will require a good bit of time and thought to develop [1]. A very good way to test rule application is with a short answer problem, or completion type test item.

Problem solving is the highest level intellectual skill. Problem solving involves the incorporation of the three more basic levels of intellectual skills: facts, concepts, and rule application. Problem solving cannot take place without facts being stored in memory and conceptual understanding, and the ability to apply rules. In actuality, the intellectual skill level of problem solving can be broken into three distinct sublevels: solving simple problems, solving complex problems, and the most difficult problem solving type, identifying a problem. The identification of problems is seldom done in classroom learning. Most of the learning classified as classroom learning in undergraduate school involves either simple numerical or verbal problems, or complex numerical or verbal problems. A simple problem can be defined as one involving the application of a single concept or rule to find the solution. A complex problem can be defined as one involving a variety of concepts and rules, and perhaps a series of equations, to find a solution. The key phrase to both of these definitions of problem solving is 'find a solution.' To represent true problem solving, the test question should not be designed so that the students can respond from memory alone. The difficulty with many test questions thought to be problem solving is that they simply require the memorizing of a set of steps, and repeating the steps. This algorithmic style of arriving at a solution is not problem solving, but is actually the more basic factual intellectual skill. The classic definition of problem solving described here can be found throughout the research in psychology, related to explaining human problem solving behavior [14, 15, 28, 5]. The early Gestalt Psychologists conducted much of their research by observing and explaining problem solving behavior. For example, Katona [29], in 1940, explained that memory tasks fail to allow the learner to transfer memorized information to the problem solution stage of thinking. Early work by Wertheimer [20] yielded results that support the notion of differences between memorizing solutions and problem solving using the application of rules. Similar explanations of problem solving can be found in very early work by the Gestalts. For example, as early as 1925 and 1930, Kohler [30] and Maier [32] documented their work on problem solving, indicating differences between the intellectual skills of memorizing solutions, versus problem solving by deriving unique solutions. Later Gestalts, using more experimental methods, noted that memory skills alone do not allow for complex and creative solutions to problems [32, 33], and in some cases memory problem solving can interfere with seeing a solution. However, this information contrasting memory skills versus problem solving skills, is probably not a great surprise to most engineering faculty members since they observe this phenomenon in students at chronic levels. To help avoid this difficulty, test items should be designed to require true problem solving involving; recalling some facts, differentiating concepts, and applying rules, to arrive at a unique solution not encountered before. The test items most adept at this type of engineering problem solving are long answer problems or essay and short answer problems or completion. The rule of thumb for the test developer, when writing problem solving questions, is to consider the question: 'Can my students solve the problem by using a memorized solution?' If they can simply write out a memorized algorithm, the test question is not a problem solving question, regardless of its format, essay or completion, or complex multiple choice, but is rather a factual question.

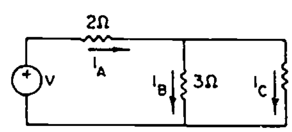
Another powerful psychological learning variable which is part of testing, but seldom considered by engineering faculty members, is that of performance feedback. The effects of feedback on learning are well documented in the classic learning theories by Hilgard and Bower [15], and in more applied explanations of psychological learning related to school learning by Travers [34]. Performance feedback can be found in learning theory research under the rubric of reinforcement, cognitive feedback, and informative feedback. This feedback variable can have a significant effect upon learning, if used appropriately as part of classroom testing. In general, the research on feedback concludes that a student will learn more about a particular intellectual skill, if more information is provided about the quality of the performance, including an explanation of what was correct and what was incorrect and why. This information should then be beyond simple feedback, like posting letter grades, but what is called elaborate feedback. The elaborate feedback method can take place by explaining classes of problems students tended to answer incorrectly. Such explanations should take place in class during post-test reviews. If entire groups of test questions are missed, it may be necessary to review that particular material in a good bit of detail during a post-test review session. Additionally, as part of the post-test review, the instructor should take time to explain the relative application of important concepts, rules, and problems, to future work in the course. The elaborate feedback method turns the testing function of the instructional process into a true learning experience, aimed at improving intellectual skills for future application.

SAMPLE TEST ITEMS AND SOME ADDITIONAL SUGGESTIONS

The sample test items will provide some practical examples of designing questions at different intellectual skill levels. The samples here are from courses taught at the Penn State College of Engineering.

Sample 1

How many independent equations based on Kirchhoff's Current Law may be written for this circuit?



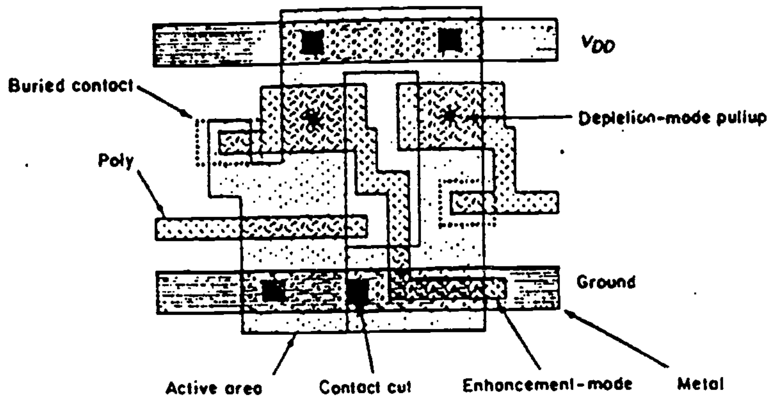
How many based on Kirchhoff's Voltage Law?

The Sample 1, completion test item (short answer problem) is at the rule application level, since it requires the learner to determine which equations apply to the circuit problem and how many. The KCL and KVL equations are being defined as rules that can be applied to solve the problem, or in this case analyze the problem. It would be difficult to respond simply from memory, unless this exact circuit was memorized, including the accompanying equations.

Sample 2

The layout illustrated in the figure below represents which of the following circuits?

a. CMOS Inverter
b. NMOS NOR Gate
c. Dual NMOS NAND Gate
d. Dual NMOS Inverter



Sample 2 represents a multiple-choice test item at the concept learning level. The circuits are defined as concepts, since they are made up of a definition formed from a set of attributes. The task in Sample 2 is to analyze the attributes of the circuit in the figure, and determine what category of circuit the example falls onto. While memory would help with this task, memory alone would not allow for a correct conceptual analysis.

Sample 3

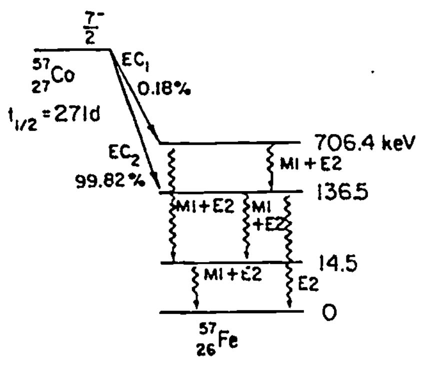
The term 'Metal Lift-Off' refers to:

a. Reliability problem in IC metallization layer
b. Processing sequence which defines metal lines
c. Selective editing on a full custom layout
d. Fatigue problem in IC package pins

Sample 3 is a multiple choice item at the factual intellectual skill level. While the fact being tested is important if it was committed to memory the item can be easily answered. However, while factual learning is a basic intellectual skill, if certain facts must be learned they should appear on the test.

Sample 4

1.



a. Calculate log ft for the decays EC_1 and EC_2 and give the most likely classification.

Decay	E_0 (Mev)	log f	log ft	classification
EC_1				
EC_2				

b. Assign spins and parities to the unlabelled levels in ^{57}Fe.
c. Now, check the EC classification in part a and give the final classification.

State	I^{π}
706.41 keV	
136.5 keV	
14.4 keV	

The test item in Sample 4 is a long answer problem (essay) at the problem solving level. Note here that to evaluate the student's response his or her work would be collected. This is a complex problem requiring the recall of facts, the ability to apply most mathematical and verbal rules, and comprehend concepts. The mathematical work is obvious from the statements in the problem, the rules to be applied relate to spins and parities, and concepts relate to EC-classifications.

Sample 5

An NMOS enhancement mode transistor with a 2 volt threshold and gain factor $B = 20 \times 10^{-6}$ is operating the saturation region, with $V_{GS} = 4V$. What is the Drain to Source current IDS.

a. 10 micro-amps
b. .4 milli-amps
c. 1 micro-amp
d. 40 micro-amps

Sample 5 is a multiple-choice item at the problem solving level. However, this problem is a simple numerical problem, and not as complex as Sample 4. This problem involves the application of the correct equation, the rule in this case, and factual information in terms of how to calculate data while completing equations.

A number of excellent texts are available to help engineering faculty with the development of effective tests. To summarize the work of these authors is beyond the scope of this paper but a detailed reading of the following would be helpful, particularly for new engineering faculty.

(1) Wilbert J. McKeachie, *Teaching Tips, A Guidebook for the Beginning College Teacher*, D. C. Heath (1986).

Chapters 8 and 9 discuss practical suggestions for test development and methods of assigning grades.

(2) Elliot A. Weiner and Barbara J. Stewart, *Assessing Individuals, Psychological and Educational Tests and Measurements*, Little, Brown (1984).

This is a cook book approach to testing, but provides numerous example test items. The text also contains a discussion of grade reporting procedures and basic statistical methods.

(3) Lynn Lyons Morris and Carol Taylor Fitz-Gibbon, *How to Measure Achievement*, Sage Publications (1978).

A basic, but practical guide to developing classroom examinations, and evaluating test results.

(4) Robert F. Mager, *Measuring Instructional Results, from the Mager Library Set*, Pitman Learning (1984).

For those using an objective based teaching method, this will provide further information on relating lesson objectives to test items. There are a number of good examples of test questions in this text.

TESTING METHODS USED BY ENGINEERING FACULTY

A survey was conducted at the Penn State College of Engineering during Fall Semester 1987. The survey items appear in Table 1. The survey was mailed to 226 College of Engineering faculty members, and 153 responded. Items 1, 2, and 3 on the survey measure were to determine type of course taught, and relate this information to type of test item typically used, and level of intellectual skill that test items tended to address. The results from items 1, 2, and 3 are graphically presented in Figures 1 through 10. Survey items 4 through 9 evaluated additional issues related to testing in the engineering classroom. All survey data are presented as percents of those responding to the options on each survey item. The data from the survey should be representative of other engineering colleges, having a large undergraduate enrollment, and offering comprehensive masters and doctoral degree programs. However, the majority of undergraduates at Penn State College of Engineering are upper level undergraduates, in their last two years, or at least starting their fourth semester out of eight semesters. Penn State has 21 branch campus locations at which many freshmen and beginning level sophomore students start their programs, prior to arriving at the main campus at University Park. However, there are beginning level students and courses at College of Engineering main campus at University Park. One additional distinction needs to be noted, that is, the difference between service courses and required courses, i.e., major area courses. At Penn State in the College of Engineering a service course is a general course in engineering taken by all students, such as thermodynamics or basic electronics.

Table 1. Sample questions and overall summary data

1. Your response refers to what type of course?
   (a) Freshman, Sophomore Service Course
   (b) Junior, Senior Service Course
   (c) Required Course in Major
   (d) Graduate Level Course
   (e) Elective Course in Major
2. What type of test item do you tend to use most often?
   (a) Essay-long answer problem (numerical or verbal)
   (b) Completion-short answer problem (numerical or verbal)
   (c) Multiple-choice
   (d) True-false
   (e) Matching
   (f) Mixed Method—Some combination of these on a given test
3. Most frequently, the primary purpose of my test question is to:
   (a) Measure factual knowledge, i.e., recall of information
   (b) Measure ability to apply mathematical, or verbal rules, e.g., use equations
   (c) Simple solutions of numerical problems
   (d) Solutions of complex numerical problems
4. Do you tend to give partial credit for numerical problems?
   94% (a) Yes
   1% (b) No.
   5% (c) Sometimes
5. Exams are most often graded by:
   71% (a) Professor
   4% (b) TA
   8% (c) TA supervised by the Professor
   17% (d) Both TA and Professor
6. Do exams tend to be:
   45% (a) Open book in class
   49% (b) Closed book in class
   6% (c) Take home
7. How frequently do you give major exams?
   2% (a) Every 2 weeks
   4% (b) Every 3 weeks
   21% (c) Every 4 weeks
   66% (d) Every 5–7 weeks
   7% (e) Once per semester
8. Do you give any type of quizzes?
   73% (a) No
   27% (b) Yes (24%) (3%)
   (c) If yes: (1) Pre-scheduled (2) Pop quiz
9. How do you assign grades?
   62% (a) Curve, or norm referenced grading
   34% (b) Absolute, or by points equaling grade
   4% (c) Other—standard scores, like T-score

For results on 1, 2, 3, see Figs. 1–10.
Percent responding to each option.

Figures 1 through 5 provide percent responding data, and list the test item types. Those test item types are: essay or longer answer problem, completion or short answer problem, multiple choice, true-false, matching, and mixed method. Figures 1 through 5 compares the results of survey items 1 with 2, or academic level and typical test item type used on a test. Figure 1 indicates that for beginning

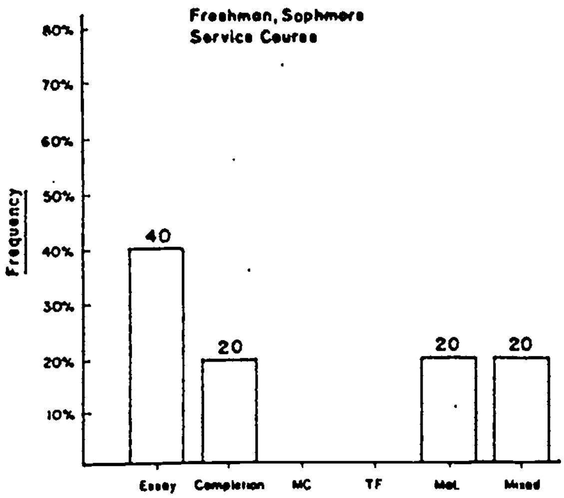


Fig. 1.

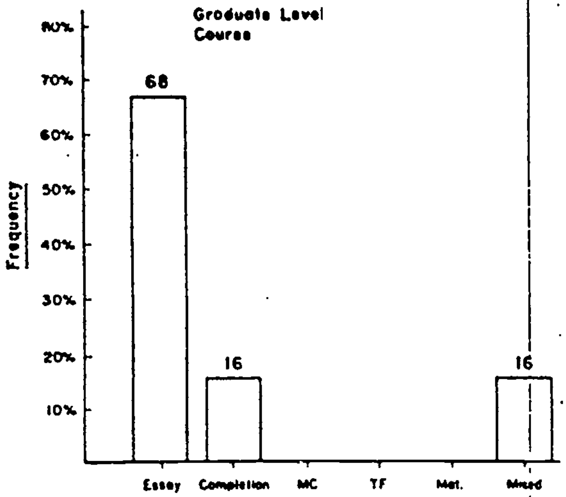


Fig. 4.

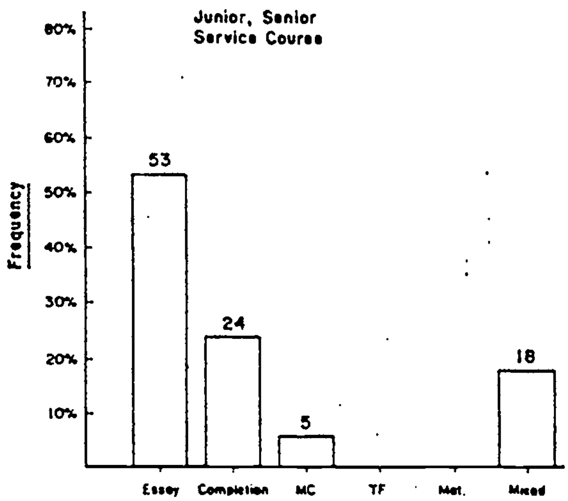


Fig. 2.

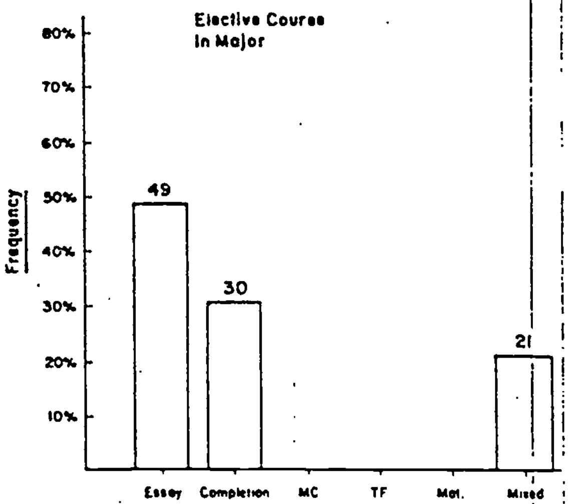


Fig. 5.

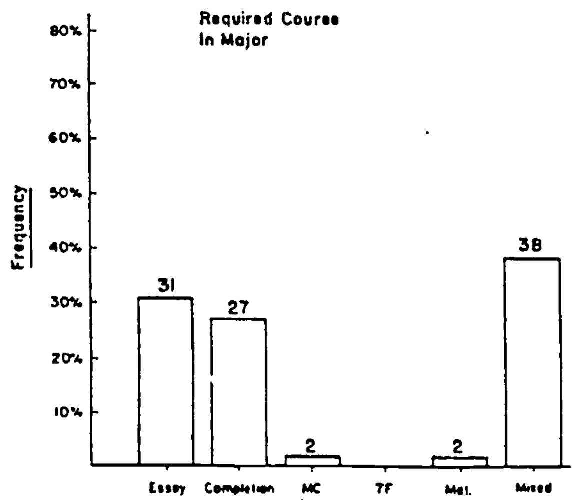


Fig. 3.

level service courses faculty members tended to use completion items about 20% of the time, but used long answer problems, 40% of the time with some matching and mixed. The mixed method is a test method with a combination of item types. Figure 2 indicated that for service courses at an upper level, junior/senior, more essay items are presented on tests. Short answer problems or completion items are used about the same as the mixed method however no matching items are given. A small amount of multiple-choice items are use for this academic level.

Looking at Fig. 3, it indicates that in required major area courses, the testing methods tended to differ from service courses. There is an equal amount of long answer problems (essay) and short answer problems (completion) on each test, with very little multiple choice or matching. However, a mixed method tends to be used more often, probably mixing short answer and long answer problems. Interestingly, Fig. 4 indicates that in graduate level courses most tests are essay, long answer problems, with very little completion or mixed method. The difference in frequencies between graduate and undergraduate test item types is quite significant. In elective courses in a major, the faculty tended to use testing methods similar to the junior/senior service courses, with mostly essay and completion and some mixed method.

Figures 6 through 10 compared survey item 1 with survey item 3, evaluating academic level and intellectual skill type the test questions attempted to address. Figure 6 considered the service courses for freshman and sophomore level. Most test questions, 60%, were designed to evaluate rule application, with some test items involving simple numerical problem solving, and complex problem solving. For junior/senior service courses (Fig. 7) the results are similar to Fig. 6, but Fig. 7 indicates that more factual level questions are used. However, at the junior and senior level, with service courses, the stress is still on rule application and problem solving.

Interestingly, the required courses in a major, Fig. 8, results are similar to results on service courses. In required courses, the faculty are stressing rule application, with a reasonable amount of factual knowledge. Figure 9, indicates a similar stress on application of rules, but problem solving tends to be more complex, which is expected in graduate level courses. Finally Fig. 10, indicates a stress on the application of rules, but factual learning is significantly higher for these elective courses.

Figures 1 through 10 indicate favorable results in light of ever increasing enrollments at Penn State and probably other similar engineering colleges. As enrollments increase, it becomes more difficult to evaluate and grade essay and completion type items, particularly at the rule application and problem solving level. One may hypothesize that

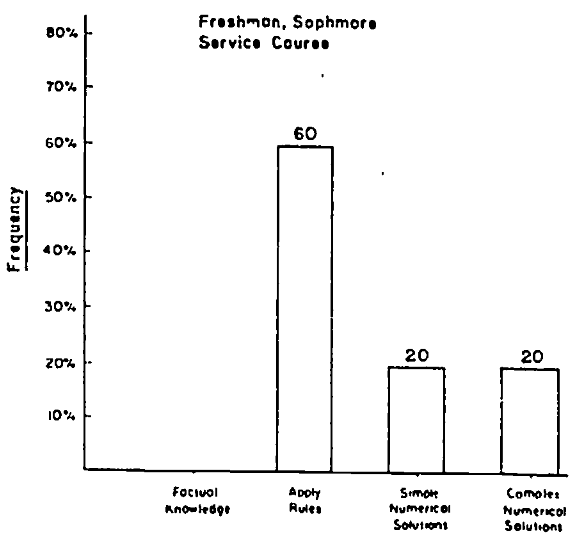


Fig. 6.

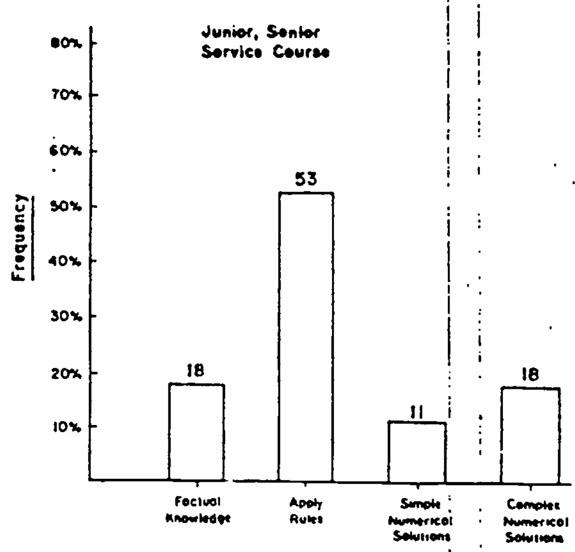


Fig. 7.

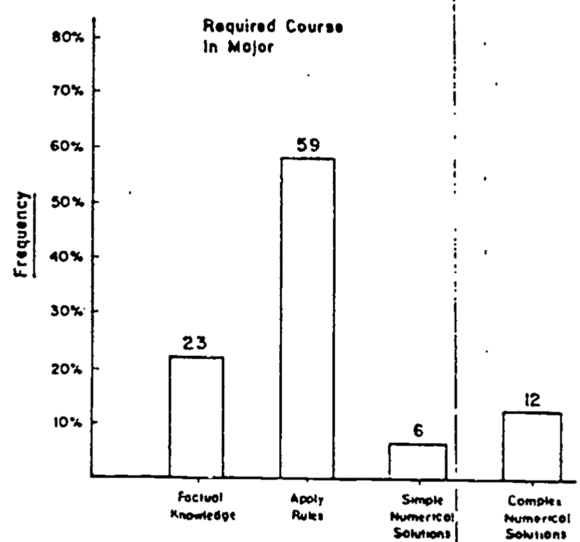


Fig. 8.

increasing enrollments would lead to factual oriented testing with multiple-choice and other objective style test items, but this has not been the case. Faculty members are consistently attempting to stay with rule application and problem solving oriented tests, using long answer and completion problems, as well as mixed methods. Addressing these upper level intellectual skills via testing is critical in the engineering curriculum, and should not fall victim to enrollment pressures.

Survey item 4 indicated that most faculty use a partial credit grading method. This is consistent for testing at the rule application and problem solving level, using mostly essay and completion test item types. Item 5, indicates that the professor is not delegating test grading to the teaching assistant most of the time:

(1) 71% of the time the professor does all grading
(2) 25% of the time the professor and TA do grading.

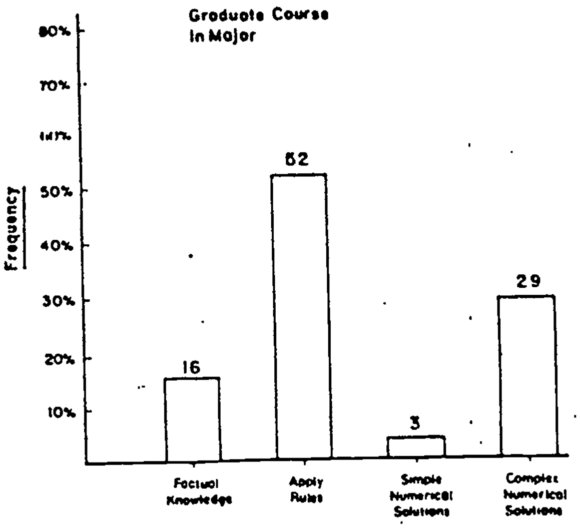


Fig. 9.

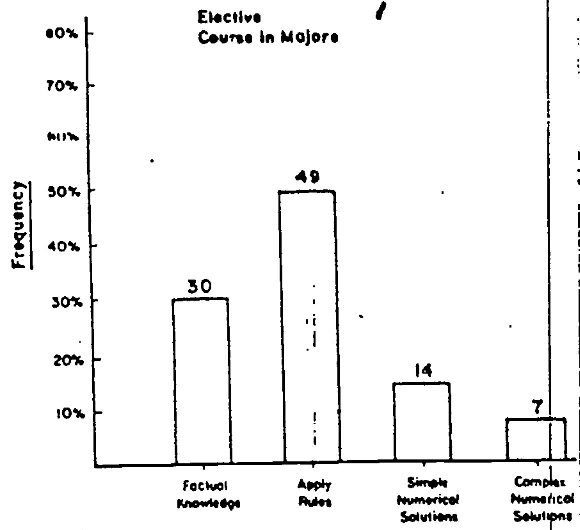


Fig. 10.

Item 6 indicates that open book exams are used about half the time. Most faculty members tend to give major tests about every 5 to 7 weeks; 87% responded in these categories. While 5–7 weeks may be a bit too long between tests, item 8 indicates that 27% of faculty give quizzes, thus, adding needed study and motivation. Additionally, many Penn State College of Engineering faculty members give graded homework between major exams, to provide performance feedback. Finally, item 9 indicates that while 62% of faculty graded on a curve, about 34% used an absolute method based on accumulated points to get a pre-specified grade.

A future work is planned by the authors on testing, to evaluate the testing methods used by other engineering faculty at other universities. Plans are to use the same testing survey measure, but stratify results by:

(1) 2 year technical degree programs,
(2) 4 year bachelor degree programs,
(3) Graduate degree programs.

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