A Knowledge Base for Chemical Engineering High Jump: Setting and Clearing the Bar

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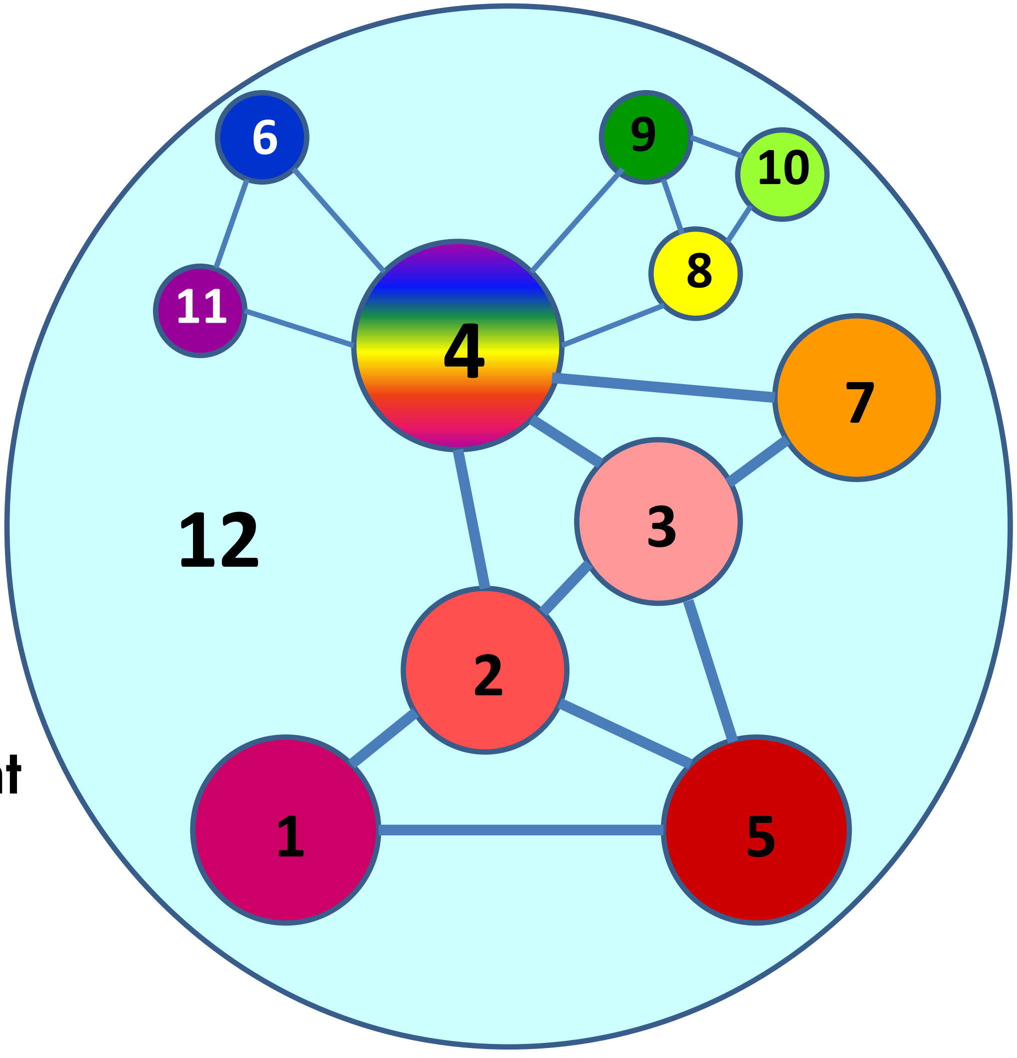
Design at the Pinnacle of Engineering Education

1. A knowledge base for engineering
2. Problem analysis
3. Investigation
4. Design
5. Use of engineering tools
6. Individual and team work
7. Communication skills
8. Professionalism
9. Impact of engineering on society and the environment
10. Ethics and equity
11. Economics and project management
12. Life-long learning



From Knowledge Base to Design: Connections in the Cognitive Domain

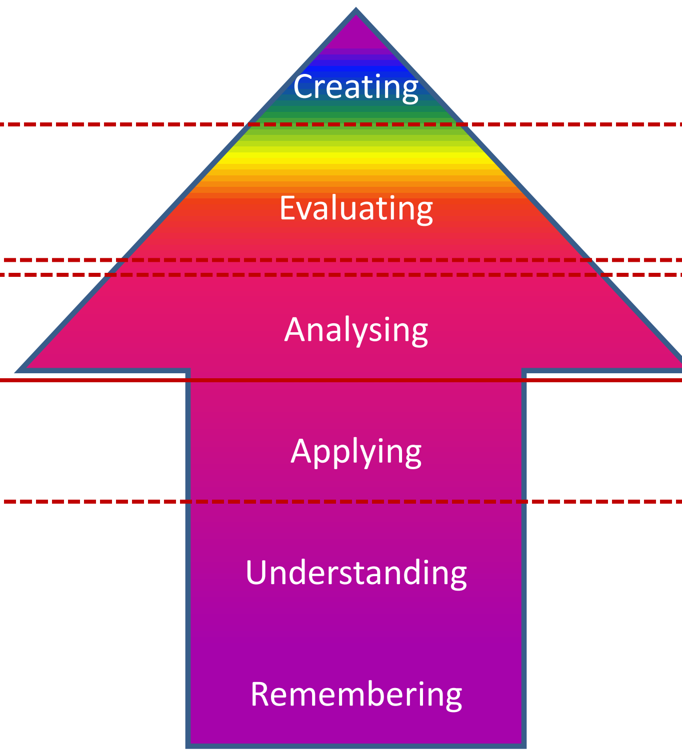
4. Design: An ability to design solutions for **complex,** open-ended engineering **problems** and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.

3. Investigation: An ability to conduct investigations of **complex problems** by methods that include appropriate experiments, **analysis** and interpretation of data, and synthesis of information in order to reach valid conclusions.

2. Problem analysis: An ability to use appropriate **knowledge** and skills to identify, formulate, analyze, and solve **complex** engineering **problems** in order to reach substantiated conclusions.

1. A knowledge base for engineering: Demonstrated competence in university level **mathematics**, **natural sciences**, **engineering fundamentals**, and specialized engineering knowledge appropriate to the program.

BLOOM'S REVISED TAXONOMY



A Taxonomy of Chemical Engineering Concepts

- Structure and properties of materials
  - The structure of materials is hierarchical in nature
  - Material properties, structure and interactions are interdependent
- Conservation
  - "Stuff" (mass, momentum, energy) does not magically appear or disappear
- Thermodynamic equilibrium and spontaneity
  - A physical system can reach a state of equilibrium in which no net change (movement or transformation of "stuff") takes place
  - Spontaneous changes are always towards equilibrium

The Taxonomy of Chemical Engineering Concepts

- Rates of reaction and transport
  - Change (movement or transformation of stuff) is not instantaneous ("it takes time to change")
- Mathematics
  - Relationships between physical quantities in all of the above can be described and manipulated both symbolically and numerically using a common precise language

Recognizing a "Threshold Concept" (G. Cousin, "Planet", vol. 17, 2006)

- Grasping a threshold concept is **transformative** because it involves an ontological as well as a conceptual shift. We are what we know. New understandings are assimilated into our biography, becoming part of who we are, how we see and how we feel.

- Grasping a threshold concept is often **irreversible**; once understood the learner is unlikely to forget it (this does not exclude subsequent modification or rejection of the concept for a more refined or rival understanding).

- Grasping a threshold concept is **integrative** in that it exposes the hidden interrelatedness of phenomenon. Mastery of a threshold concept often allows the learner to make connections that were hitherto hidden from view.

Recognizing a "Threshold Concept"

(G. Cousin, "Planet", vol. 17, 2006)

- A threshold concept is likely to be **bounded** in that 'any conceptual space will have terminal frontiers, bordering with thresholds into new conceptual areas' (Meyer and Land, "Overcoming Barriers to Student Understanding: threshold concepts and troublesome knowledge", London and New York: Routledge, 2006) → curriculum design perspective should aim for an approach to mastery which always leaves room for questioning the concept itself*!*

- A threshold concept is likely to involve forms of **'troublesome knowledge'**, which appears counter-intuitive, alien (emanating from another discourse), or seemingly incoherent. From this view, mastery of a threshold concept can be inhibited by the prevalence of a 'common sense' or intuitive understanding of it. Getting students to reverse their intuitive understandings is also troublesome because the reversal can involve an uncomfortable, emotional repositioning.

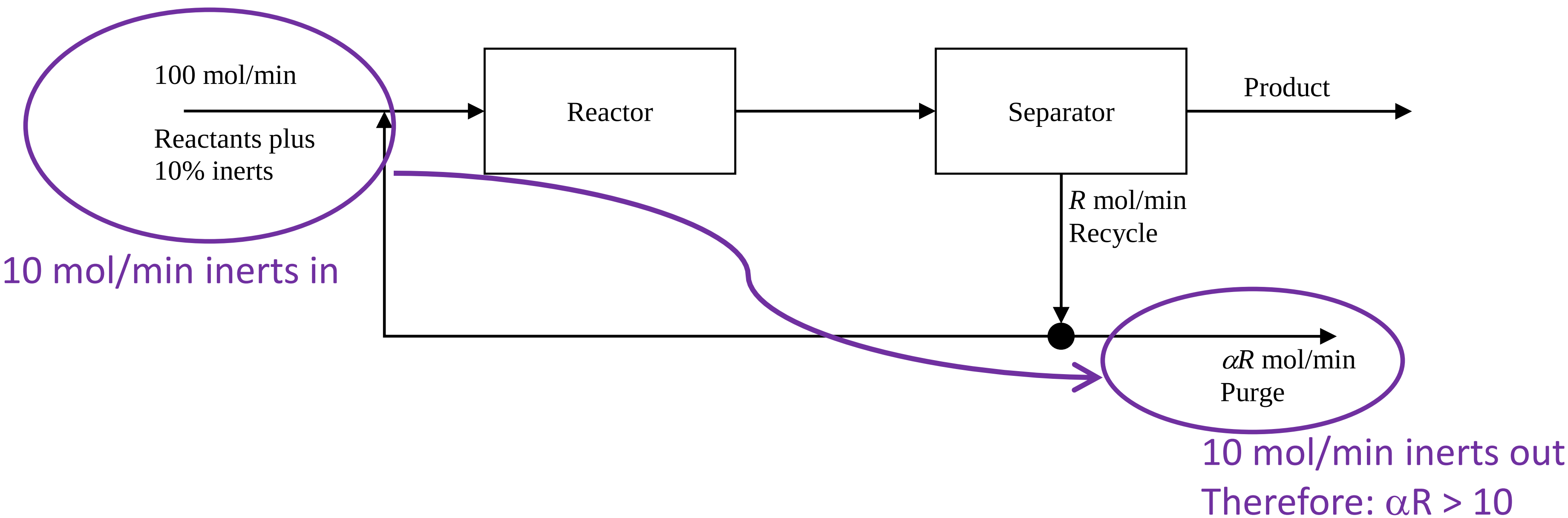
A Map of Chemical Engineering

Term	Concept domains in core courses				
1A	CHE 100	CHE 102	MATH 115	MATH 116	PHYS 115
1B	CHE 101	CHE 121	CHE 161	GENE 123	MATH 118
2A	CHE 200	CHE 220	CHE 230	CHEM 262	MATH 217
2B	CHE 211	CHE 231	CHE 241	MATH 218	
3A	CHE 312	CHE 314	CHE 322	CHE 330	
3B	CHE 313	CHE 331	CHE 361	CHE 425	
4A	CHE 420	CHE 480			

- **Structure and properties of materials**
- **Conservation**
- **Rates of reaction and transport**
- **Thermodynamic equilibrium and spontaneity**
- **Mathematics**
- **Excludes labs, technical electives and complementary studies**

Sample Concept Question on Conservation (ChE 100)

Consider the process flow diagram shown below. The inlet stream consists of the reactants plus 5% inerts. The single-pass conversion of the reactor is known to be less than 50%. The reactor products are separated into a pure product stream and a recycle stream. A fraction α of the recycle stream is purged and the remainder recycled to the reactor inlet.



Consider the flowrate of the purge and recycle streams. Indicate clearly with an X which combinations of recycle rate *R* and purge fraction α may give valid solutions.

"Standard" Question on Conservation

Production of phtalic acid anhydride ($C_8H_4O_3$) is obtained by the oxidation of o-xylene:

$$C_8H_{10} + 3\ O_2 \rightarrow C_8H_4O_3 + 3\ H_2O$$

The fresh feed contains 6 moles o-xylene/hour and 94 moles air/hour. It is combined with a recycle stream and enters the reactor. The reactor output, 118 moles/hour, is sent to a condenser where all of the $C_8H_4O_3$ produced is removed as the product stream (pure $C_8H_4O_3$ stream). The unreacted C_8H_{10}, O_2, H_2O and nitrogen are recycled. A purge stream is required to prevent build-up of nitrogen in the system. The purge gas is 78% nitrogen.

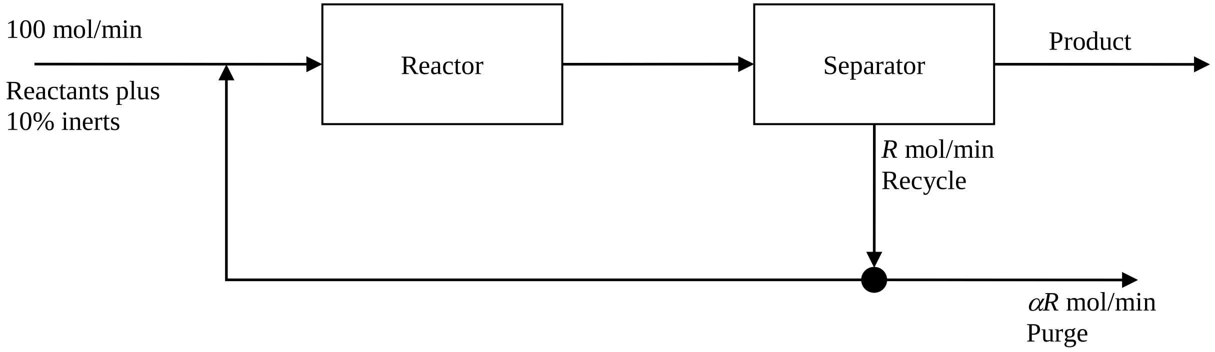
a. [3 pts] Draw a diagram and label known/unknown variables.
b. [4 pts] Perform a degree of freedom analysis for each of the reactor, the condenser and the overall process.
c. [14 pts] Estimate, purge flow rate (mol/h), product flow rate (mol/h) and the purge composition (mol% of each species).
d. [4 pts] Estimate the recycle flow rate (mol/h), that is the flow rate of the stream after the purge returning to the reactor.

Hint: you will notice from the stoichiometry of the reaction that the total number of moles does not change after the reaction.

Additional data:
Consider air: 21% O_2, 79% N_2

"Standard" Question on Conservation

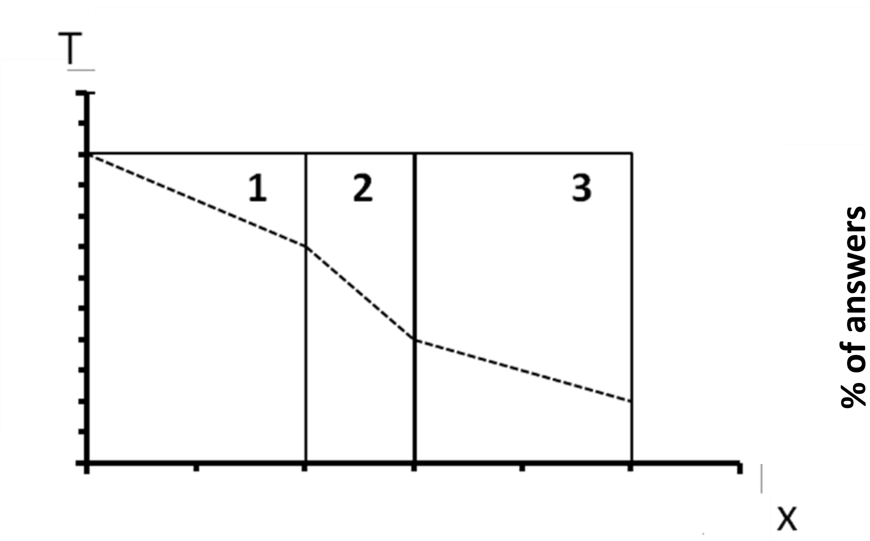
- Answering this involves drawing the following diagram and calculating the values of all unknowns:

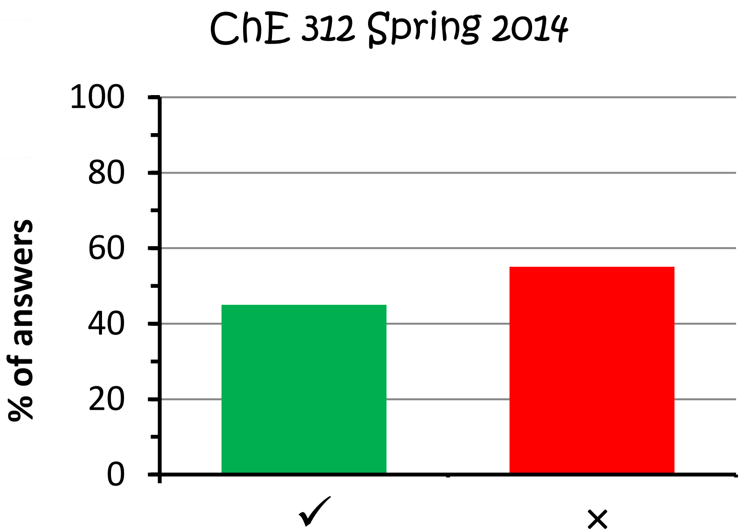


- **Concept question correct: 20%**
- **Average score on "standard" question: 21/25**

Heat is transferred steadily through a 3-layer composite wall. Looking at the graph below, order the thermal conductivities of the three solids

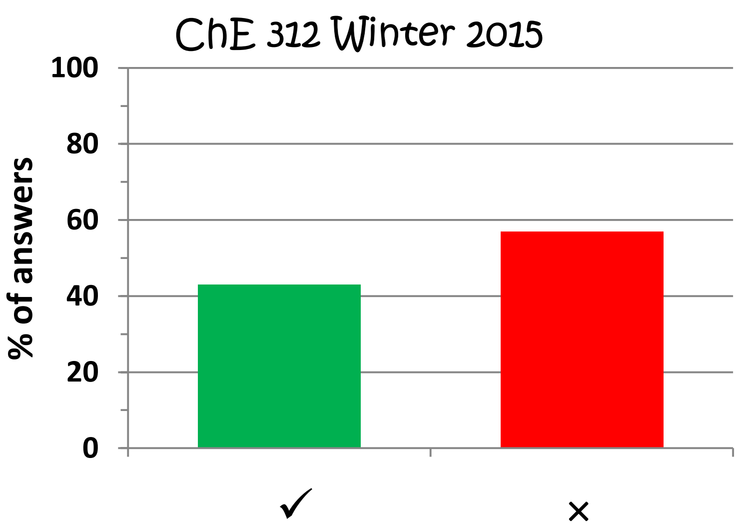
(*e.g.*, $k_1 < k_2 < k_3$)



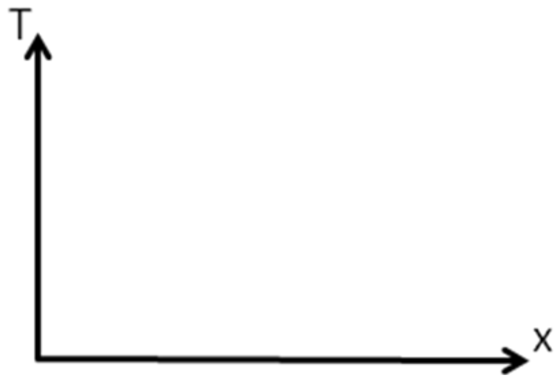


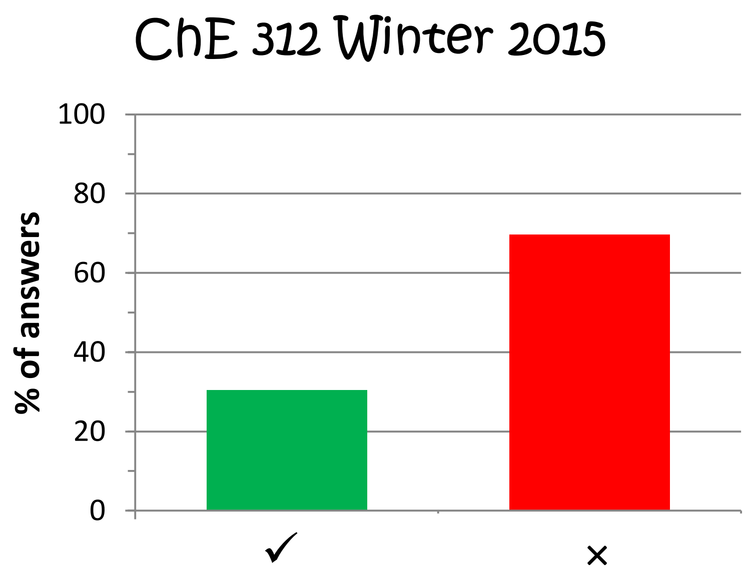
Threshold concept:

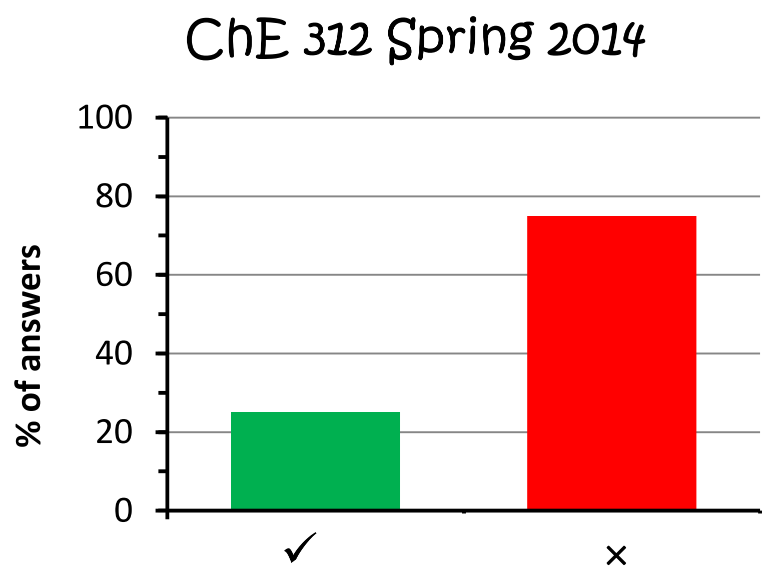
Relationship of conduction heat flux to the temperature gradient



A flat sheet of metal has thickness L and initially uniform temperature T_o. One face of the metal sheet is perfectly insulated. Suddenly, the temperature of the other face of the sheet is lowered to a value T_1. On the following graph, sketch how the temperature distribution inside the metal sheet ($0 \le x \le L$) will vary over time:







Conclusions

- Concept domain mapping provides insight into the program
- Threshold concept testing formative & summative assessment opportunities
- Further work needed to demonstrate validity and reliability
- How should concept testing relate to grades?
- What is preventing students from attaining fundamentally important concept thresholds?