Experimentation on Fostering Critical Thinking In STEM Education

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Overview

- Background: University-Wise Critical Thinking (CT) Effort
- Integrating CT into STEM courses
- Experimentation and Examples with Paul-Elder CT Approach
- Experimentation with Concept Maps
- Conclusions
Background: University-Wise Critical Thinking (CT) Effort

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QLT REPRESENTATIVE FOR SCE

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University of Houston-Clear Lake

- University of Houston-Clear Lake (UHCL) was established in 1974.
- UHCL of is one of four universities that make up the University of Houston System.
- UHCL is a comprehensive university with four schools:
  - School of Business and Public Administration
  - School of Education
  - School of Human Sciences and Humanities
  - School of Science and Computer Engineering
University of Houston-Clear Lake (cont.)

- UHCL enrolls about 9,000 students in 41 bachelor and 45 master level and 2 doctoral degree programs, with over 220 full, associate, and assistant professors, and over 530 staff.

- UHCL has a distinctive reputation as a community-minded, partnership-oriented university.
Quality Enhancement Plan (QEP)

- In early 2013, UHCL QEP entitled *Applied Critical Thinking (ACT) for Lifelong Learning and Adaptability* was approved by the Southern Association of Colleges and Schools (SACS).

- Applied Critical Thinking (ACT) means that students not only know how to think critically, but they also have the disposition to do so; apply critical thinking skills on a daily basis.

- Thus, UHCL QEP was designed to integrate ACT into multiple courses and syllabi.
QEP Process

Main QEP process designs:

1. Established of a QEP Leadership Team (QLT) with strong faculty, administration, and staff representation.

2. A rigorous endorsement process for ACT enhanced courses: QEP’s cornerstone.

3. Extensive professional development support in critical thinking for faculty and staff.
Foundation of Critical Thinking helped UHCL in all three major components of the QEP plan.

Paul-Elder CT Model serves as the basis for:
- The ACT enhanced course endorsement
- The professional development of faculty/staff at UHCL

Even though each school has different characteristics—we have elected to focus on common vocabulary, common language, and common assessments of critical thinking skills.
ACT Syllabus Endorsement Process

1. A faculty member attends at least 4 days of workshops in ACT over a period of one or more years.
2. A QLT school representative works with the faculty member to prepare a draft ACT enhanced syllabus.
3. A QLT peer committee reviews the syllabus and provides feedback with different outcomes.
4. The faculty member makes the necessary modifications to achieve the endorsement.
1. A standardized ACT statement

2. A description of how critical thinking manifests within the course or profession

3. At least three student learning outcomes, each grounded in a unique element of thought (ACT-SLO) and intellectual standards

4. Course assignments and activities that clearly link to the ACT-SLO’s

5. A plan which enables a three-level assessment of each student’s individual performance relative to the ACT-SLO’s.

An ACT-endorsed syllabus contains
CT Elements of Thought

Why the Analysis of Thinking is Important
Everyone thinks; it is our nature to do so. But much of our thinking, left to itself, is biased, distorted, partial, uninformed, or downright prejudiced. If we want to think well, we must understand at least the rudiments of thought, the most basic structures out of which all thinking is made. We must learn how to take thinking apart.

All Thinking Is Defined by the Eight Elements That Make It Up. Eight basic structures are present in all thinking: Whenever we think, we think for a purpose within a point of view based on assumptions leading to implications and consequences. We use concepts, ideas and theories to interpret data, facts, and experiences in order to answer questions, solve problems, and resolve issues.

Thinking, then:

- generates purposes
- raises questions
- uses information
- utilizes concepts
- makes inferences
- makes assumptions
- generates implications
- embodies a point of view

Simply "Mouse Over" any object on the page to learn more about it.
Some Intellectual Standards

- Clarity
- Accuracy
- Precision
- Relevance
- Depth
- Breadth
- Logic
- Significance
- Fairness
Student Learning Outcomes (SLO)

• Most UHCL courses already have well-defined SLOs.

• Faculty selects three SLOs to explicitly add:
  o Three distinct Elements of Thoughts (EoT)
  o Three distinct intellectual standards

• Rationale: Students taking multiple ACT courses will graduate with a diverse exposure to various aspects of critical thinking.

• Using a common set of vocabularies reinforce adaption of CT.
ACT Activities and Assignments

- Directly related to the three ACT SLOs.
- Contain graded assignments which will be assessed.
- Likely to create artifacts (papers, assignments, case studies) to show CT competence level.
ACT Assessment

- Link to ACT SLOs.

- Assessment levels for each student will be Unacceptable, Acceptable, Excellent, or Incomplete.

- All assessment data sent to the Director of Assessment and Planning of the Office of Institutional Effectiveness for university-wise analysis.
Integrating CT into STEM Courses

1. The Endorsement Process
2. Data: Faculty, Staff, Courses, and Students
3. Mentoring a Successful Course Endorsement
ACT Participation in SCE

- SCE participation in ACT activities is high.
  - 43% of approved ACT syllabi from SCE.
  - 44% of faculty members with an ACT syllabi from SCE.

- One reason: SCE feels that ACT has a natural fit for Science, Technology, Engineering, and Mathematics (STEM).
### Broad-Based Participation

<table>
<thead>
<tr>
<th>Subject</th>
<th>ACT Syllabi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>1</td>
</tr>
<tr>
<td>Chemistry</td>
<td>2</td>
</tr>
<tr>
<td>Computer Information Systems</td>
<td>4</td>
</tr>
<tr>
<td>Computer Science</td>
<td>6</td>
</tr>
<tr>
<td>Engineering Management</td>
<td>1</td>
</tr>
<tr>
<td>Industrial Hygiene</td>
<td>1</td>
</tr>
<tr>
<td>Mathematics</td>
<td>1</td>
</tr>
<tr>
<td>Physics</td>
<td>1</td>
</tr>
<tr>
<td>Statistics</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18</strong></td>
</tr>
</tbody>
</table>
As a component of the QEP process on Applied Critical Thinking (ACT), faculty who complete the requisite professional development revise their syllabi to address the Elements of Thought and Universal Intellectual Standards of critical thinking, based on the Foundation for Critical Thinking model. These syllabi go through a peer review process among faculty to ensure elements and standards are effectively incorporated based on a set evaluation rubric. An endorsed ACT course syllabus follows a format that clearly describes to the reader how ACT will be used in delivering course content to develop students’ abilities in analyzing and evaluating information. The review process is detailed below.

Proposal Form
Syllabus Template
Endorsed Syllabi
CHEM 4373 Quantitative Chemical Analysis

Quantitative Analysis
CHEM 4373, Fall 2014

Laboratory: Thursday, 19:00 - 21:50 PM (B3506)
Instructor: [Blank]
Office Hours: [Blank]
Graduate TA: [Blank]
Prerequisite: General Chemistry
CHEM 4373-5331
Quantitative Chemical Analysis
Spring 2015
T 6:00 – 9:50 pm, Bayou 3506

UHCL Quality Enhancement Plan (QEP): Applied Critical Thinking (ACT) for Lifelong Learning and Adaptability

Applied Critical Thinking Statement:

This course has been authorized by UHCL as an Applied Critical Thinking (ACT) Course which means that in addition to learning about the specified course content, students will be engaged with some or all of the Elements of Thought and Universal Intellectual Standards of critical thinking. The objective of an ACT course is to develop the student’s ability to become skilled at analysis and evaluation by applying a set of intellectual tools that may be effectively used across all disciplines (as well as to the student’s personal life). Based on the Foundation for Critical Thinking (http://www.criticalthinking.org/), critical thinking involves thinking for a purpose, asking questions, using information, applying concepts, drawing inferences and conclusions, identifying assumptions, anticipating implications and consequences, and
Critical Thinking in Quantitative Chemical Analysis

Analytical Chemists use Critical Thinking in solving chemical quantitative problems that require systematic solutions with high accuracy and precision. Specifically, such solutions require analytical methods and operations that focus on assumptions, information, and consequences. Analytical Chemist focus on understanding the principles that connect unknown samples with analysis methods to provide an infrastructure for problem solution. All of this begins with clearly understanding a question that needs a solution. Specific questions addressed in this course are:

- How to select a fair quantitative analysis method for an unknown sample in order to obtain the most reliable data for the task?
- How to conduct the data analysis for the task, i.e. an evaluation on how accurate and precision the data would be, and within how much confidence range that we can trust the data we obtained?
# CHEM 4373 Syllabus (cont.)

## Tentative Lab Schedule
**Spring 2015 (Jan.20–May 04)**

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Date</th>
<th>Lectures / Experiments</th>
<th>Quizzes</th>
<th>Report Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jan 20</td>
<td>Lab Check-In and preparation&lt;br&gt;Class Note 1: Intro topics and Gravimetric Analysis</td>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>2</td>
<td>Jan 27</td>
<td>Lab 1: Calibration of Glassware</td>
<td>--------</td>
<td>Feb 03</td>
</tr>
<tr>
<td>3</td>
<td>Feb 03</td>
<td>Lab 2: Gravimetric Cl</td>
<td>Quiz 1</td>
<td>Feb 17</td>
</tr>
<tr>
<td>4</td>
<td>Feb 10</td>
<td>Class Note 2: Volumetric Analysis and Precipitation Titrations&lt;br&gt;Lab 3: Volumetric Cl (Fajans Method)</td>
<td>Quiz 2</td>
<td>Feb 17</td>
</tr>
<tr>
<td>5</td>
<td>Feb 17</td>
<td>Lab 4: Volumetric Cl (Volhard Method)</td>
<td>Quiz 3</td>
<td>Feb 24</td>
</tr>
<tr>
<td>6</td>
<td>Feb 24</td>
<td>Class Note 3: Acid-Base Titrations&lt;br&gt;Lab 5: Acid-Base Titration (Soda Ash Unknown)</td>
<td>Quiz 4</td>
<td>Mar 03</td>
</tr>
<tr>
<td>7</td>
<td>March 03</td>
<td><strong>Exam 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>March 10</td>
<td><strong>Spring Break</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>March 17</td>
<td>Lab 6: KHP Determination (Acid-Base titration)</td>
<td>Quiz 5</td>
<td>Mar 31</td>
</tr>
<tr>
<td>10</td>
<td>March 24</td>
<td>Lab 7: EDTA Titration (Mg Unknown)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>March 31</td>
<td>Class Note 4: Complex ion and EDTA titrations&lt;br&gt;Lab 7: EDTA Titration (Mg Unknown)</td>
<td>Quiz 6</td>
<td>Apr 07</td>
</tr>
<tr>
<td>12</td>
<td>Apr 07</td>
<td>Lab 8: EDTA Titration (Ca and Mg in tap water)</td>
<td>Quiz 7</td>
<td>Apr 14</td>
</tr>
<tr>
<td>13</td>
<td>Apr 14</td>
<td>Class Note 5: Oxidation-Reduction Titrations&lt;br&gt;Lab 9: KMnO₄ Determination of Ca</td>
<td>Quiz 8</td>
<td>Apr 21</td>
</tr>
<tr>
<td>14</td>
<td>Apr 21</td>
<td><strong>End of Semester Project:</strong> unknown sample analysis</td>
<td></td>
<td>Apr. 28</td>
</tr>
<tr>
<td>15</td>
<td>Apr 28</td>
<td><strong>Exam 2</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Student Learning Outcomes (SLOs)

Upon completion of this course, students will be able to:

1. Gain in-depth understanding of the basic concepts of quantitative chemical analysis clearly and precisely, and master basic principles underlying all the types of quantitative chemical analysis.

2. Clearly identify the purpose of the major task of quantitative chemical analysis. Not only know what, how but also why.

3. Clearly understand how important the accuracy and precision are in a specific quantitative chemical analysis, and know in depth how to achieve a reliable analysis.

4. Develop accurate methods for data evaluation for the information collected from a specific quantitative chemical analysis, and logic and fair error analysis for experimental inference.

5. Acquire relevant laboratory skills via hands-on practices of quantitative chemical analysis, aimed at accuracy and precision of the data.

6. Develop significant collaborating skills with the awareness of implication and consequences by engaging in various lab analysis tasks with lab partners.

7. Logically design a relevant practical quantitative analysis method for an unknown sample based on the concepts learned in the course.
Critical Thinking Activities and Assessment

A semester-end project on the quantitative determination of an unknown sample will be assigned to the students in an earlier time of the semester. The students are encouraged to work in groups (freedom on combination, but no more than 4 students per group). The evaluation of the activities is used to assess how well critical thinking is incorporated into the course. These assessments will be used as input to the UHCL Critical Thinking database for internal assessment of Critical Thinking, and will not affect your grade of the course.

1. With the given information, student is required to logically design a relevant analysis procedure for an unknown sample based on the concepts learned in the course, and conduct the experiments on their own which will be due right before the final exam. (SLO #2, 7)

2. Student will perform accurate data evaluation for the information collected by developing logic and fair error analysis for experimental inference. Student will also develop significant collaborating skills with the awareness of implication and consequences by engaging in independent lab analysis tasks with lab partners. (SLO #4, 6)
Some Lessons Learnt in CHEM 4373

- The instructor went beyond ACT syllabi requirements to utilize CT as a lens for course improvement.

- CT brings focus on its capstone laboratory project.

- Faculty seem to think that CT may help minimize mistakes, which are especially important to avoid in laboratories.
Experimentation and Examples with Paul-Elder CT Approach

1. Critical Thinking and Education
2. UHCL First Year Experience (FYE)
3. Humanities and ACT
4. Empowerment through Education
Many STEM courses have successfully completed ACT offerings.

This talk focuses on experimentations with two Computer Science (CS) and two Computer Information Systems (CIS) courses taught by the presenters.

- CS: Undergraduate Database
- CS: Graduate Database
- IS: Undergraduate IS Theory and Practice
- IS: Graduate Strategic Information Systems
Instructors experimented with using CT elements to construct logic for thinking for disciplines and courses.

Examples: Logic of thinking for
- Information Systems: discipline level
- Relational Database Systems: course level
- Mapping from the Object-Oriented Model to the Relational Model: topic level

Provide a lens and chances for instructors to rethink about their courses at a higher level.
The logic of Information Systems in Business in ACT Elements

[a] Purpose: To effectively use information systems to support and expand business performance of an organization.

[b] Question: How do we identify the needs, challenges and opportunities of an organization, and use information systems to effectively satisfy the needs and challenges, and exploit the opportunities?

[c] Information: Relevant information about the organization, industry and the economy that can effectively be collected. Relevant information, concepts and theories of information systems and information technologies.

Note: This includes an understanding of the context of the collected information and the uncertainty and partiality of the information.
[d] Interpretations and inferences: Design, develop, evolve, and manage information systems, policies, guidelines, and cultures that support business functions and decision making.

[e] Essential concepts: IS, IT, management, business and other relevant concepts and theories that guides the design, management, use, and assessment of information systems.

[f] Assumptions: It is possible to devise cost effective information systems to support various needs of an organization.
Logic of Thinking in IS (cont.)

[g] Implications and consequences: Well-designed IS solution to well-defined problems can be effective. Poorly designed IS solutions can be detrimental.

[h] Point of view: Numerous possible considerations within an organized need to be considered and balanced to capture and model the problems, and design and evolve effective IS solutions.
Experimenting with using CT technique, such as SEE-I and Fundamental and Powerful Concept (FPC) in class.

SEE-I:
- State
- Elaborate
- Exemplify
- Illustrate

Iteratively use SEE-I to refine understanding.
SEE-I Example

- Iterative refinement of modeling a concept using SEE-I in CSCI 5333 Database Management System (DBMS) in classroom
  - Topic: composition and aggregation in UML Class diagram
  - Two classroom exercises (in two sections)
    1. From scratch
    2. Using Wikipedia as a starting point
Classroom exercise goal: Use SEE-I and FPC to apply critical thinking to learn aggregation and composition in Unified Modeling Language (UML) class diagram.

Aggregation is an association between two objects modeling “a part of” relationship. Example: an engine is a part of a car.
**Aggregation** is a variant of the "has a" association relationship; aggregation is more specific than association. It is an association that represents a part-whole or part-of relationship. As shown in the image, a Professor 'has a' class to teach. As a type of association, an aggregation can be named and have the same adornments that an association can. However, an aggregation may not involve more than two classes; it must be a binary association. Furthermore, there is hardly a difference between aggregations and associations during implementation, and the diagram may skip aggregation relations altogether.\(^6\)

**Aggregation** can occur when a class is a collection or container of other classes, but the contained classes do not have a strong *lifecycle dependency* on the container. The contents of the container are not automatically destroyed when the container is.

In UML, it is graphically represented as a *hollow diamond shape* on the containing class with a single line that connects it to the contained class. The aggregate is semantically an extended object that is treated as a unit in many operations, although physically it is made of several lesser objects.

Example: Library has Students and books. Here the student can exist without library, the relation between student and library is aggregation.
Example: Iterative Annotation

From Wikipedia: additional annotations or comments made are in red and enclosed by parenthesis.

**Aggregation**

![Class diagram](image)

Class diagram showing Aggregation between two classes

*Aggregation* is a variant of the "has a" association relationship; aggregation is more specific than association. (What do we mean by ‘has’?) It is an association that represents a part-whole or part-of relationship. As a type of association, an aggregation can be named and have the same adornments that an association can. (Thus, an aggregation is a type of associations and share many properties of an association, such as having an association class.) However, an aggregation may not involve more than two classes; it must be a binary association. (This is because a part-of relationship always has two objects: the part and the whole.)

*Aggregation* can occur when a class is a collection or container of other classes, but the contained classes do not have a strong *lifecycle dependency* on the container. The contents of the container are not automatically destroyed when the container is. (In other words, a part may exist on its own without a whole.)
Example: Aggregation: State

(1) Aggregation:

- State:
  - V1: An aggregation is a 'has-a' relationship between two classes.
  - V2: An aggregation is a relationship between two classes that indicates a part-of or a part-whole relationship.
  - V3: An aggregation is an association between two classes that indicates a part-whole relationship.

[Note: Mostly from Wikipedia]
Example: Aggregation: Elaborate

- Elaborate: note that the portions of the following points that are not included directly in Wikipedia are italicized.

1. Strictly speaking, it models a *part-of* or a *part-whole* relationship between two objects of the two classes. The parts are aggregated into the whole.
2. The contained object may exist on its own. There is *no strong life-cycle dependency* on the container object.
3. In UML, it is *represented by a hollow diamond* on the container class.
4. It *must be a binary association* as a part-of relationship is always between two objects.
5. An aggregation is a special case of an association of UML and it inherits properties of an association.
Example: Aggregation: Exemplify

- Exemplify:
  - Two notions of ‘has’:
    1. A person has a brain: part-of relationship.
    2. Tom has a car: ownership but not part-of.
  - The relationship between an engine and a car may be modeled as an aggregation.
    1. An engine X may be a part of car A. Thus, there is an aggregation relationship between the object engine X and the object car A. There is no such aggregation relationship between engine X and another car B.
    2. We assume that the engine in this application may exist on its own. For example, we may remove engine X from car A before destroying A. If no such assumption can be made, the relationship may not be aggregation.
Aggregation: State

(1) Aggregation:

- State:
  - V1: An aggregation is a ‘has-a’ relationship between two classes.
  - V2: An aggregation is a relationship between two classes that indicates a part-of or a part-whole relationship.
  - V3: An aggregation is an association between two classes that indicates a part-whole relationship.
**Aggregation** (from Wikipedia): Revisited

**Aggregation** is a variant of the "has-a" association relationship; aggregation is more specific than association. It is an association that represents a part-whole or part-of relationship. As shown in the image, a Professor 'has a' class to teach. As a type of association, an aggregation can be named and have the same adornments that an association can. However, an aggregation may not involve more than two classes; it must be a binary association. Furthermore, there is hardly a difference between aggregations and associations during implementation, and the diagram may skip aggregation relations altogether.\(^6\)

**Aggregation** can occur when a class is a collection or container of other classes, but the contained classes do not have a strong lifecycle dependency on the container. The contents of the container are not automatically destroyed when the container is.

In **UML**, it is graphically represented as a *hollow diamond shape* on the containing class with a single line that connects it to the contained class. The aggregate is semantically an extended object that is treated as a unit in many operations, although physically it is made of several lesser objects.

Example: Library has Students and books. Here the student can exist without library, the relation between student and library is aggregation.
SEE-I can be effectively used in an iterative manner to build a better cognitive model of a topic.

- More accurate
- More refined
- More correct
- More rich

Lesson learnt: It is easier to build a cognitive model from existing resources than from scratch.
Using EoT in Case Analysis

- Case studies have been known as a great teaching tool to promote critical thinking, especially in IS curricula. However, the benefits come with inherent problems:
  - In-class or take home?
    - In-class case studies are often constrained by time.
    - Quality of in-class studies often relies on the instructor’s capability of “asking the right questions” without “do the thinking for the students”.
  - Quality control and guidance?
  - What are the actual thought processes?
Using EoT in Case Analysis (cont.)

• Effective probing utilizing Intellectual Standards:
  1. Could you be more specific on that (clarity)?
  2. Can you show us how is that related to what we are discussing here (relevance)?
  3. Why do you think that is important (significance)?
  4. Do any of you think there might be other explanations to that (breadth and fairness)?
  5. I am having trouble seeing the connection. Could you elaborate on that (logic)?
  6. Would you mind giving me an example to elaborate on that (depth)?
  7. Let me get it straight, so what you are saying is...(precision and accuracy).
Using EoT in Case Analysis (cont.)

- Effective probing utilizing EoT:
  1. What are the assumptions we are making in our discussion?
  2. Will the solution still be valid if one of the assumptions changes? If so, why?
  3. Who are the stakeholders in this case?
  4. Will your conclusion change if your perspective changes from one kind of stakeholders to another?
  5. Are there any theories and frameworks we can apply to this case?
Pilot CT Survey

- Pilot survey on CT in courses
- Example: CSCI 5333 Spring 2015: 26 respondents.

[1] In the past, how often did you think about how you think? Average: 3.92

(1) Nearly never.
(2) Once about every several years.
(3) Once about every several months.
(4) Once about every several weeks.
(5) Once about every several days or even more frequently.
[2] In the past, how often did you think about ways to improve your thinking?
Average: 3.65

(1) Nearly never
(2) Once about every several years
(3) Once about every several months
(4) Once about every several weeks
(5) Once about every several days or even more frequently

[3] Comparing to the average skills or subjects, how important do you think critical thinking is for CS and CIS? 1.81

(1) Much more important
(2) More important
(3) About the same
(4) Less important
(5) Much less important
[4] How useful and important was the iterative SEE-I and annotation classroom exercise (aggregation and composition with Wikipedia material as the source of information)? 1.85

(1) very useful and important
(2) useful and important
(3) neutral
(4) useless and unimportant
(5) very useless and unimportant

[5] How interesting was the iterative SEE-I and annotation classroom exercise (aggregation and composition with Wikipedia material as the source of information)? 2.08

(1) very interesting
(2) interesting
(3) neutral
(4) uninteresting
(5) very uninteresting
Another Example Experimentation

- Classwork: students work individually on a topic (selected from a list) using a critical thinking form:

<table>
<thead>
<tr>
<th>CT Element Of Thought</th>
<th>Notes</th>
<th>Standards to improve on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question at issue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solution/</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CT Classwork

- This is followed by resolving the form between a team of students on the same topic.
- Students then rated on how easy, useful, and interesting the individual and group exercise is.
- Rating from 1 (negative) to 7 (positive)
Survey Result:

- **Individual Exercise:**
  - Interesting: 5.13
  - Useful: 4.73
  - Easy: 5.03

- **Group Exercise:**
  - Interesting: 5.17
  - Useful: 5.20
  - Easy: 5.20

- **Lesson Learnt:** Some critical thinking exercises may be more effective in groups.
Classroom Exercise (Examples)

- From Daniel Kahneman, Thinking Fast and Slow.
- To show bias and why critical thinking is needed.

(4) Answer the following question:

A bat and ball cost $1.10.
The bat costs one dollar more than the ball.
How much does the ball cost? _________

(5) Is the following logical argument valid? _______

All roses are flowers.
Some flowers fade quickly.
Therefore, some roses fade quickly.
Results

- **Question 4:**
  - Correct answer: 5 cents
  - Result: correct answer: 47%.
  - Nearly all correct given enough time and mindfulness.

- **Question 5:**
  - Correct answer: incorrect logic.
  - Result: correct answer: 59%.
  - Compare (exemplify):
    - All humans are animals.
    - Some animals can fly.
    - Therefore, some humans can fly.
<table>
<thead>
<tr>
<th>CT in less than 30 words (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking hard about something. Being analytical.</td>
</tr>
<tr>
<td>Critical thinking means to analyse the problem from all possible perspectives and form a judgment about the problem.</td>
</tr>
<tr>
<td>I do not know.</td>
</tr>
<tr>
<td>Critical thinking is the best logical way to think, where you can make logical argument.</td>
</tr>
<tr>
<td>The ability to examine a problem/question and provide an explanation and fairly accurate answer.</td>
</tr>
<tr>
<td>Thinking of how to solve a problem.</td>
</tr>
<tr>
<td>In depth thinking of a topic and surrounding topics and how they pertain (help or hinder) that topic.</td>
</tr>
<tr>
<td>Critical thinking is systematically analyzing a problem and generating optimal solutions.</td>
</tr>
<tr>
<td>Critical thinking is applying logical reasoning to situations to determine a conclusion.</td>
</tr>
<tr>
<td>Grasping the question or problem with a complete understanding of the issue and then solving it completely (meeting requirements).</td>
</tr>
<tr>
<td>A way to view a problem that is logically sound and based on evidence not personal bias.</td>
</tr>
<tr>
<td>Critical thinking is a way to solve a problem or question in a different way of thinking which could require more or less thinking.</td>
</tr>
<tr>
<td>Think within a certain time to solve a problem.</td>
</tr>
<tr>
<td>Critical thinking is not taking anything at face value. You gather all facts and come to a conclusion based on your own examination.</td>
</tr>
<tr>
<td>Thinking through problems.</td>
</tr>
</tbody>
</table>
Experimentation with Concept Maps

1. Critical Thinking and Education
2. UHCL First Year Experience (FYE)
3. Humanities and ACT
4. Empowerment through Education
Paul-Elder-Nosich Framework

- Elements of Thought: What is CT?
- Intellectual Standards: How to judge the quality of CT results?
- Intellectual Traits: What habits/traits are desirable for CT?
- **What is the CT process? How do I think critically?**
  - SEE-I
  - Subject-specific
  - ...
Meaningful Learning

- Ausubel’s Theory of Cognitive Learning: *Meaningful learning* is signified by integrating new concepts and propositions with existing relevant ideas in some substantive ways, within one’s cognitive structure.

- An iterative refinement process which is complimentary to CT.

- CT Elements of Thoughts, Intellectual Standards and intellectual traits can be used in this iterative building and refinement process.
Concept Map (CM)

- Invented by Novak: a graphical notation for capturing knowledge and concept.
  - A concept is usually a word or a short phrase representing perceived regularity or pattern in events or objects, or records of events or objects.
  - Linking words are used to connect two concepts to indicate relationships.
  - Concepts and the links between them form propositions.
A Simple Example of Concept Map
Concept Map of CMs

- **Node:** concept.
- **Edge:** relationship between nodes.
CmapTool

• CmapTool is a software created by the Florida Institute for Human & Machine Cognition (IHMC), and free for educational use.
• It empowers users to construct, navigate, share and criticize knowledge models represented as concept maps.
• There are other advantages as well.
• Possible demonstration of CMapTool.
Possible demo of CmapTool if time allows.
Within the FCT framework, CMs enable us to address and use both EoT and CT standards.

**CMs for EoT:**
- CMs make it easier for us to address ‘**Question at Issue**’ through focus questions.
- The flexible structure allows us to incorporate appropriate ‘**Concepts**’ from various ‘**Points of View**’.
- The relationships between concepts can represent ‘**Assumptions**’, ‘**Implications and Consequences**’, ‘**Interpretation and Inference**’, or ‘**Information**’.
CMs for/and CT (cont.)

- The efforts on establishing meaningful relationships require the application of CT standards.
  - The relationships have to be ‘Relevant’.
  - The label and direction of the relationships have to be ‘Clear’, ‘Precise’, ‘Accurate’, and hopefully with ‘Depth’.
Some Experimentations with CMs

- Use CM in classes to show how cognitive structures evolve, highlighting CT EoT involved.

- CM assignments to assess subject matters and CT.

- Surveys and quantitatively analysis on CM perception and effectiveness (especially for CT).

- Investigate how CM can be effectively used in different scenarios and learning objectives.

- Investigate analysis of CM structures.
Distinctiveness of CMs

• It provides a 2-d *structure* (graph), (unlike an essay, for example.)

• The structure may more directly reflect the cognitive structure.

• The structure can be analyzed for assessment and evaluation.

• Automatic analysis of the topology is possible.
Feasibility of Introducing CMs into CT Teaching

• CM as a knowledge representation technique, can be easily grasped by our students—the learning curve is short.

• Only brief introduction was given in classes followed by suggested readings. Student survey reveals:
  o “CMs are easy to understand” at a rating of 5.35/7.
  o “CMs are easy to use” at a rating of 5.36/7
  o “CMs are useful for CT” at a rating of 6.37/7
Relevance of CMs to CT

- After discussion and activities of CM and CT, survey reveals students’ perception of using CMs for CT:
  - CM is useful in illustrating EoT (6.01/7)
  - CM is useful in illustrating CT standards (5.80/7)
  - CM is useful in illustrating iterative refinement in knowledge modeling (6.19/7)
  - CM is useful in illustrating relational database concepts as subject matter (5.91/7)
  - CM is easy to understand (5.91/7)
  - CM is useful overall (6.07/7)
  - CM is effective overall (5.99/7)

- The results indicate that majority students consider CM a useful and easy-to-use tool in helping them understand and apply EoT and CT standards—the two corner stones of our CT teaching efforts, as well as learning the subject matter.
Example of Applying CT in CMs

- Facilitated refinement of a partial CM helps students to see how CT improves CM.
<table>
<thead>
<tr>
<th>Step</th>
<th>Rationale and notes</th>
<th>EoT</th>
<th>CT Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>“Database managers” may refer to DBMS (software) or Database Administrators (person). Change to DBMS to resolve ambiguity.</td>
<td>Concept Information</td>
<td>Accuracy Precision Clarity</td>
</tr>
<tr>
<td>2</td>
<td>The concept “Relational DBMS” is introduced to provide the proper context of the focus question.</td>
<td>Point of View Concept Assumption</td>
<td>Clarity Relevance Precision Fairness</td>
</tr>
<tr>
<td>3</td>
<td>DB Engine is distinguished from DBMS to clarify SQLite from other DBMS.</td>
<td>Concept Information Point of View</td>
<td>Clarity Accuracy Precision Depth</td>
</tr>
<tr>
<td>4</td>
<td>The concept “SQL Queries” may have several meanings: SQL (which is a language), SQL command (that performs operations), or SQL query (that returns results). The trade-offs for creating three separate concepts are discussed before settling the label to the more inclusive term “SQL”.</td>
<td>Concept Purpose Implication</td>
<td>Accuracy Precision Clarity</td>
</tr>
<tr>
<td>5</td>
<td>Fix a misconception. Formally, SQL queries return a table.</td>
<td>Concept Information Implication</td>
<td>Accuracy Precision Logic Clarity</td>
</tr>
</tbody>
</table>
CSCI 4333 Design of DB Syllabus: Elements of Thought in Concept Map (Examples)

Concept and information related to most nodes and edges in the concept map.

- **Programming Language**: Python
- **Web Applications**: Purpose
- **Relational DB**: Problem, is implemented in, manipulates
- **Query Language**: Inferences
- **Relational Calculus**: SQL
- **Relational Algebra**: is a part of
- **Data Manipulation Language (DML)**
- **Data Description Language (DDL)**
- **Entity Relationship Diagram**
- **Normalization Theory**
- **Modeling Language**
- **Data Model**
- **Problem**, **Assumption**
- **Concept Map**
- **Critical Thinking**
- **Point of View**
CM Take Home Assignments

- Students from four classes were asked to complete a CM as homework assignment within a week of relevant course content was covered.
  - Using CmapTool
  - With or without a focus question
  - Start with or without a set of initial concepts
  - In our experiment, we have two types of assignments
    - Type 1: With focus question but no initial concepts
    - Type 2: With initial concepts but no focus question
A Sample CM from an IS Student

- Undergraduate IS student was asked “What are the IS-related ethical and social issues?”
## Observed CT in the sample CM:

<table>
<thead>
<tr>
<th>Propositions</th>
<th>Related EoT</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Issues” such as “Ethical issues”</td>
<td>Question at Issue</td>
</tr>
<tr>
<td>“Health Risks” has negative impact on “Quality of Life”</td>
<td>Implications and Consequences</td>
</tr>
<tr>
<td>“Ethical Principles” guide “Ethical Analysis”</td>
<td>Purpose Concepts</td>
</tr>
<tr>
<td>“Utilitarian Principle” is an “Ethical Principles”</td>
<td>Information</td>
</tr>
<tr>
<td>“Spyware” (is) a challenge for “Privacy”</td>
<td>Interpretation</td>
</tr>
<tr>
<td>“Copyright” is a form of “Intellectual Property”</td>
<td>Concepts</td>
</tr>
</tbody>
</table>
Grading of the CMs

- Students’ work is evaluated using a “Master CM” constructed by the instructor.
- Three scores:
  - Holistic score
    - Assess the overall understanding of the content (i.e., the subject matter) via the lens of CT
    - Instructor used four CT standards (Breadth, Depth, Logic, and Relevance) to judge the overall quality
  - Existential Score
    - Captures the presence or lacking of concepts, weighted by their relative significance
  - Relational Score
    - Measures the existence and correctness of relationships between concepts
The overall score is calculated as follows:

$$\text{Overall} = \left( \frac{10 \times E}{E_{\text{max}}} + \frac{10 \times R}{R_{\text{max}}} + H \right) / 3$$

Maximum E and R scores are calculated using master CM.

Some observations:

- Students’ performance on this assignment positively correlates with their final grades in the course.
- Students’ performance in Relational score tends to be lower than other categories.
Post-Survey on Perception of CM for CT

A survey of 32 items are used to evaluate 6 constructs.

- Graduate students in general think more positively of CMs than undergraduate students. In addition, graduate students are more inclined than undergraduate students to use CMs for CT ($t = 3.749$, $p < 0.001$) and learning of subject matter ($t = 4.371$, $p < 0.001$).

<table>
<thead>
<tr>
<th>Construct</th>
<th>Cronbach’s Alpha</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM makes CT easier</td>
<td>0.9137</td>
<td>5.10</td>
</tr>
<tr>
<td>CM makes CT more useful</td>
<td>0.9267</td>
<td>5.19</td>
</tr>
<tr>
<td>CM helps to learn CT</td>
<td>0.9322</td>
<td>5.10</td>
</tr>
<tr>
<td>CM helps to learn subject matter</td>
<td>0.9300</td>
<td>5.18</td>
</tr>
<tr>
<td>Intend to use CM for CT</td>
<td>0.9211</td>
<td>4.36</td>
</tr>
<tr>
<td>Intend to use CM for learning</td>
<td>0.9387</td>
<td>4.57</td>
</tr>
</tbody>
</table>
Does CM Enhance Students’ Perception of CT?

- We conducted perception of CT surveys pre- and post- the CM treatment.
- The survey results, through hypothesis testing (one side t test), suggest that:
  - Students are more willing to apply CT.
  - Students find applying CT become more voluntarily.
  - Students agree applying CT is not as hard as they thought before.
  - Students agree more that there are resources to make learning and applying CT easier.
Conclusions

1. Critical Thinking and Education
2. UHCL First Year Experience (FYE)
3. Humanities and ACT
4. Empowerment through Education
Conclusions

• University-wise approach to critical thinking has potentials.
• Integrating CT into STEM courses can be cost effective.
• The Paul-Elder-Nosich’s approach serves as a good basis for our efforts.
• Many promising experimentations and results in STEM course.
• Concept Map is a useful tool that complement CT well.

Questions?