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Evaluating Critical Thinking and Problem Solving in Large Classes

Model Eliciting Activities for Critical Thinking Development – Appendix

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Appendix 1: APSC 100 Course Syllabus

Objective

APSC-100 was developed to encourage a sense of creativity and curiosity about engineering work, and to develop professional skills used by engineers. This module focuses on developing general problem solving, critical thinking, and modeling skills in the context of the engineering profession using content knowledge from science and mathematics. It also focuses on helping students use MATLAB as a tool for solving engineering problems.

Specific course learning outcomes include:

1) Apply a prescribed process for solving complex problems
2) Select and apply appropriate quantitative model and analysis to solve problems.
3) Effectively communicate following a prescribed format and using standard grammar and mechanics.
4) Apply concepts including occupational health and safety principles, economics, law, and equity to engineering problems.
5) Apply critical and creative thinking principles to solve contextualized problems.
6) Apply numerical modeling tool to create model used for solving complex problems.

Course Structure

This module is structured quite differently than most university courses. It is structured around three complex problems known as model eliciting activities (MEAs) that we will address sequentially for about three weeks each throughout the semester. Most weeks you will have a pre-class reading related to the problem and that week's lecture topic. Each week you will have one hour of lecture, which will follow a structure like:

1) The instructor will present a short problem to the class which students respond to in teams
2) Some recall and conceptual questions will be presented from the weekly readings
3) Short lecture on a topic related to the problem being studied
4) Student work on the problem which will contribute to the solution to be presented related to the current MEA.

You will also have a two-hour studio each week. Before the studio you will be assigned an online learning activity about MATLAB to prepare you for the studio. At the beginning of the studio you will have a short quiz on the concepts in the readings. A teaching assistant will then review some important concepts related to MATLAB, then help you as you work on a small problem related to the current MEA.

At the end of each three-week segment you will submit a report identifying your team's solution to the presented problem.

The three MEAs are:

MEA 1: Cable ferry failure (Weeks 2-4): This problem will focus on the failure of a cable system. The problem also will focus also on risk analysis, strength of materials, communications, and critical thinking.
MEA 2: Wind turbine design (Weeks 6-8): This problem will focus on the analysis and design of a wind turbine. The problem also will focus on fluid dynamics, electrical power, electric motors, and codes of ethics.
MEA 3: Building heat loss (Weeks 9,11,12): This problem will focus on the design of the insulation for a house being used by the Queen's University team for the Solar Decathlon 2013. The problem will focus also on heat transfer, economic analysis, equity, and environmental impact.

Why this structure?

The course is structured this way to help you develop confidence and skills in solving complex engineering problems – problems for which all information is not known, in which there is ambiguity, where the goals are not necessarily explicitly laid out, for which there may be conflicting or changing information and goals. These are characteristics of real engineering problems. It is important for engineering students to develop not just the knowledge needed by engineers, but also the critical thinking and problem solving skills used by engineers.

Throughout the course we will also encourage you to think about the process you are using to solve problems and how you are learning so that you can evaluate and improve the way you solve problems and think.

Lecture structure

Each class uses digital Socratic approach which starts with a "critical thinking" news problem or story where they have to dig out the erroneous information/assumptions, etc., be expected to dig down to the "real" problem, critically evaluate assumptions made in the problem, evaluate assumptions, work with uncertain information, evaluate sources, etc. We will use web-based responses to allow interaction between students and the instructor. We will also talk about effective communication strategies.

The lecture time will focus on approaches to solving these kinds of problems, and will be active. A portion of the lecture time will involve content taught by the instructor, and portions will require students to work in small groups on a problem, and provide a response to the problem using a web-based response system (TopHat Monacle).

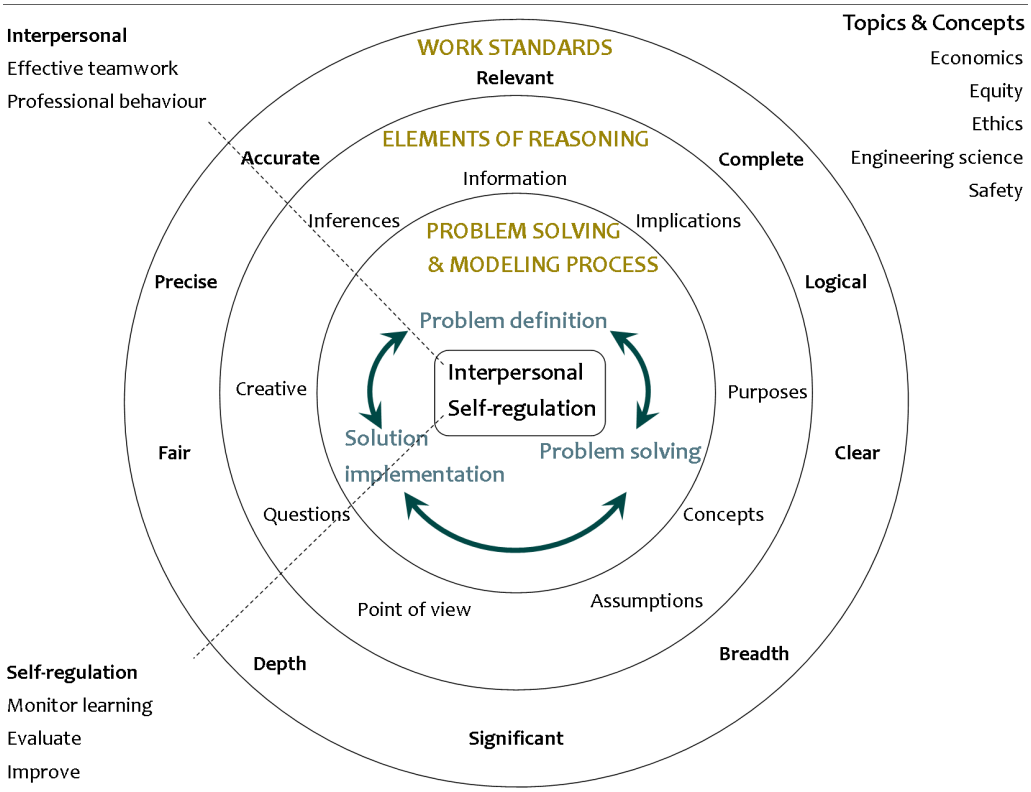
Class Expectations

Come prepared with readings done, laptop and or smartphone preferably, paper, calculator.

Course overview

We will be using the following diagram to describe the course activities and objectives. Throughout the course the activities are designed to develop strong **interpersonal skills**, and encourage you to think about your learning, and processes used to solve these problems, and to continue improving them (**self-regulation**). These are shown in the centre of the circles below. The **problem solving** process is shown as a cycle in the centre of the circle, generally involving three steps: (1) determine information, determining the problem goals and constraints (*problem definition*), (2) using modeling approaches to design and compare possible solutions (*problem solving*), and then (3) implementing and evaluating a solution (*solution implementation*).

We will apply the **elements of reasoning** to the problems we solve (shown in the middle ring below), which we will discuss in the context of the problems we solve. Finally, your written work will be evaluated against the work standards shown in the outermost ring. We will learn about specific topics and concepts shown in the top right hand corner as needed in the practice of engineering.



The table below shows the objectives and activities for the course. This is subject to minor change as we move through the course.

APSC-100: Engineering Practice I 2012-2013 || Course overview				
Course learning outcomes: **Students will be able to:** 1) Apply a prescribed process for solving complex problems 2) Select and apply appropriate quantitative model and analysis to solve problems. 3) Effectively communicate in written document following a prescribed format and using standard grammar and mechanics. 4) Apply concepts including occupational health and safety principles, economics, law, and equity to engineering problems. 5) Apply critical and creative thinking principles to solve contextualized problems. 6) Apply numerical modeling tool to create model used for solving complex problems.				
Pre-class: A pre-class reading or learning activity will be assigned before most lectures and studios. A short quiz will be held at the beginning of the studio each week on the pre-class readings.				
Week		Instructional approach and content *(Instructor activity)*	Learning activity (Student activity)	Evaluation
1:Sep 10		***Lecture***: motivation, course overview, models, self-regulation.	***In-lecture:*** 1. Opening problem, 2. Group activity to consider model for MEA1	***Studio:*** Critical thinking pre-test **(CLO5)** Word/Excel assignment **(CLO 3)**
2:Sep 17	MEA 1	***Lecture:*** (CT:conceptual framework, questions), complex problem solving and critical thinking overview, asking good questions, strength of materials – stress and strain, tensile strength WHMIS course (evening)	***Pre-reading:*** stress and strain, tensile strength ***In-lecture:*** Group activity to develop process for resolving elevator failure problem ***MATLAB Studio*:** Intro to MATLAB (MATLAB problem #1: Starting MATLAB, variables, operations, plotting, scripts, and publishing a MATLAB script).	***Studio:*** MATLAB quiz #1 OHS online test **(CLO4)**
3:Sep 24		***Lecture:*** (CT: purpose, concepts) concept maps, establishing objectives and constraints, safety and hazard analysis. Concision (look at previous examples of student submissions on safety and hazard analysis).	***Pre-reading:*** problem solving and critical thinking overview (write up a 2-3 page summary of problem-solving/design process and critical thinking), occupational health and safety module ***In-lecture:*** Group activity to develop process for resolving elevator failure problem ***MATLAB Studio***: Date importing and functions (problem #2)	***Studio:*** MATLAB quiz #2
4:Oct 1		***Lecture:*** (CT:point of view), argumentation, brainstorming.	***In-lecture:*** analyze past assignments for effective argument, group activity for MEA ***MATLAB Studio***: Curve fitting and interp (problem #3)	***Studio:*** MATLAB quiz #3
5:Oct 8		***Lecture:*** Teaming & leadership (KW)	***In-lecture:*** teaming activi***MATLAB So:*** Conditional statements (problem #4) M3 first team meeting and teaming inventory	MEA 1 SUBMISSION (CLO1,2,3,4,5,6) ***Studio:*** MATLAB quiz #4

Week		Instructional approach and content (Instructor activity)	Learning activity (Student activity)	Evaluation
6:Oct 15		***Lecture:*** (CT:information) information, credibility, bias, intellectual property	***Pre-reading:*** Information learning module on types of information, authority, objectivity, intellectual property ***In-lecture:*** analyzing information sources, looking for bias	STUDIO: MATLAB MIDTERM
7:Oct 22		***Lecture:*** (CT: induction/deduction) Engineering law and professional associations, standards, and codes; induction/deduction. Entrepreneurship?	***Pre-reading:*** Engineering law and associations, codes and standards needed for MEA ***In-lecture:*** use codes, standards set in context of MEA ***MATLAB Studio:*** Loops (problem #5)	***Studio:*** MATLAB quiz #5
8:Oct 29	MEA 2	***Lecture:*** (CT:Implications, point of view) Codes of ethics, framework for resolving ethical dilemmas	***Pre-reading:*** Codes of ethics, framework for resolving ethical dilemmas ***In-lecture:*** ethical dilemmas related to MEA ***MATLAB Studio:*** Functions (problem #6)	***Studio:*** MATLAB quiz #6
9:Nov 5		***Lecture:*** (CT: Implications, point of view), Economic analysis, and putting value to environmental issues	***Pre-reading:*** Time value of money, NPV, environmental value ***In-lecture:*** NPV problems, decision making ***MATLAB Studio:*** Matrices (problem #7)	MEA 2 SUBMISSION ***Studio:*** MATLAB quiz #7
10:Nov 12		***Lecture:*** (CT: point of view) Client interaction and audience analysis, preparation for interview of an engineer (KW)	Pre-reading: TBD ***MATLAB Studio:*** Numerical methods (problem #8) ***In-lecture:*** client interaction activities, preparation for interview of the engineer	***Studio:*** MATLAB quiz #8
11:Nov 19		***Lecture:*** (CT: inferences), diversity and equity. International operations, variation in social norms and laws.	***Pre-reading:*** Article on diversity of opinion in engineering, maybe Mill's sociological framework ***In-lecture:*** diversity and equity cases	STUDIO: MATLAB FINAL EXAM
12:Nov 26	MEA 3	***Lecture:*** Course summary, preparation for client meetings in January, interview of an engineer. Video on engineering. Relating content to M3 projects	Pre-reading: TBD In-lecture: TBD	MEA3 SUBMISSION IN WK 13 ***Studio: CT*** *P*ost-test **(CLO5)**

Grading

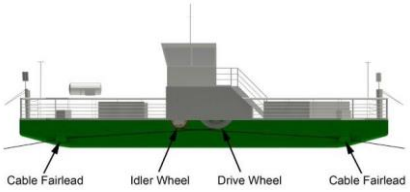
Overall in the course your grade is made up of an equal weight for Modules 1, 2, and 3. For Module 1 the grade weighting is as shown below.

Deliverable	Weight
Word assignment	2
Pre-test on critical thinking completion	1
Occupational health and safety quiz completion	2
Moodle quizzes on MATLAB (best 6 of 8 quizzes)	3
MATLAB studio assignment completion (best 6 of 8 assignments)	3
Completion of questions in lectures using TopHat (tentative)	2
MEA1	10
MEA2	20
MEA3	25
MATLAB Midterm test	10
MATLAB final test	20
Course survey	1
Post-test on critical thinking completion	1
	100

Appendix 2: MEA 1 Objectives and Rubric

Ecolos Cable Ferry Failure

Model Eliciting Activity #1
APSC-100 Module 1 2012-2013



Objectives

This activity is intended to develop the ability to resolve engineering problems by applying mathematical models, critical thinking, and professional judgement. Specific objectives of this include:

- Problem analysis (defining a problem, complex problem solving, modeling)
- Professionalism (importance of public safety in engineering practice, risk assessment)
- Critical thinking (asking useful questions, assessing the credibility of information, argumentation)
- Communications (English mechanics, report formatting)

As you complete your report, ensure that it meets these overall objectives.

Scenario background

In the scenario presented below your team has been asked to conduct a Transportation Safety Board of Canada (TSB) investigation into the failure of the *Ecolos* Cable Ferry. A preliminary investigation team has provided the information attached below in advance of your visit to the site. Like any information source the information presented to you by the on-site team may be suspect, so you should look out for information that is not realistic. Before you arrive on site you have been asked to submit an **investigation proposal report** addressed to the Transportation Safety Board that describes the process your team will follow to investigate this incident, provides an analysis of hypothetical situations that may have caused failure using some simple MATLAB models, and what factors may have led to the failure. In the scenario this report is intended to help determine what to investigate, and what questions to ask. It is expected that you apply principles for complex problem solving, critical thinking, and safety analysis.

Note that the details provided below have been modified from the original case published on the TSB website.[1] You are free to refer to the TSB report if you would like, but note that because some aspects have been changed for the purpose of this assignment that you should be careful about using information from it.

[1] Available online at: http://www.tsb.gc.ca/eng/rapports-reports/marine/2010/m10c0092/m10c0092.asp

	0-2 (below)	***3-4 (marginal)***	***5-6 (expectation)***	***7-8 (outstanding)***
Information summary section *(team)*	Little useful information, or information directly copied from assignment.	Some important information or biases not identified, or trivial/incorrect information included.	Summarizes and assesses credibility of information used, evaluates uncertainty and biases.	**Meets expectations and:** Includes information from authoritative sources to inform process, model, and conclusions.
Proposed process section *(team)*	No or inadequate process	Process identified misses some important factors; some assumptions left unidentified or unjustified.	Creates justified process for solving problem, supported by information.	**Meets expectations and:** Comprehensive process model; comparison with other possible approaches.
Model section *(team)*	No analysis, or model/analysis selected is inappropriate	Model is not sufficient to make reasonable conclusions; errors in analysis or inappropriate assumptions.	Creates and compares quantitative models in MATLAB using reasonable approximations and assumptions.	**Meets expectations and:** Sophisticated model used incorporating several effects; uncertainty in model's input variables shown by range of output values
Safety analysis in Conclusions section *(individual)*	No or trivial analysis.	Analysis includes some factors, but some important factors missed.	Assesses risk; makes supported conclusions about failures and recommendations for improvement.	**Meets expectations and:** Comprehensive range of risks analysis, qualitative where possible.
Model results in Conclusions section *(individual)*	No evaluation of solution.	Superficial evaluation of solution	Evaluates validity of results and model for error, uncertainty, drawing well-supported conclusions.	**Meets expectations and:** Evaluates model conclusions and presents potential improvements to the models.
Self-assessment section *(individual)*	No or superficial assessment.	Analysis of team and individual work identifies few areas for improvement.	Critical analysis that identifies limitations, potential biases, potential inaccuracy, etc.	**Meets expectations and:** Comprehensive and deep analysis applied with clear proposals for potential improvement.
Argumentation *(individual)*	Unsupported or trivial arguments	Arguments include some but not all critical elements	Makes claims supported by data and backing, with appropriate qualifiers	Claims supported by authoritative backing and comprehensive description of context in which they apply.
Communication (throughout report)	Report difficult to understand	Understandable but not formatted following guidelines; many grammatical errors	Clearly formatted following guidelines with few grammatical errors	**Meets expectations and:** Concise, varied transitions, attractively formatted, no grammatical errors

Appendix 3: MEA 2 Objectives and Rubric

Wind Turbine Analysis

Model Eliciting Activity #2
APSC-100 Module 1 2012-2013

Objectives

[1]This activity is intended to help develop the ability to resolve engineering problems by applying mathematical models, critical thinking, and professional judgement. Specific objectives of this assignment include:

- Design – comparing multiple options
- Problem analysis, specifically defining a problem and modeling
- Professionalism, including the using engineering codes and standards
- Critical thinking, specifically assessing the credibility of information and making an effective argument
- Communications, including proper English mechanics, clear formatting, and concision.

As you complete your report, ensure that it meets these overall objectives.

Scenario background

Your team is working for a consulting firm that has been asked to make recommendations for the installation of a standalone energy system in remote communities of Northern Ontario. Some provincial government officials are pushing for wind turbines, others for solar panels, others are pushing for gas turbines, and others for some combination of those.

You have been asked to design a wind turbine to be installed as a pilot project to provide real-world data that can be used to make a decision about wider implementation wind turbines or other options. You have also been asked to provide a balanced critical review of the merits of wind turbines to the provincial government in comparison with other options.

You will need to pick a town in northern Ontario to serve as the location for this pilot project, and design your turbine from there. You should ensure that the location picked has suitable wind characteristics for the evaluation, and that you can find information about the community to make an informed recommendation for power generation. Your design must include characteristics of the wind turbine blades, and a recommendation for the motor to be used (the best is to recommend a commercially available model that is rated for the power level required).

[1] Image source: http://www.fortiswindenergy.com/

	0-2 (below)	***3-4 (marginal)***	***5-6 (expectation)***	***7-8 (outstanding)***
Cover letter *(team)*	Unclear; objectives and conclusions not identified	Summary is missing some key objectives or conclusions; unsuitable for intended audience	Clear, concise summary of objective, conclusions, and recommendations using professional language and appropriate formatting	**Meets expectations and:** Letter is tactful, authoritative and convincing with varied transitions, no extraneous information, and professional quality formatting.
Information summary section *(team)*	Little useful information, or information directly copied from assignment.	Some important information or biases not identified, or trivial/incorrect information included.	Summarizes and assesses credibility of information used, evaluates uncertainty and biases.	**Meets expectations and:** Includes information from authoritative sources to inform process, model, and conclusions.
Model and optimization section *(team)*	No analysis, or model/analysis selected is inappropriate	Model is not sufficient to make reasonable conclusions, or missing support for optimized values; errors in analysis or inappropriate assumptions.	Adapts model in MATLAB to optimize design using supported approximations and assumptions.	**Meets expectations and:** Uncertainty in input variables examined by simulating over a range of values; adapts model to consider options identified by independent research
Power generation alternatives section *(team)*	No significant comparison/ analysis of alternatives	Evaluates alternatives without supporting rationale for recommendations (e.g. no support for how criteria are weighted)	Evaluates alternatives based on appropriate criteria supported by clear logical arguments.	**Meets expectations and:** Evaluation uses authoritative knowledge, mathematical models, appropriate design tools and client/user feedback to select best solution
Model results in Conclusions section *(individual)*	No evaluation of solution.	Superficial evaluation of solution	Draws well-supported conclusions from model, describes uncertainty, and recommends power generation alternative.	**Meets expectations and:** Evaluates model conclusions and presents potential improvements to the models.
Critical evaluation section *(individual)*	No or superficial assessment.	Analysis of team and individual work identifies few areas for improvement.	Critical analysis that identifies limitations, potential biases, potential inaccuracy, etc.	**Meets expectations and:** Critically analyzes using authoritative resources and presents clear proposals for potential improvement for the report.
Argumentation *(individual)*	Unsupported or trivial arguments	Arguments include some but not all critical elements	Makes claims supported by data and backing, with appropriate qualifiers	Claims supported by authoritative backing and comprehensive description of context in which they apply.
Communication (throughout report)	Report difficult to understand	Unnecessary text; understandable but not formatted following guidelines; many grammatical errors	Concise and clearly formatted following guidelines with few grammatical errors	**Meets expectations and:** Concise, varied transitions, attractively formatted, no grammatical errors

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Appendix 4: MEA 3 Objectives and Rubric

1

NetZero home building design

Model Eliciting Activity #3
APSC-100 Module 1 2012-2013

Objectives

This activity is intended to develop the ability to resolve engineering problems by applying mathematical models, critical thinking, and professional judgement. Specific objectives of this include:

- Problem analysis (defining a problem, complex problem solving, argumentation, modeling)
- Design (brainstorming, evaluating options)
- Ethics and equity
- Economics

As you complete your report, ensure that it meets these overall objectives.

Background

In this scenario your team are civil engineers working for NetZero Design Consultants, reporting to Dr. Eva Rogers, the company's Director of Engineering Operations. She has assigned your team the project requested by the client, Marblestone Design and Build, Inc., and passed along the letter from the client (attached). As described in the attached letter, NetZero Design has been asked to design part of a net-zero home (i.e. a home with zero net energy consumption due to design for high efficiencies and on-site energy generation from renewable sources). You have been asked to model the temperature distribution through the walls of the house and to select appropriate insulating materials for the house. Dr. Rogers is going away on an extended business trip, and has asked you to do some preliminary analysis on the house, and to create a draft of a cover letter in response to the requests from Marblestone for her to review upon her return. You can assume that the temperature distribution has reached equilibrium.

Figure 1: The Queen's Solar Education center

	0-2 (below)	***3-4 (marginal)***	***5-6 (expectation)***	***7-8 (outstanding)***
Cover letter *(team)*	Unclear; objectives and conclusions not identified	Summary is missing some key objectives or conclusions; unsuitable for intended audience	Clear, concise summary of objective, conclusions, and recommendations using professional language and appropriate formatting	**Meets expectations and:** Letter is tactful, authoritative and convincing with varied transitions, no extraneous information, and professional quality formatting.
Model section *(team)*	No analysis, or model/analysis selected is inappropriate	Model is not sufficient to make reasonable conclusions, or missing support for optimized values; errors in analysis or inappropriate assumptions.	Creates model of heat loss and temperature profile in MATLAB using supported approximations and assumptions.	**Meets expectations and:** Uncertainty in input variables examined by simulating over a range of values; adapts model to consider options identified by independent research
House design *(team)*	No significant comparison/ analysis of alternatives	Evaluates alternatives without supporting rationale for recommendations (e.g. no support for how criteria are weighted)	Evaluates alternatives for house design based on appropriate criteria supported by clear logical arguments.	**Meets expectations and:** Evaluation uses authoritative knowledge, mathematical models, and/or appropriate design tools to select best solution
Model results in Conclusions section *(team)*	No evaluation of solution.	Superficial evaluation of solution	Draws well-supported conclusions from model, describes uncertainty and limitations of conclusions drawn.	**Meets expectations and:** Evaluates model conclusions and describes how model could be improved/extended; considers incorporating feedback from stakeholders for future improvement.
Ethical reasoning (Appendix) *(team)*	Does not recognize an ethical dilemma, or provides an unsupported solution.	Recognizes and resolves an ethical dilemma with reference to principles and codes of ethics, but not well supported.	Recognizes and resolves an ethical dilemma supported by ethical principles and relevant codes of ethics.	**Meets expectations and A**nalyzes alternatives approaches to resolving a dilemma and how they will impact various stakeholders
Critical evaluation section *(individual)*	No or superficial assessment.	Analysis of team and individual work identifies few areas for improvement.	Critical analysis that identifies limitations, potential biases, potential inaccuracy, etc.	**Meets expectations and:** Critically analyzes report and presents clear proposals for potential improvement for the report and conclusions.
Argumentation *(team)*	Unsupported or trivial arguments	Arguments include some but not all critical elements	Makes claims supported by data and backing, with appropriate qualifiers	Claims supported by authoritative backing and comprehensive description of context in which they apply.
Communication *(team)*	Report difficult to understand	Unnecessary text; understandable but not formatted following guidelines; many grammatical errors	Concise and clearly formatted following guidelines with few grammatical errors	**Meets expectations and:** Concise, varied transitions, attractively formatted, no grammatical errors

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Appendix 5: Mini-MEA A (Think aloud pre-test)

Scenario

Your team is a local engineering firm hired by the city of Rockplace to recommend the safety procedures for a toboggan hill to be setup for their annual winter festival.

For those unfamiliar with tobogganing, or snow sledding, please watch this youtube video.

Your team will need to analyze the material provided and create a response as directed below.
These materials have been provided to help you address this problem. They include:

1. An independent opinion on toboggan safety
2. A newspaper article on tobogganing safety
3. A student-created list of friction coefficients
4. A textbook excerpt of friction coefficients
5. Information about average mass of American children and adults
6. A scientific article on human tolerance and crash survivability
7. Physics equations

You are asked to create a written response that makes recommendations for appropriate setup of the hill and guidelines for the event organizers, supported by analysis. This problem is obviously more complex than the one you just did, but the principle remains the same: identify problems based on the information provided, propose and evaluate your solutions, and make recommendations accordingly.

Email to your team

To: {Your team}

From: Robert Brinkenhof, Rockplace Sliding Centre

The Rockplace city council thanks you for agreeing to consult on the design of our SuperSlider sliding run for our annual winter festival. Our hill has a roughly 30 degree slope and a total length of 200 m.

We request:

Guidelines for dealing with potential impact to two solid objects that the bottom of the hill - one is a tree with a trunk around 1 m in diameter, and the other is a yet to be erected fence located 50 meters from the bottom of the hill. We would like the fence to double as a crash barrier, as well as protecting spectators. One of the city counselors with prior military experience suggests that deceleration due to impact be limited to around 100*g (i.e. around 2000 N) survivability.

Guidelines for slope conditions and sleds to maintain a safe speed on the hill-
Any other recommendations for safety

Additionally, we are considering creating an “ice slide” on part of the hill for visitors who don’t have sleds could enjoy. We would appreciate a brief recommendation on whether or not this would be a safe inclusion to our festival.

Supplemental Information:

The following information is provided for you:

Independent opinion on toboggan safety
Ken Fingler, Western Financial Group Solutions, 2008.

Newspaper article
"Hockey Helmets Best for tobogganing: study." Derek Abma, Ottawa Citizen Jan 23rd, 2012

Coefficients of friction on ice and snow:
Various Sources, Citations included:
Serway Physics for Scientists and Engineers 4th edition (p. 126)

Excerpts from Scientific Studies on average mass of American Children and Adults:
Ogden, C. L., Fryar, C. D., Carroll, M. D. & Flegal, K. M. Mean body weight, height, and body mass index, United States 1960–2002. Advance data from vital and health statistics Table 2 & 7 (2004)

Excerpts from Scientific Articles on Human Tolerance and Crash Survivability:
Viano, D. C. & Lau, I. V. A viscous tolerance criterion for soft tissue injury assessment. J Biomech 21, 387–388 (1988).

Physics Equations:
Advanced placement physics C equations for 2008 and 2009. College Board (2007). Accessed at www.collegeboard.com/apstudents. September, 2012.

Appendix 6: Mini-MEA B (Think aloud post-test)

Your team is a local engineering firm hired by FunZone Amusements to recommend safety procedures for shuttle loop rollercoaster prototype for their amusement park.

For those unfamiliar with rollercoasters or amusements parks, please watch this YouTube video (http://youtu.be/cIs3rGUqIiU).

Your team will need to analyze the material provided and create a response as directed below. These materials were provided to help you address this problem. They include:

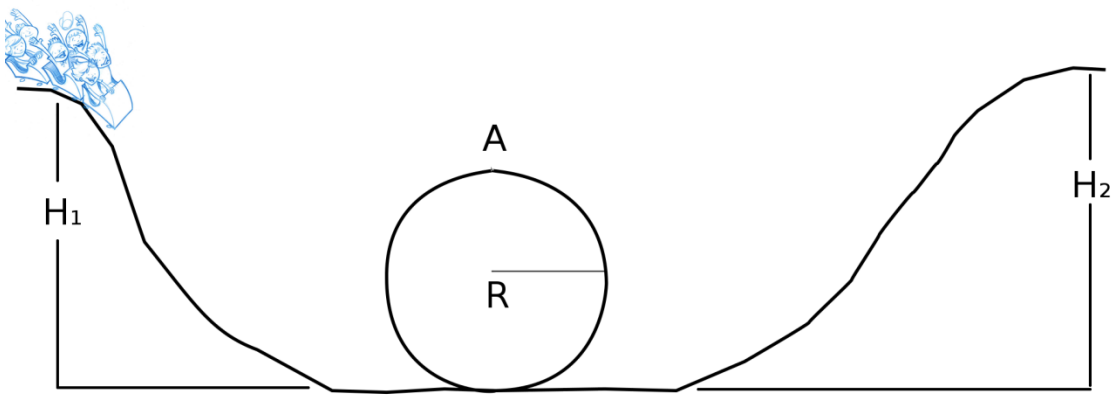
- Summary of American Society of Testing and Materials (ASTM) Standards on Amusement Park Device Design
- Scholarly articles on Rollercoasters and G-Forces
- Reports & Articles on roller coaster safety
- A physics equation sheet

You are asked to create a short response that makes recommendations for design and safety guidelines of the rollercoaster prototype for the amusement park, supported by analysis. This problem is obviously more complex than the warm up you just did, but the principle remains the same: identify problems based on the information provided, make and describe any assumptions, propose and evaluate your solutions and make recommendations accordingly.

Email to your team

To: {Your team}
From: Bill Smith, FunZone Amusements

FunZone Amusements thanks you for agreeing to consult on the design of our prototype rollercoasters. We are hoping to implement a prototype rollercoaster into our parks during the next few years. The rollercoaster cart will launch at the top of the first hill (H_1), go through the loop, reach the top of the second hill (H_2), stop and go backwards through the loop before braking at the top of H_1. A sketch of the proposed prototype is shown below (A denotes the top of the loop):



We would like to have the roller coaster be a fast and thrilling ride. An initial guiding committee of amusement park enthusiasts suggested the loop diameter to be 20m and the speed through the loop to be 25m/s. We would like save on potential costs by reusing an existing cart train. The restraint system present in the existing car is a lap-bar system (two seated riders are restrained by a simple bar resting across their thighs).

We request:

- Guidelines & suggestions for:
    - The height of the launch hill, H_1
    - The height of the braking hill, H_2
- Any safety concerns and recommendations resulting from unsafe conditions.
- Any design alterations or recommendations

Supplemental Information

The following is provided for you:

Excerpts on Information on Roller Coaster Loop Shapes
Ann-Marie Pendrill. *Roller coaster loop shapes. Phys. Ed.*, 43:517-518, 2005.

Elizabeth Craig and Jocelyn Dansey. *Under the Tracks: Roller Coaster Mechanics and Safety*. Paper 2147. Student Paper accessed at http://136.142.82.187/eng12/Author/data/2147.docx

Excerpts from ASTM Standards regarding Harnessing Selection
ASTM International. *F2291 Standard Practice for Design of Amusement Rides and Devices*. 5-7, 2011.

Excerpts on Information Regarding the G-Force Safety in Roller Coasters
Douglas Smith and David Meaney. *Roller Coasters, G Forces and Brain Trauma: On the Wrong Track?*. Journal of Neurotrauma. 19(10)1117-1120

Alice Stroll. *Human Tolerance to Positive G as Determined by the Physiological End Points.* Aviation Medicine, 356-367, 1956.

Physics Equations
Advanced placement physics C equations for 2008 and 2009. College Board (2007). Accessed at www.collegeboard.com/apstudents. September, 2012.

Definition of G-Force

A force acting on a body as a result of acceleration or gravity, informally described in units of acceleration equal to one g (9.81 m/s^2). For example, a 12 kg object undergoing a g-force of 2g experiences 24 Newtons of force (1N= kg *m/s^2).

Appendix 7: Pre-Test Survey

APSC 100 Survey

Name:_____
Student #:_____

Please answer this section using Side B of the Test Answer card

There are 10 short statements in this survey. Each statement is followed by five choices.

Please select one that best describes your answer to this question, "Why are you attending University"

1. Because I believe that a few additional years of education will improve my competence as a worker.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

2. For the satisfaction I feel when I am in the process of accomplishing difficult academic activities.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

3. Because with only a high-school degree I would not find a high-paying job later on.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

4. Because of the fact that when I succeed in college I feel important.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

5. Because this will help me make a better choice regarding my career orientation.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

6. For the pleasure that I experience in broadening my knowledge about subjects that appeal to me.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

7. Because I think that a university education will help me better prepare for the career I have chosen.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

8. For the "high" feeling that I experience while reading about various interesting subjects
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

9. In order to have a better salary later on.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

10. To show myself that I am an intelligent person.
A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

There are additional questions on the back of this sheet, please turn it over!

APSC 100 Survey

Name:_____
Student #:_____

Please answer the following questions directly on this sheet

1. Did you have to demonstrate your English proficiency in order to gain admission to the University? Please circle the appropriate response

A. Yes
B. No

2. If you answered yes to question 1, which test results did you include in your university application? Please circle the appropriate response

A. TOEFL
B. IELTS
C. CAEL
D. MELAB
E. Other/Unsure

3. If you answered yes to question 1, what were your test results? _____

Thank you for completing the survey, remember to return this sheet with your test!

Appendix 8: Post-Test Survey

APSC 100 Survey

Name:_____
Student #:_____

Please answer this section using Side B of the Test Answer card

1. **What was your critical thinking post-test?**
   A. Cornell Level Z B. International Critical Thinking Essay Test

2. **On average, how many hours per week do you spend working alone on academic work outside of class (doing individual assignments, studying for tests, reviewing lecture notes, etc.)?**
   A. 0-5 Hours B. 6-10 Hours C. 11-20 Hours D. 20-30 Hours E. 30+ Hours

3. **On average, how many hours per week do you spend working with other students on team-based activities outside of class (group projects, group reports, group assignments, etc.)?**
   A. 0-5 Hours B. 6-10 Hours C. 11-20 Hours D. 20-30 Hours E. 30+ Hours

4. **On average, how many hours per week do you spend working with other students on individual activities outside of class (doing individual assignments with others, studying for tests with others)?**
   A. 0-5 Hours B. 6-10 Hours C. 11-20 Hours D. 20-30 Hours E. 30+ Hours

The following questions will ask you how much you agree with each questions statement

5. **The experience of moving away from home and living independently contributed to developing the kind of thinking I used for the critical thinking post-test**.
   A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

6. **Working on MEAs by myself contributed to developing the kind of thinking I used for the critical thinking post-test**.
   A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

7. **Working on MEAs with other students contributed to developing the kind of thinking I used for the critical thinking post-test.**
   A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

8. **Feedback from the instructor and/or the teaching assistants in APSC 100 contributed to developing the kind of thinking I used for the critical thinking post-test.**
   A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

9. **Discussion with the teaching assistants in APSC-100 Module 1 contributed to developing the kind of thinking I used for the critical thinking post-test.**
   A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

10. **Activities and discussion in the APSC-100 Module 1 lecture contributed to developing the kind of thinking I used for the critical thinking post-test**.
    A. Strongly disagree B. Disagree C. Neutral D. Agree E. Strongly Agree

11. **During the current school year, how often have you combined ideas from different courses when completing assignments?**
    A. Very Often B. Often C. Sometimes D. Never

12. **During the current school year, how often have you discussed ideas from your readings or classes with other faculty members?**
    A. Very Often B. Often C. Sometimes D. Never

13. **During the current school year, how often have you discussed ideas from your readings or classes with others outside of class (students, family members, co-workers, etc.)?**
    A. Very Often B. Often C. Sometimes D. Never

14. **During the current school year, how often have you tutored or taught other students (either paid or voluntary)?**
    A. Very Often B. Often C. Sometimes D. Never

Please answer the following questions directly on this sheet

What do you think has contributed to developing the type of thinking used for the critical thinking post-test over the past three months?

Please rank the following course experiences (1 = Most Important, 8 = Least Important)

- APSC-100 Module 1
- APSC-100 Module 2
- APSC-111
- ASPC-131
- ASPC-151
- APSC-161
- APSC 171
- Extracurricular Activities

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____

Appendix 9: Additional Critical Thinking Frameworks

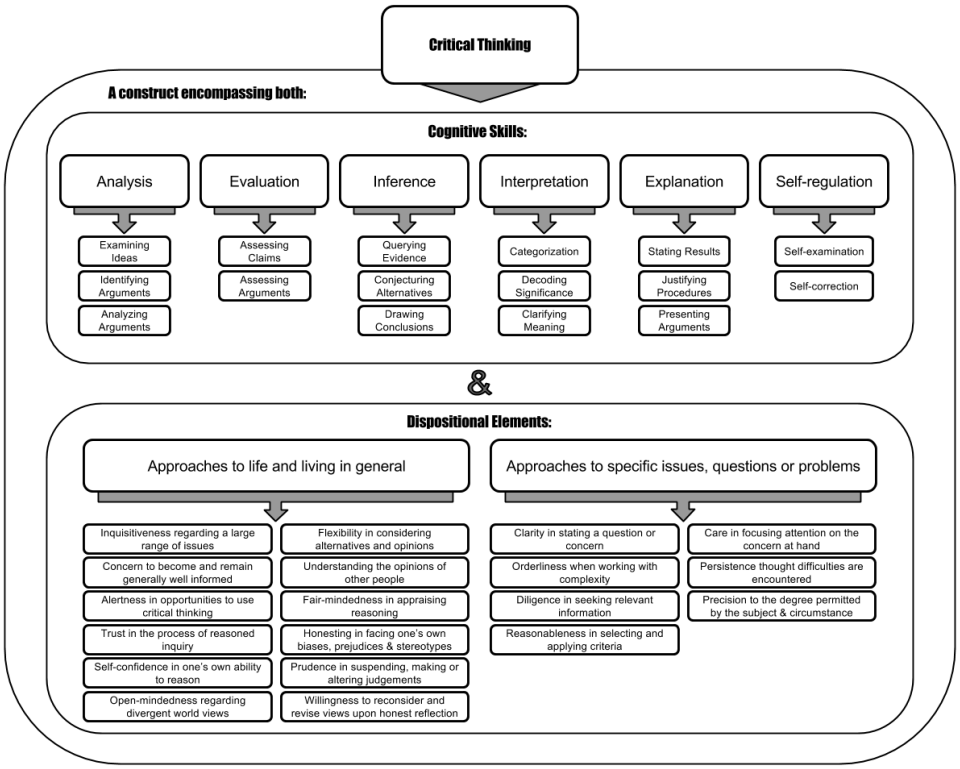
APA Delphi Model

The APA Delphi model of critical thinking was collaborative and collectively created by a panel of 46 experts and compiled by Peter Facione (Facione, 1990). It presents a great many important recommendations about critical thinking constructs, instruction and assessment. It includes the first consensus definition of critical thinking and the first common model produced by panel of experts. The Delphi model definition of critical thinking combines critical thinking itself with a list of dispositional elements:

> Critical thinking is a purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based. (Facione, 1990)

The Delphi model views critical thinking as a composite construct comprised of six cognitive skills, and personal dispositions that focus on the habits, aptitudes and traits of a skilled critical thinker. The six cognitive skills outlined by the Delphi model are further classified by sub-skills; which can be organized into a rubric to evaluate the cognitive component of critical thinking. The dispositional elements are categorized into generic and specific approaches to thinking, as illustrated in the figure below.

Figure A1. The Delphi APA Model



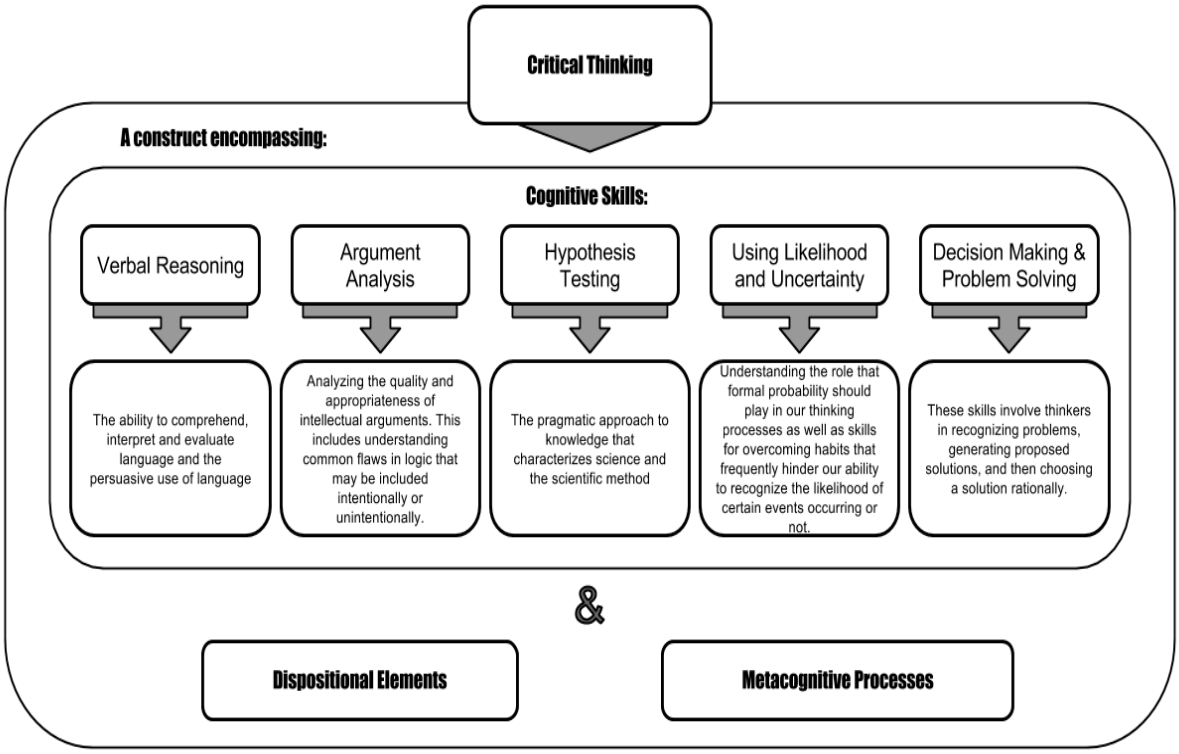
Halpern Model

The Halpern model for critical thinking is a relatively new framework that defines critical thinking as:

> The use of those cognitive skills or strategies that increase the probability of a desirable outcome. It is purposeful, reasoned, and goal-directed. It is the kind of thinking involved in solving problems, formulating inferences, calculating likelihoods, and making decisions. Critical thinkers use these skills appropriately, without prompting, and usually with conscious intent, in a variety of settings. That is, they are predisposed to think critically. When we think critically, we are evaluating the outcomes of our thought processes—how good a decision is or how well a problem is solved. Critical thinking also involves evaluating the thinking process—the reasoning that went into the conclusion we've arrived at or the kinds of factors considered in making a decision. (Halpern, 2000)

The Halpern model suggests a model for critical thinking instruction that encompasses the cognitive, skills-based aspect, as well as the dispositional and the metacognitive aspect, along with the transfer and integration of these aspects (Halpern, 1999) illustrated in the figure below. Within the cognitive aspect of instruction, Halpern presents a taxonomy or framework that can be organized as a rubric for the evaluation of critical thinking skills (Halpern, 1999).

Figure A2. The Halpern Model



Appendix 10: Additional Critical Thinking Assessments

Ennis-Weir Critical Thinking Essay Test

The Ennis-Weir Critical Thinking Essay Test (EWCTET) was developed by Robert Ennis and Eric Weir and is intended for high school and university students (Ennis & Weir, 1985). The test is built on the critical thinking framework put forth by Ennis, with only minor differences from the Cornell-Illinois model. The EWCTET is an open-ended style of test measuring students' ability to analyze and respond to a presented argument (Ennis, 1987). Students are presented with a letter to the editor in which the writer poses an argument to ban parking between 2 a.m. and 6 a.m., and are tasked to evaluate the logic of the letter in a response, providing defensible judgments based on reasoning.

The validity of the EWCTET has been an area of concern. In supplemental material to the test booklet, Ennis referenced content and construct validity through a series of studies conducted with the EWCTET. However, concerns still remain with respect to test validity based on inter-rated reliability calculations. This may be attributed to the subjective scoring process and to writing proficiency bias in graders (Adams, Whitlow, Stover & Johnson, 1996; Ennis & Weir, 1985). Lastly, the EWCTET presents similar challenge as the ICTET, including potential issues with respect to restrictive prompts and the limiting the test takes disposition towards engaging in critical thinking (Ku, 2009).

California Critical Thinking Skills Test

The California Critical Thinking Skills Test (CCTST) is a two-form, 34-item standardized multiple choice test and is intended as a general critical thinking test for university students (Facione et al., 2007). The CCTST measures discrete cognitive skills without any disciplinary context and encompasses the expert consensus definition of critical thinking from the Delphi report (Facione, 1990). This definition views critical thinking as "purposeful, self-regulatory judgment" and is comprised of five main elements (Facione et al., 2007):

1) Analysis
2) Evaluation
3) Inference
4) Inductive reasoning
5) Deductive reasoning

Both a total score and sub-scale scores of the above five elements can be calculated. Report validity, measured by Cronbach's alpha for internal consistency, ranges from α=0.61 to 0.72. The CCTST has limitations similar to those of the CLZ, with the test only addressing the cognitive and not the dispositional aspects of critical thinking and omitting the real-world multidimensional nature of critical thinking (Bensley & Murtagh, 2011; Ku, 2009). There have also been several studies which have raised concerns with measures of low internal consistency, construct validity, unstable reliability and low compatibility between forms (Bondy, Koenigseder, Ishee & Williams, 2001; Jacobs, 1995; Leppa, 1997; Stein et al., 2003). Additionally, some of the questions in the CCTST may contain errors in critical thinking (Fawkes, O'meara, Weber & Flage, 2005).

Halpern Critical Thinking Assessment

The Halpern Critical Thinking Assessment (HCTA) was developed by Diane Halpern as a means to integrate the separate cognitive abilities of critical thinking measured by multiple choice and open-ended essay tests into a single tool (Halpern, 2006). The HCTA seeks to measure critical thinking ability in a holistic manner similar to the CLA by presenting the student with loosely structured, life-like problems in a believable context.

The test draws from Halpern's model of critical thinking and measures the five categories that comprise the model:

1) Verbal reasoning
2) Argument analysis
3) Thinking as hypothesis testing
4) Using likelihood and uncertainty
5) Decision making and problem solving

The HCTA consists of 25 scenario-based questions in which students provide both multiple choice and open-ended responses, resulting in 50 responses. The authors of the test believe this format to provide a better holistic measure of critical thinking, as it combines the "free recall" and integration of skills required by open-ended essay tests with the "recognition memory" and identification required of multiple choice formats (Halpern, 2006).

The HCTA is administered and scored by computer, as part of the Vienna Test System (Schufried GmbH *Vienna Test System*, n.d.). The multiple-choice responses are automatically scored by the system, while grading prompts assist with the human scoring of open-ended responses. The validity of the HCTA has been assessed in several studies at the high school and university levels in many different nations (Butler et al., 2012; Butler & Butler, 2012; Chan, Ho & Ku, 2011; Ku & Ho, 2010b; Marin & Halpern, 2011). These have indicated sufficiently high measures of reliability, with Cronbach's alpha ranging from α=0.85 to 0.97 and inter-rater reliability of r=0.93 (Halpern, 2006). Potential areas of concern for the HCTA include the nature of its administration, as the HCTA must be purchased with a software suite of 80 tests. This may be prohibitive for small class-based assessment led by individual educators.

Critical Thinking Assessment Test

The Critical Thinking Assessment Test (CAT) was developed collaboratively by Tennessee Technological University (TTU) and faculty from participating institutions. The primary goal of this collaboration was to develop a faculty-driven assessment tool to engage the faculty in meaningful, authentic assessment with the goal of improving student learning. The CAT differs from most critical thinking tests in that it does not subscribe to a singular framework describing critical thinking. In a manner similar to the development of the APA Delphi model, the CAT is based around a consensus core set of five skills that comprise critical thinking across a variety of disciplines and 12 representative areas in which to assess these skills (Stein & Haynes, 2011):

1) Evaluating Information
    a. Separate factual information from inferences
    b. Interpret numerical relationships in graphs
    c. Understand the limitations of correlational data
    d. Evaluate evidence and identify inappropriate conclusions
2) Creative Thinking
    a. Identify alternative interpretations for data or observations
    b. Identify new information that might support or contradict an hypothesis
    c. Explain how new information can change a problem
3) Learning and Problem Solving
    a. Separate relevant from irrelevant information
    b. Integrate information to solve problems
    c. Learn and apply new information
    d. Use mathematical skills to solve real-world problems
4) Communication
    a. Communicate ideas effectively

The CAT consists of 15 questions requiring both quick-response items (multiple choice, binary scale) and short-answer essay responses that are likely to measure the cognitive elements of critical thinking and some dispositional elements through its open-ended prompts (Ku, 2009). Currently, the CAT is a paper-based test, with plans to move to a digital delivery system in the near future. The participating institutions own faculty score the CAT, through a "train-the-trainer" system and following a detailed scoring rubric. Validity and reliability measures have been published, achieving face and criterion validity through expert review of the instrument and correlation measures ($r>0.5$, $p<0.01$) with academic measures (Scholastic Aptitude Test, SAT and the American College Testing College Readiness Assessment, ACT), other tools (National Survey of Student Engagement, NSSE) and other critical thinking tests (Collegiate Assessment of Academic Proficiency Critical Thinking Module, CCTST). Reliability was assessed through test-retest reliability ($r>0.80$), inter-rater reliability (kappa=0.82) and Cronbach's alpha ($\alpha=0.695$) ("CAT Instrument Technical Information," 2010; Stein, Haynes & Redding, 2008; Stein, Haynes, Redding, Ennis & Cecil, 2007; Stein, Haynes & Redding, 2006). Despite the relative infancy of the tool, several studies have used the CAT (Gasper & Gardner, 2013; Gottesman & Hoskins, 2013) alongside many National Science Foundation (NSF)-funded initiatives ("Successful Projects | Tennessee Tech University," n.d.). Potential areas of concern with the CAT are the exam's moderate internal consistency score bringing into question the grading scales, and the grading method requiring faculty buy-in and a considerable investment in time. The establishment of inter-rater reliability is also always a concern with essay responses evaluated by multiple graders.

Higher Education Quality Council of Ontario

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