ARGUMENTATION WITH CONTRASTING CASES: FACILTATION OF DEEP STRUCTURE LEARNING IN INTRODUCTORY PHYSICS

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OUTLINE

- Motivation
- Pilot Study – General Results
- Program Overview: **ARISE: Argumentation Infused Scale-Up Environment** (NSF Award # 1712201)
  - In partnership with Purdue University
- What is Contrasting Cases and Argumentation
- **Study** – Contrasting Cases in Tutorials (Recitation)
- Future Work

MOTIVATION

- As science and technology advances in the 21st century, it is important to prepare *all* students to be STEM literate citizens.
- Problem solving is widely regard as a critical 21st Century workplace skill by a vast majority of employers (Burris, Jackson, Xi, & Steinberg, 2013; Hutchison, 2022)
  - Yet, many employers regard recent college graduates as deficient in problem solving skills (Deloitte & The Manufacturing Institute, 2011; Binkley et al., 2012; Finegold & Notabartolo, 2010; Hutchison, 2022)
- Recruitment and retention of the next generation of STEM workforce as well as the preparation of a STEM literate citizenry **resides upon the pedagogical innovations** that postsecondary students experience in science classrooms – especially in physics (Barak, 2017; Cooper et al., 2015; PCAST, 2012).

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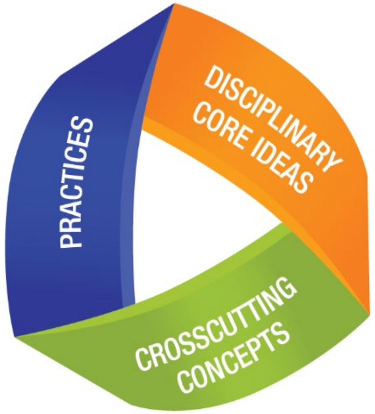
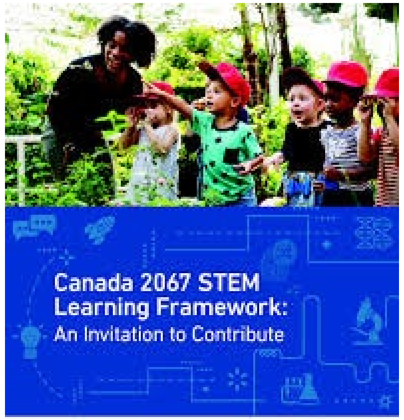
MOTIVATION



- Reform documents (NGSS Lead States, 2013; NRC, 2012) provide guidelines for improving 21st century STEM workforce skills by enumerating **core disciplinary ideas**, **crosscutting concepts**, and **science and engineering practices**.
  - *Next Generation Science Standards* (NGSS Lead States, 2013) have **inspired efforts to prepare students to think critically, to draw upon multiple disciplinary ideas, to collaboratively address non-routine problems, and to construct and evaluate evidence-based arguments** (Fisher et al., 2014; Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018).



- Canada 2067 STEM Learning Framework highlights: **multidisciplinary learning, 21st century skills or workforce development, inquiry/experiential learning, assessment strategies, etc.**
- Thus, a crucial goal is to examine ways to improve students' **evidence-based reasoning, mathematical reasoning, modeling, and problem-solving skills**.

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PILOT STUDY : GOALS

- To explore the ways in which introductory calculus-based physics students approach problems.
  - Specifically, to what extent do they attend to the underlying principles of the problems vs. the surface features.

- Investigate how deeply do students understand and can describe or represent the fundamental principles (i.e., momentum and energy principles)

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PILOT STUDY : METHODS

- Multiple Case Study (Yin, 2008) – Four Participants
- 1.5 - 2 hr. interview session:
  - Open-ended questions
    - How can they describe/explain and apply each principle
  - Concept Map for each principle
    - Short training session prior to create map for each principle
    - What relevant concepts can they identify, relations among concepts and linkages to principles
  - Card Sort of various end of the chapter problems with associated principle(s) needed to solve the problem
    - Explore how principles were applied, what features students look for to begin solving with principle(s)
- Case profiles and cross-case analysis
  - Organized data into case record
  - Open coding of interviews, analysis of concept maps, and card sorting results
  - Codes collapsed into themes (Creswell, 2006)

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PILOT STUDY : SUMMARY OF GENERAL RESULTS

- Most students resort to formula-based strategies for solving problems, similar to traditional course.
- Decide when to use a particular principle based on what is given and what is asked.
- Concepts maps show scant evidence of connections between principles: Seem to see principles as compartmentalized ideas.

Lack of principle-based reasoning, even though curriculum emphasized principles

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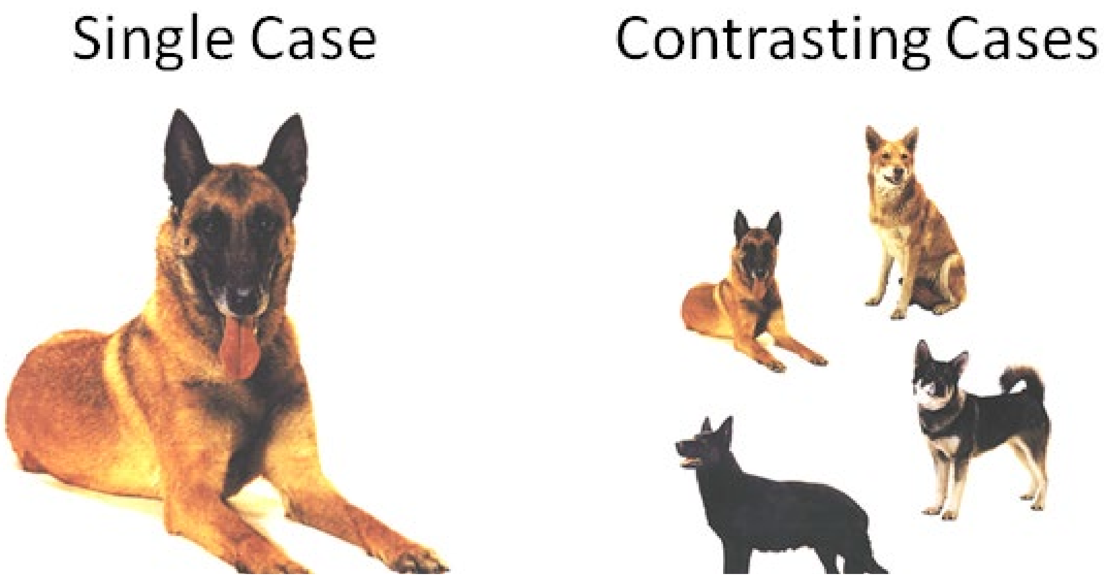
PILOT STUDY : IMPLICATIONS

- Physics students often lack understanding of the underlying principles that should be applied (Leonard et al., 1996)

- **Contrasting cases** foster deep learning by simultaneous consideration of multiple, juxtaposed cases (Chase, Shemwell, & Schwartz, 2010)
  - Facilitate moving beyond surface features to search for patterns in which underlying principles are applied.

CONTRASTING CASES : WHAT ARE THEY?



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- Two or several cases that are simultaneously compared and contrasted
- Increases the number and variability in examples (Glick & Holyoak, 1983; Nokes & Ohlsson, 2005)

CONTRASTING CASES : WHAT CAN THEY DO?

- Designed to…
  - foster deeper learning and focus on underlying principles
  - have embedded similarities and differences which highlight target principles or concepts (Chi, Feltovich, & Glaser, 1981)
  - facilitate students to move beyond examining surface features to make comparisons to search for patterns in which underlying principles are applied (Roelle & Berthold, 2015)
- Emphasize simultaneous consideration of multiple, juxtaposed problems or cases
  - NOT treat problems as separate unique instances (Chase, Shemwell, & Schwartz, 2010)
  - Consider similarities and differences as you make sense of the problems.

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CONTRASTING CASES : HOW DO WE USE THEM?

- Studies have shown that students need **prompts** to compare cases on their own. (e.g., Roelle & Berthold, 2015)
  - Students prompted to invent or construct a single unifying explanation across cases had better learning outcomes than those who prompted to describe similarities/differences between cases. (Chin, Chi, and Schwartz, 2016)
  - Latter group tended to focus on differing surface features as opposed to considering how variations across cases related to underlying principle
- To support students to identify underlying principles, contrasting cases should be…
  - Appropriately designed
  - Scaffolded through carefully designed prompts that facilitate students to attend to the underlying principles of the problem cases, rather than surface features.

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WHAT IS ARGUMENTATION?

Argumentation is a process of making claims and providing justifications for the claims using evidence and considering alternatives

(Cho & Jonassen, 2002; Sampson & Clark, 2008)

Argument is an artifact of argumentation. It is a claim with accompanying justification/rational

(Kuhn, 1991; Sampson & Clark, 2008)

Framework: Claim, Evidence, Reasoning

(McNeill & Krajcik, 2012)

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WHAT IS ARGUEMENTATION?

- From a situated perspective, argument can be seen to take place as an individual activity, through thinking and writing, or as a social activity taking place with a group (Driver et al., 2000)

- Dialogic process (Jimenez-Aleixandre, 2008)
  - More than 1 voice, view
  - Can be a personal process of meaning making (old/new ideas, voices) played in an individual's mind

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WHY ARGUMENTATION IN UNDERGRADUATE STEM?

- Need for evidence-based teaching to improve the STEM pipeline highlighted by *Engage to Excel,* a report by President's Council of Advisors on Science & Tech. (PCAST, 2012)
- Post-secondary science educators have also begun to realize *NGSS's* importance for college science teaching
- Recent *Science* article (Cooper et al., 2015) states that "increasing numbers of students will enter college whose learning has been informed by the *Framework*", and that "it would be a disservice to throw these students back into typical introductory [college] courses that focus on memorizing facts and algorithmic calculations."
- Scientific argumentation has been highlighted in *NGSS* as one of the key science and engineering practices.
- Studies have shown that embedding scientific argumentation in problems can enhance conceptual understanding and problem-solving skills.

ARGUMENTATION IN UNDERGRADUATE PHYSICS

- Few attempts to embed argumentation to support critical thinking
  - *Physics by Inquiry* (*PbI*) (McDermott, 1996)
  - *Physics for Elementary Teachers* (*PET*) (Goldberg, et al., 2006)
    - Both are designed to enhance students' scientific reasoning skills.
    - Both use both open-ended questions and hypothetical student debate tasks requiring application of conceptual knowledge and reasoning skills – useful context for argumentation
- Yet, little argumentation purposefully embedded in courses for science majors
- Growing interest of argumentation various STEM disciplines.

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WHY ARGUMENTATION IN PROBLEM-SOLVING?

- Students seldom encouraged to justify or explain their solutions or rarely reflect on the appropriateness of their responses and consider alternative solutions
- Physics courses (*especially*) traditionally emphasize quantitative problem solving, yet solving such problems …
  - encourages answer-oriented rather than process-oriented (Selvaratnam & Canagratna, 2008)
  - seldom encourages students to consider alternative solutions, reflect on answers, or justify solution approaches
  - does not enhance deeper conceptual understanding (Durfresne et al., 1997; Leonard et al., 1996)
- To become a better problem solvers students must be engaged in tasks that require meaningful justifications, such as argumentations (Jonassen et al., 2009)

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IN AN ARGUMENTATION ENVIRONMENT…

Students should…

- Generate answers/claims/products/experimental designs
- Choose among two or more competing theories/explanations or alternatives
- Back claims with evidence
- Use criteria to distinguish good/poor arguments
- Talk and write science
- Persuade others or reach agreement with peers

Instructor should…

- Model and guide inquiry
- Encourage students to provide evidence, justify positions, challenge ideas, point out limitations or inconsistencies (i.e., open questions)
- Develop and provide criteria for construction and evaluation of arguments and its components either as prompts or rubrics
- To encourage reflection of students' positions or changes in
- Translate epistemic goals

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KEY DESIGN AND FACILITATION CONSIDERATIONS

- Need a carefully designed learning environment in which (Berland & McNeill, 2010; Jim´enez-Aleixandre et al., 2000)…
  - Students solve authentic problems
  - Ask questions
  - Compare solutions
  - Analyze and interpret data
  - Consider alternatives
  - Justify choices
  - Incorporate multiple modes of representations
- The audience in which students are to argue to
- Consideration for what is and the role of appropriate evidence
  - From data and not from opinion

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KEY DESIGN AND FACILITATION CONSIDERATIONS

- Explicit formal teaching of argumentation or by designing an environment which embeds argument competencies (Jimenez-Aleixandre, 2008)
- Students should be prompted to construct oral and written arguments (i.e., justification prompts) (Ge & Land, 2003)
  - The type of prompts depends on the nature of the task
- Instruction should emphasize the role of evidence in explanations (Christoudoulou & Osborne, 2014)
  - Open-ended questions that require evidence and justification

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KEY DESIGN AND FACILITATION CONSIDERATIONS

- Scaffolds/prompts for argumentation can include (Cho & Jonassen, 2002; Jonassen & Kim, 2010):
  - Clear directions or question prompts
    - Could be in the form of reminders or requests
      - “What I want you to do now is to try to justify your answer”
      - “Why?” or “How do you know?”
      - Can you come-up with another argument for your point of view?
      - Can you think of an argument against your point of view?
  - Sentence stems
      - What makes you think [ ]?
      - What is your reason for [ ]?
      - How do you know [ ]?
      - What is your evidence for [ ]?
      - Why do you feel that [ ] is the most important evidence?
  - Graphical aids or Note-starters
  - Science Writing Heuristics (Choi, Hand, & Greenbowe, 2013)

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MOTIVATION AND PURPOSE

- Inclusion of contrasting cases and scientific argumentation can improve students' conceptual understanding and reasoning skills.
  - Success depends on appropriate scaffolding of cases and argument tasks (Chin, Chi, & Schwartz, 2016; Rebello, Sayre, & Rebello, 2012)

- Purpose: To investigate three forms of writing prompts to :

I. <u>Compare</u> among multiple problem cases,
II. <u>Invent</u> a general explanation of how to approach solving problems that would work across all cases,
III. Evaluate multiple competing explanation to produce an <u>argument</u> for "good" general explanation.

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RESEARCH QUESTIONS

1. Which condition (compare, invent, or evaluate arguments) best facilitates students' use of "deep structure" and scientific appropriateness in their responses?

2. What patterns emerge in relation to level of deep structure use, attention to surface features, and scientific appropriateness?

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CONTEXT OF STUDY

- Participants: 71 Honors Engineering and Physics majors
  - Three recitation sections → Three conditions (compare, invent, & evaluate arguments : <u>independent variables</u>)
  - 1st sem., calc-based, *Matter & Interactions* (Chabay & Sherwood, 2015)
  - Problems, with prompts corresponding to each condition, provided to students during recitation

- Written responses openly coded using a three-point rubric reflecting three problem solving dimensions (structure, surface feature, & scientific appropriateness : <u>dependent variables</u>)
- End of term post-recitation survey

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CONTRASTING CASE PROBLEMS

- Three juxtaposed problems were provided to students during recitation
  - Two analogous problems to solve and one example problem (from lecture, text, or prior homework problem)
  - All problems emphasized the same principle(s) and problem-solving process; differing surface features and/or assumptions needed
  - Each recitation received the same problems

Condition	Writing Prompt
Compare & Contrast	Identify and explain all relevant similarities and differences across the given problems. • You may want to focus on features of the problems, the way in which the problems are solved, and/or problem solutions. • You may also consider other problems solved in the course and describe how they are similar or different from the given problems.
Invent	Create a single, unifying explanation that will address how the problems are solved in any given case that would work across all the given problems.
Argument	Which explanation provided best addresses how the problems are solved in any given case that would work across all the given problems? or do you have a different explanation? Explain, elaborate, and justify your preferred explanation. HINT: In your response, you may want to consider: • What evidence and reasons supports your selection? • Explain your reasoning for not choosing the alternative solution(s). What are the weaknesses in the alternative argument(s)? • How might a classmate supporting another explanation disagree with your preferred solution and how would you respond to them?

HYPOTHETICAL STUDENT DEBATE (ARGUMENT CONDITION)

- The problem statement consists of three hypothetical student statements that provide alternative solutions/competing theories to solve a given problem.
- Each hypothetical student statement consist of a misconception or inaccuracy in the problem-solving process
- Students needed to evaluate each statement and construct their own response

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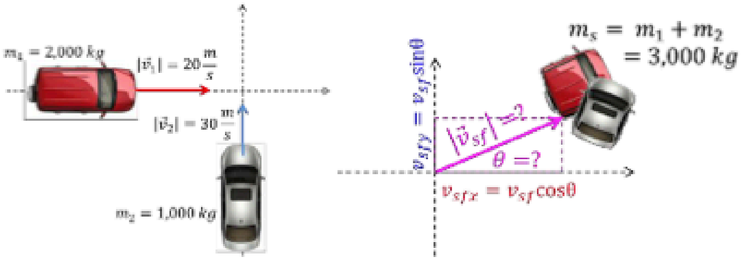
Example Problem: Two vehicles, one traveling East and one traveling North, as shown, collide with each other. After the collision, the wreck of the two vehicles sticking together slides along the road. What is the magnitude and direction of the wreck's velocity immediately after the collision?



System: Both cars
Surroundings: Air, Road etc.
Assume: Frictionless surface, No air drag.
Isolated System: $\Delta\vec{p}_{sys} = 0 \ \rightarrow \ \vec{p}_{si} = \vec{p}_{sf}$

So,

$$\vec{p}_{si} = \vec{p}_{sf}$$
$$\vec{p}_1 + \vec{p}_2 = \vec{p}_{sf}$$
$$\langle m_1 v_1, 0{,}0\rangle + \langle 0, m_2 v_2, 0\rangle = \langle m_s v_{sfx}, m_s v_{sfy}, 0\rangle$$
$$\langle m_1 v_1, m_2 v_2, 0\rangle = \langle m_s v_{sf} cos\theta, m_s v_{sf} sin\theta, 0\rangle$$
$$\langle m_1 v_1, m_2 v_2, 0\rangle = \langle m_s v_{sf} cos\theta, m_s v_{sf} sin\theta, 0\rangle$$
$$\langle 4x10^4, 3x10^4, 0\rangle = 3x10^3\langle v_{sf} cos\theta,\ v_{sf} sin\theta, 0\rangle$$

Separating into components:
$4x10^4 = (3x10^3)v_{sf}cos\theta \quad \| \quad 3x10^4 = (3x10^3)v_{sf}sin\theta$
Divide y-equation, by x-equation: $\theta = \arctan(3/4) = 37°$
Substituting back: $v_{sf} = 16.7\frac{m}{s}$

Problem 1: A binary star system consists of stars, A and B, very far away from other stars. Their masses are $m_A = 4\times10^{30}$ kg and $m_B = 2\times10^{30}$ kg. Their initial positions and velocities in a particular coordinate system are $\vec{r}_{A,i} = \langle -1.33\times10^{12}, -1.00\times10^{12}, 0\rangle$m, $\vec{r}_{B,i} = \langle 2.67\times10^{12}, 2.00\times10^{12}, 0\rangle$m, $\vec{v}_{A,i} = \langle 1.14\times10^4, -1.52\times10^4, 0\rangle$m/s and $\vec{v}_{B,i} = \langle -2.28\times10^4, 3.04\times10^4, 0\rangle$m/s. The magnitude of the gravitational force each exerts on the other when in their initial positions is 2.0×10^{25} N.

Part 1. What is the initial momentum of this binary star system? Estimate the system's momentum one week later. Explain briefly why you think your estimate is reasonably accurate. Express your answer symbolically before calculating a numerical answer.

Part 2. What is the initial momentum of star B? Estimate the change in its momentum during the following week. What is the corresponding change in the velocity of star B? Explain briefly why you think your estimates are reasonably accurate.

Part 3. What is the initial momentum of Star A? Estimate the changes in its momentum and its velocity during the following week. Note: You can use your previous results to do this quickly and easily.

Problem 2: In outer space a small rock with mass 5 kg traveling with velocity <0,1800,0> m/s strikes a stationary large rock head-on and bounces straight back with velocity <0,-1500,0> m/s.

After the collision, what is the vector momentum of the large rock?

- State all objects in your system and surroundings.
- Provide any assumptions you may use to solve the problem.

Student A: Both objects together constitute the system. You first compute the momentum of one object and then the momentum of the other object. Adding them vectorially together gives you the momentum of the system. Then you find the force of the interaction, and use the momentum update principle on the system as a whole. This allows you to calculate the change in momentum of the system as a whole, and the new momentum is divided between the two objects in proportion of their masses.

Student B: You can treat one object as the system and the other object as the surrounding. You first compute the initial momentum of one object and the final momentum of the same object after the interaction You do this using the momentum update principle on just one object, because you know the force of interaction and the time interval of interaction. This gives you the change in momentum of that object due to the interaction. Due to reciprocity, the change in momentum of the other object should be equal and opposite. Using this, you can find the momentum of the other object after the interaction.

Student C: The system is the two objects together. You first find the momentum of each object initially and add it up vectorially to get the momentum of the system. As per the law of conservation of momentum, we know that the momentum of the system as a whole does not change. So, the two objects continue to have the same momentum after the interaction. This is because of reciprocity. You can find the net force of interaction using the formula for gravitational interaction between the two objects. This net force remains constant throughout the interaction, so you can use it to find the new momentum and new position.

RUBRIC

Three aspects

- Structure
- Surface Features
- Scientific Appropriateness

Structure	Definition	Score
Deep	Identifies and applies most of: relevant principle(s), system and surroundings, appropriate approximations and assumptions	3
Moderate	Some identification and application of: relevant principle(s), system and surroundings, and/or appropriate approximations and assumptions	2
Low	No identification or application of: relevant principle(s), system and surroundings, appropriate approximations and assumptions. Utilizes a means-end problem solving approach	1
Surface Feature	**Definition**	**Score**
High	Descriptive detail of most of the problem features within and across cases	3
Moderate	Descriptive detail of some, but not all of the problem features across cases	2
Low	Little to no attention to problem features that are relevant to problem solving	1
Scientific Appropriateness	**Definition**	**Score**
Correct reasoning	Correct identification and application of principle(s) with correct justification	3
Some correct reasoning	Correct identification of principle(s) with some correct application and justification of principle(s)	2
Incorrect or no reasoning	Incorrect or no identification and application of principle(s) with incorrect or no justification	1

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ANALYSIS & RESULTS

- Three case sets were provided during three recitations (Rec 02, Rec 03, Rec 06)
- Written responses coded by two raters and discussed codes for 100% agreement
- MANOVA : significant differences b/w conditions [Wilks' Λ= 0.209, $F(18, 102.0) = 6.717$, $p < .001$, $\eta^2 = 0.542$]

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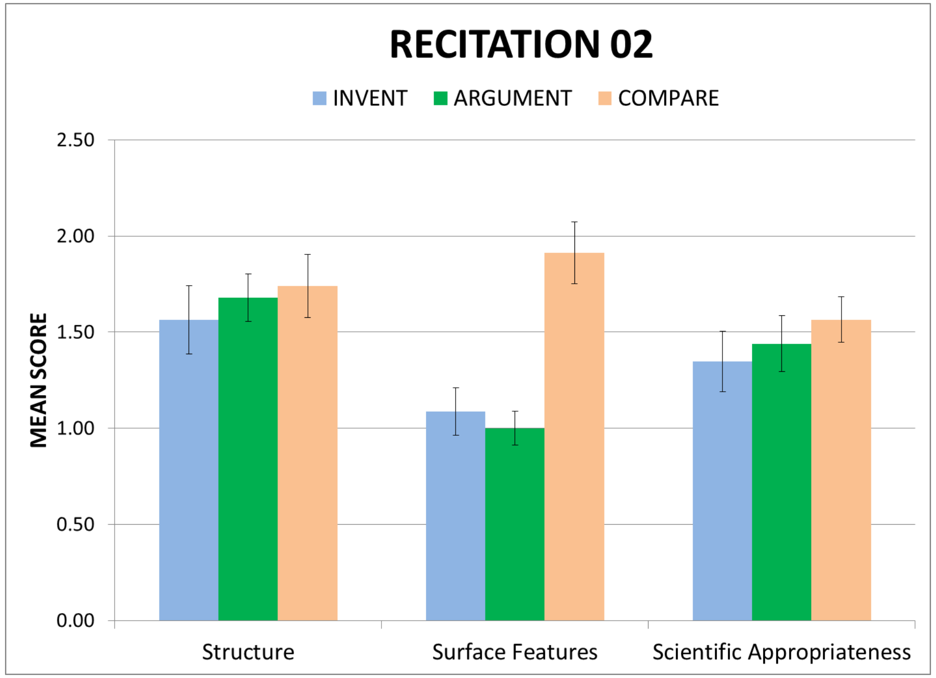
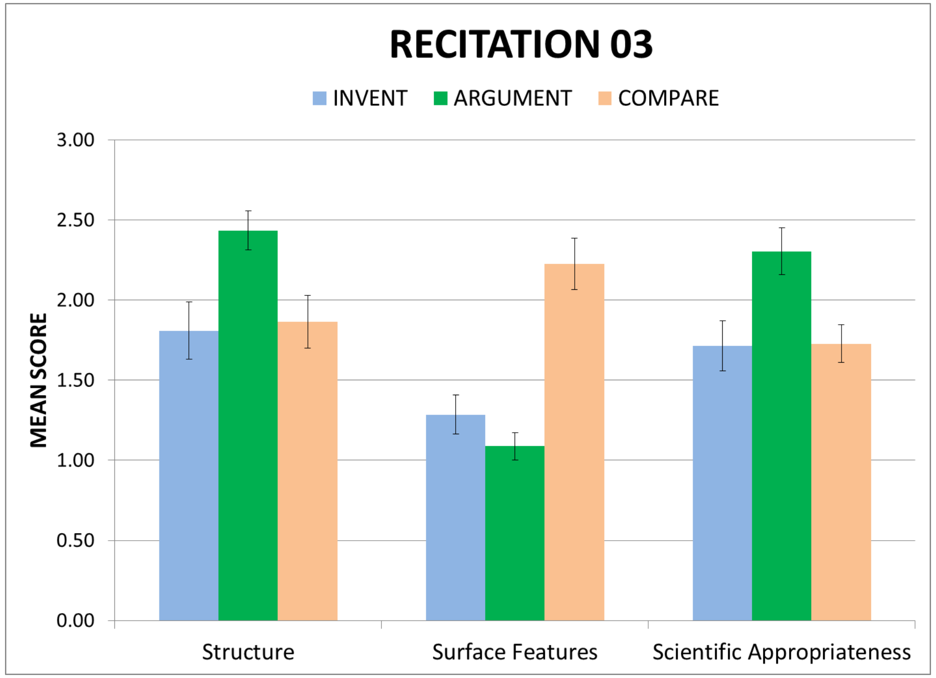
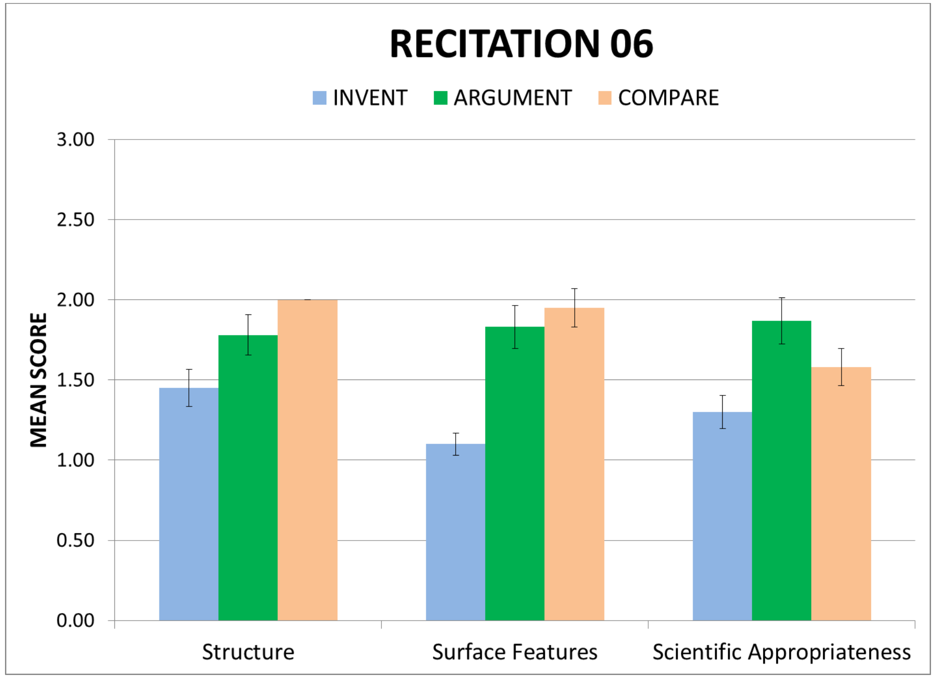
RESULTS







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ANALYSIS

- Follow-up Tukey's HSD, $\alpha = .05$: **compare** significantly ($p<0.001$) outperforms other conditions with regard to surface features for Recitations 02 &03. For Recitation 06, **compare** and **argument** significantly outperforms **invent** for surface features. No difference between **argument** and **compare**.

- The **argument** condition statistically significantly outperformed other conditions in Recitation 03 in structure ($p<.05$) and scientific appropriateness dimensions ($p<.05$).

- The **argument** condition statistically significantly outperformed **Invent** in Recitation 06 in structure ($p<.05$) and scientific appropriateness dimensions ($p<.05$). **Compare** significantly outperforms **invent** for structure and no difference between **argument** and **compare** for structure or scientific appropriateness.

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EXAMPLE DATA

INVENT

"Identify the system and surroundings and depending on the information given apply either the momentum or energy principle. If time is given, use momentum, if distance is given, use energy principle."

Tends to be generic problem-solving statement, limited claim and reasoning as to what principle(s) should be applied & how

Structure = 1
Surface Features = 1
Scientific Appropriateness = 1

COMPARE

"The first and third problem are very similar. They both deal with a constant force being applied over a distance. Both could be solved using momentum update, but more efficiently solved by energy principle because distance rather than time is being given. The main difference between them is that the relativistic form of equations are necessary for the third problem …. The second problem, like the first, requires relativistic equation because mass is being converted to energy. For calculating the KE of the deuteron, however, nonrelativistic equation can be used due to its relatively low speed."

Tends to compare & contrast surface features or basing problem-solving approaches

Structure = 2
Surface Features = 3
Scientific Aptness = 1

ARGUMENT

"Student A: When we solve question 2, we need to used energy principle. We should use total energy to get KE. Therefore, A is wrong. Student B: The mass may change but we assume the mass is constant in these problems. These three questions are same. We use energy principle to get KE. And then we can get the momentum. Student C: C is the best. The speed in the first two questions is much smaller than speed of light, so we don't need to consider the change in mass. In question 3 we need to consider about the change of mass.

Tease apart hypothetical statements describing application; limited reasoning, justification for principle

Structure = 2
Surface Features = 2
Scientific Aptness = 2

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CONCLUSION

- As expected from literature, **compare** condition consistently had higher scores for level of **surface features** across cases.
  - Hence, students are more likely to focus on identity of surface features irrelevant to problem solving.

- The **argument** condition revealed significant differences for **deep structure** and **scientific appropriateness** in Recitations 3 & 6.
  - Argument condition is more likely to provide deep level of principle-based understanding and apply these principles in appropriate ways to solve problems.

- **Invent** condition tended not to have significant effects (or greater means) for structure and scientific appropriateness. Hence difficulty creating an explanation.

SUMMARY & IMPLICATIONS

- Learning to engage in argumentation may require training, but the training seems to pay dividends later in semester.
- Possible limitations to problem topic.
- More research in this area is warranted to study the issue further.

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THANK YOU!

Questions?

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