Computer Simulations versus Physical Experiments: A Gender Comparison of Implementation Methods for Inquiry-Based Heat Transfer Activities

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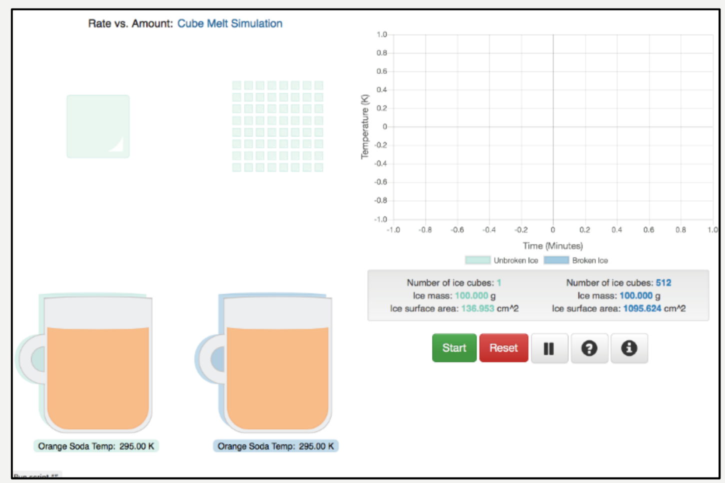
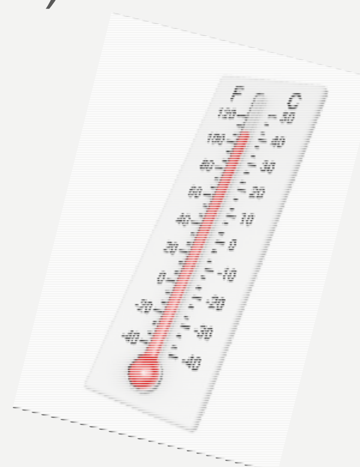
Cooling Liquids with Ice



HEAT AND TEMPERATURE CONCEPTS

- Known for creating conceptual difficulties for students (Thomaz et al., 1995).
- Students hold a variety of alternate conceptions (Carlton, 2000; Self et al., 2008; Thomaz et al., 1995).
  - –e.g., heat = temperature



CONCEPTUAL ISSUES PERSIST

- Engineering undergraduates have difficulty understanding concepts of heat and temperature (Miller et al., 2006).
  - Almost 30% chemical/mechanical engineering seniors could not, "…logically distinguish between temperature and energy in simple engineering systems and processes" (Self et al., 2008, p. S2G-1).
  - Have misconceptions about thermal radiation (Nottis et al., 2010, 2017).
  - Number of semesters/courses of physical science taken had "minimal influence" on students' correctly answering questions on thermal equilibrium and heat transfer (Jasen & Oberem, 2002, p. 892).

INQUIRY-BASED ACTIVITIES CAN ALTER MISCONCEPTIONS

- Inquiry-based (IB) activities have been shown to be effective in altering undergraduate engineering students' misconceptions about heat transfer (Prince et al., 2009).
  - IB Physical experiments can increase students' understanding of difficult engineering concepts (Vigeant et al., 2016).
    - Can be obstacles to their implementation, e.g., money for materials and training, faculty preference, lack of curriculum modification by the institution (Wright & Sundal, 2004).

OTHER METHODS OF IMPLEMENTATION

- Simulations, can be an alternative to physical experiments.
  - Both simulations and physical experiments have been effective in science courses (De Jong et al., 2013).
  - Simulations may more clearly demonstrate a concept than a physical experiment (Trundle & Bell, 2010).
  - No significant differences in understanding of temperature or changes in temperature with physical or virtual manipulatives (Zacharia & Constantinou, 2008).

OTHER FACTORS CAN INFLUENCE EFFECTIVENESS OF METHOD

- Lab group composition
  - Females in single-gender dyads significantly outperformed females in mixed-gender dyads; didn't see the same for males (Ding et al., 2011)
- Gender
  - Self-efficacy
  - Prior knowledge

PURPOSE OF STUDY

- To compare the effectiveness of computer simulations with primarily physical experiments on undergraduate engineering students' understanding of rate vs. amount and thermal radiation concepts.
  - –Secondary Purpose
    - To determine whether computer simulations and physical experiments would be equally effective by concept area and gender.

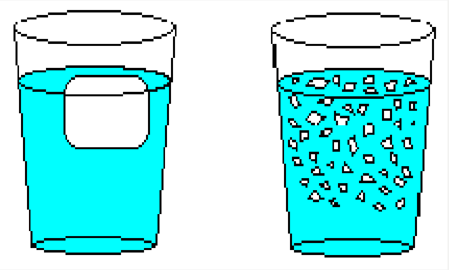
METHODOLOGY

- Design
  - Quasi-experimental study
    - One group used computer simulations while other group used primarily physical experiments.
    - Pre-post comparisons made.
- Participants
  - 2 intact groups of engineering undergraduates from 2 different universities across multiple semesters.

DEMOGRAPHICS OF GROUPS

Demographic Characteristics	**Student Simulation N = 161**	**Student Physical Experiments N = 88**
Gender	72.7% Male 26.1% Female (1.2% Other)	58% Male 42% Female
Race/Ethnicity (top 2 provided)	72.1% White 10% Asian/Pacific Islander	79.6% White 11.4% Asian/Pacific Islander
Major (top 2 provided)	**66.5% Mechanical Eng.** 25.5% Chemical Eng.	**98.9% Chemical Eng.** Remainder "other"
Year (top 2 provided)	47.2% Sophomore **44.1% Junior**	**98.9% Junior** 1.1% First Year

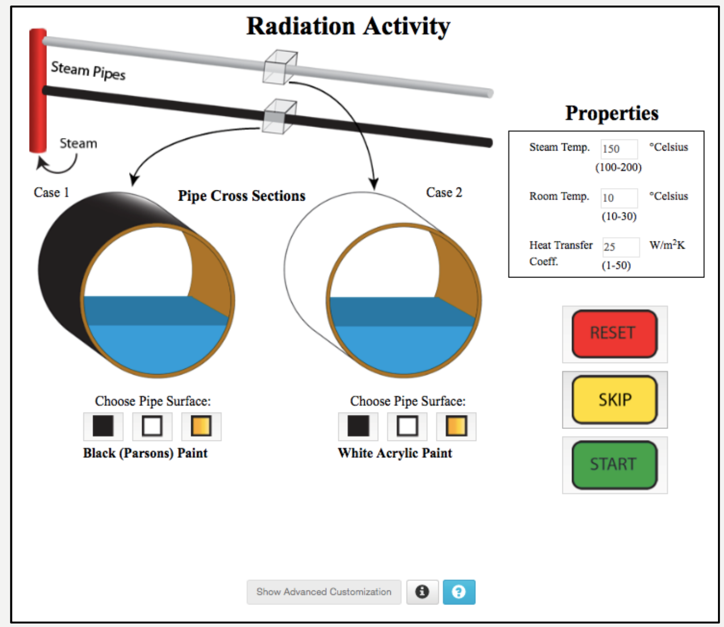
MATERIALS



- Inquiry-Based materials
  - 2 activities for each concept area
    - Rate vs. Amount
    - Thermal Radiation
  - Set of simulations and a set of primarily physical experiments
    - Each began with description of a physical situation and asked students to predict what would happen.
    - Each ended with students answering reflection questions that asked them to reconsider original ideas.

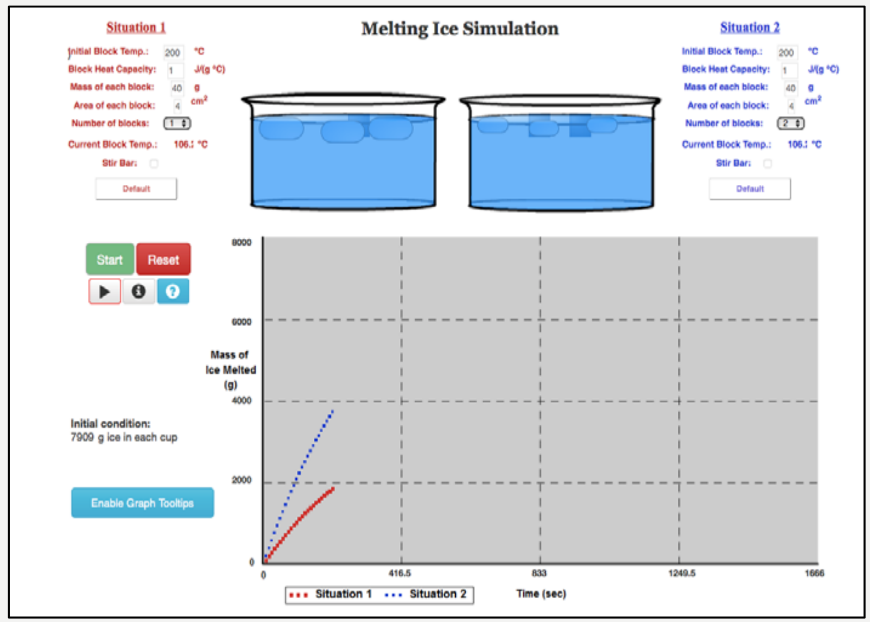
INQUIRY-BASED ACTIVITY OVERVIEW: RADIATION

- **Steam Pipe**: Steam condenses in a polished metal pipe where there are pipes painted black and white.
- **Sun Lamp**: Students predict/observe heating/ cooling curves for bare copper tubing and white & black painted tubing, heated by lamp or allowed to cool on a lab bench.



INQUIRY-BASED ACTIVITY OVERVIEW: RATE *VS.* AMOUNT

- **Cooling Beverage**: Students predict/observe rate of cooling and final temperature of cups of water chilled by “snowball” or chipped ice of equal mass.
- **Melting Ice**: Students predict/observe how much ice can be melted by heated metal blocks when number, size, & thermal properties blocks controlled. (**SIMULATION ONLY**)



MATERIALS: HEAT AND ENERGY CONCEPT INVENTORY (HECI)

(PRINCE ET AL., 2010)

- Patterned after other concept inventories
- 36 multiple choice questions
- 4 concept areas addressed; each examined as a separate sub-test:
  - **Rate versus Amount of heat transferred**
  - Temperature versus Perceptions of Hot/Cold
  - Temperature versus Energy
  - **Thermal Radiation**

HECI SUB-TESTS

- Two Sub-tests used
  – Rate vs. Amount – 8 questions
    - Estimates of internal consistency reliability measured by the KR #20 were 0.76
  – Thermal Radiation – 11 questions
    - Estimates of internal consistency reliability measured by the KR #20 were 0.75
- Each concept area evaluated separately using the appropriate sub-test.

PROCEDURE

- First 2 weeks of semester, students completed electronic version of HECI
- During semester, students used either physical experiments or computer simulations to learn concepts
  - Physical Experiment group did both concept areas each time.
  - Simulation group did one concept area each year; one year was rate vs. amount, next year was thermal radiation.
- At end of term, students again completed an electronic version of HECI

STUDENTS DOING PHYSICAL EXPERIMENTS DID BETTER ON HECI

Teaching Method	Mean Pre-Test Score	Mean Post-Test Score
Computer Simulation	16.73 (SD = 5.73) n = 157	20.61 (SD = 6.12) n = 145
Physical Experiments	17.00 (SD = 5.13) n = 88	26.35** (SD = 5.19) n = 84

** Significant difference on post-test, $p < .01$, with a large effect size, favoring Physical Experiments.

MALES/FEMALES: PHYSICAL EXPERIMENT GROUP HIGHER (HECI)

Instructional Method	Gender			
	Male		Female	
	Pre-Test	Post-Test	Pre-Test	Post-Test
Student Simulation	17.47	20.94	14.39	19.74
Student Physical Experiment	18.55	27.98	14.86	24.37

SIGNIFICANCE TESTS: METHOD AND GENDER

- 2-way Analysis of Variance (ANOVA) examining gender and instructional method showed significant difference between males and females on the pre-test with a medium effect size.
  - No significant difference between the two groups by method.
- Due to pre-test finding, Analysis of Covariance (ANCOVA) done on post-test results, holding constant pre-test scores.
- 2-way ANCOVA, examining gender and instructional method, with pre-test as the covariate, revealed a significant difference with a large effect size for instructional method.
  - Physical Experiment group scored significantly higher than Simulation group.
  - No significant gender differences
    - Supports previous research (Noack et al., 2009; Nottis et al., 2017).

MEAN POST SUB-TEST SCORES FOR INSTRUCTIONAL METHOD

Concept Area	Student Simulation	Student Physical Experiment
Thermal Radiation (11 questions)	5.62 (51.1%) SD = 2.35 n = 83	7.96 (72.4%) ** SD = 2.26 n = 82
Rate versus Amount (8 questions)	4.57 (57.1%) SD = 1.86 n = 62	5.71 (72.3%) ** SD = 1.97 n = 83

** Significant difference on post-test, $p < .01$ favoring Physical Experiment. Large effect size for radiation, moderate effect size for rate vs. amount.

MEAN POST SUB-TEST SCORES BY INSTRUCTIONAL METHOD & GENDER

	Computer Simulation		Primarily Physical Experiment	
	Male	Female	Male	Female
Thermal Radiation (11 questions)	5.85 (53.2%)	5.09 (46.3%)	8.31 (75.6%)	7.41 (67.4%)
Rate vs. Amount (8 questions)	4.49 (56.1%)	4.75 (59.4%)	6.11 (76.4%)	5.34 (66.8%)

Significant differences by instructional method ($p < .01$), favoring Physical Experiment for both concept areas and both genders.

CONCLUSIONS

- Students using each instructional method showed improvement after instruction
- Students doing primarily physical experiments consistently had higher mean scores than those using computer simulations.

WHY WOULD PHYSICAL EXPERIMENTS WORK BETTER?

- Differences between the two groups in major, year, etc.
- Physical Experiment group:
  - Taught both concepts with the same method in a semester.
  - Composed primarily of juniors -- more prior knowledge?
  - Had one activity always a computer simulation. Could be combination of methodologies made it more effective.
    - Would support previous research that found when physical and virtual labs used together, students scored higher than when doing only a physical lab (Zacharia et al., 2008).

WHAT ABOUT PREFERENCE BY GENERATION?

- Participants were all in Millennial Generation or Generation Y.
  - Previous research found almost 60% of those surveyed preferred “hands on,” “interactive labs,” or “experiential learning.”
  - Also found, “…60% of students said that hands-on experiential activities get them more engaged and act as a pivotal aid in their learning” (Therrell & Dunneback, 2015, p. 55, 59).
- Could students in physical labs be more actively engaged than those watching/using a computer simulation?

Heat Transfer - Radiation IBAs

This instructional tool contains two inquiry based activities that address the following misconception, identified as both prevalent and persistent among undergraduate engineering students:

Students are often confused about the effect of surface properties on the rate of radiative heat transfer.

- Introduction and Overview
- Pre-term and post-term Heat Transfer Concept Inventories
- Activity 1 (Steam Pipes) Delivery Options

Click an Option # below for details and setup instructions.

Option	Type	Delivery Mode	Effectiveness (Explanation)	Ease of Use (Explanation)
1	Physical Experiment	Performed by students	High (details)	Higher Effort (details)
2		Instructor demonstration	Medium (details)	Higher Effort (details)
3	Simulation	Performed by students	Low (details)	Low Effort (details)
4		Instructor demonstration	Medium (details)	Low Effort (details)
5	Thought Experiment	Instructor-led discussion	Medium (details)	Low Effort (details)

FUTURE RESEARCH

1. Investigate each method more thoroughly with a larger, more diverse sample.

2. Examine conditions under which simulations done. Relook at simulations to see if they can be more interactive.

3. Try these methods FREE at AIChE Concept Warehouse

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