Comparing Pedagogical Strategies for Inquiry-Based Learning Tasks in a Flipped Classroom

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Cognitive Conflict or Analogy: How does Pedagogical Strategy Influence Inquiry-Based Learning?

Introduction
The flipped classroom environment has become increasingly popular in recent years. In a flipped classroom, students watch video-recorded lectures at home which frees time to engage them in socially-mediated, active learning in class. The flipped class instructional design is based on the principles that class time should be used to elicit deep thinking and that students learn better through discussion and negotiation with their peers. Thus, appropriate activities focus on the most difficult aspects of learning a subject. While there has been attention to the mechanics and principles of how to deliver the lecture component asynchronously, or the effectiveness of a flipped classroom relative to traditional instruction, less attention has been given to systematically explore the most effective instructional strategies for the in-class activities within the flipped classroom.

In this paper, we look at in-class activities in a flipped classroom directed at cultivating deep conceptual understanding. Engineering educators and industry partners emphasize the need for students to apply their knowledge to new and challenging problems. A lack of conceptual understanding has been shown to severely restrict students’ ability to solve new problems, since they do not have the foundational understanding to use their knowledge in new situations. However, traditional lecture-based instruction often reward students more for rote learning and algorithmic substitution than for conceptual understanding. As a result, many of our classes are ineffective for developing students’ understanding of fundamental concepts.

This study investigates active learning activities in a flipped classroom aimed at a common misconception in heat transfer – the Rate vs. Amount misconception in which students conflate the rate of energy transferred and the amount of energy transferred. We compare two inquiry-based in-class activities developed with different strategies, one based on a cognitive conflict strategy and the second an analogy strategy. The research question we ask is, “How do the measured learning gains of the Rate vs. Amount concept compare when students complete an inquiry-based activity developed with a cognitive conflict strategy to one developed with an analogy strategy?”

Theoretical Framework
Synthesizing the flurry of research and instructional development activity on conceptual change in the 1980s, Scott, Asoko, and Driver cite three levels of pedagogical decisions that are needed in designing instruction to foster conceptual change: learning environment, teaching strategies, and learning tasks. The learning environment is at the highest level and provides the affordances for activities and support needed for learning. At the second level, the teaching strategy guides the overall design and sequence of instructional activities. Finally, the learning tasks sit at the finest level; they comprise the specific activities students are asked to complete to promote conceptual change.

Our study design focuses on the second level of teaching strategies for conceptual change. Scott, Asoko and Driver divide effective reform strategies into two broad groupings. The first
grouping refers to strategies that seek to elicit cognitive conflict and create “teachable moments” through the resolution of the conflicting perspectives. The second grouping contains strategies that seek to build on and extend existing ideas, often using metaphor or analogy.

**Cognitive conflict strategy**
The first activity is based on a cognitive conflict strategy for conceptual change. Strategies based on cognitive conflict, also referred to as cognitive dissonance, stem from a constructivist perspective of learning in which the learner's active part in reorganizing their knowledge is critical. Posner and colleagues propose that four stages are needed for conceptual change. The stages include: (i) dissatisfaction with current conceptions, followed by a new conception that is (ii) intelligible, (iii) plausible, and (iv) potentially fruitful.

The goal of the cognitive conflict inquiry-based method is to produce a teachable moment for students by promoting cognitive conflict and leading the learner through these four stages. To initiate this process, the instructor puts students in situations where they make a commitment to and then unavoidably confront a misconception to promote dissatisfaction. This strategy was used by the Activity-Based Physics group to develop inquiry-based activities in Mechanics and has extensive empirical support for its effectiveness. Building on this success, engineering educators have adopted this strategy for instruction in heat transfer, thermodynamics, and dynamics.

However, questions have arisen about the effectiveness of the cognitive conflict strategy for promoting conceptual change for several reasons. First, students simply sometimes ignore the conflicting information. Second, while higher performing students might embrace the “conflict,” less successful students have been observed to try to avoid the conflict and thereby develop negative attitudes. Third, there may not be support to reconstruct a normative conceptual understanding following dissatisfaction with the original misconception. Finally, as Smith, de Seessa and Roschelle argue, this strategy potentially undermines student confidence in their sense-making abilities.

**Analogy strategy**
The second activity is based on an analogy strategy, which also has long been advocated as a strategy for promoting conceptual change in science. An analogy connects a new concept or topic, the target domain, to situations or experiences which are more familiar, the source analogy. This strategy focuses more on providing scaffolding for students to learn new concepts. As a classic example, Gentner describes the use of the Bohr model to introduce atomic structure (target domain) by providing middle school students an analogy to the more familiar solar system (source analogy).

Brown emphasizes that analogic comparisons to concrete sources are most effective for stimulating conceptual change. These concrete comparisons allow students to attribute properties in the target domain to the entities in the source analogy, and work best when grounded in students’ subconscious core intuitions. To illustrate with an example, de Almeida, Salvador and Costa developed an analogic comparison of children in a school yard with the possibility of being given ice cream (source analogy) to help 9th grade students understand the fundamental aspects of Drude’s free electron model in metals (target domain). They report this concrete
comparison of a school yard helped students learn the associated concepts of electric current and EMF. Brown and Clement further advocate the need for interactive learning environments rather than didactic presentation for the analogy strategy to be successful.

However, the use of analogy is criticized by some because analogies can reinforce false associations between the target domain and the source, leading students to develop further misconceptions about target concepts. Clement includes four reasons that an analogy might not be successful in promoting conceptual change, including: insufficient understanding by the student of the source; the student cannot connect the source to the target (unable to map); the student might transfer too much from the source to the target (overmap); the source may not contain all the relations of the target concept.

**Methodology:**
Our study is designed to provide an empirical comparison of two activities that we have developed which correspond to each of Scott, Asoko and Driver’s groupings of effective reform teaching strategies: the cognitive conflict strategy and the analogy strategy. The learning environment is a studio classroom that is structured so students work in groups to interactively engage and make meaning of course content under facilitation and guidance from an instructor. For each strategy, the learning tasks are directed through worksheets in the studios. We have done our best to carefully and thoughtfully develop the tasks. However, we acknowledge that there are many choices in task development and communication that influence student learning, and that the learning tasks can always be improved through observation and iteration. The results from our comparison of teaching strategies should be considered with this limitation in mind.

**Participants and setting**
All participants in this study were enrolled in a junior-level heat transfer course. It is the second course of a three-quarter Transport Phenomena sequence that is required for chemical engineering, bioengineering, and environmental engineering majors. The entire cohort met in one large group for traditional lecture twice a week (instead of recorded video) and was divided into six different studio class sections twice a week where the class was “flipped.” Each week of the ten-week term, students engaged in the following sequence: lecture, studio, lecture, studio.

The Institutional Review Board approved the research and every participant signed an informed consent form. In addition, to be included in the study, the students needed to participate in all activities described below. 37 students met these criteria for the cognitive conflict strategy condition and 47 students for the analogy strategy condition. More details of their self-reported demographics are described in Table 1.

| Table 1. Self-reported participant demographics |
|-----------------------------------|----------|----------|----------|
| Gender                           | Conflict Strategy | Analogy Strategy | Total |
| Male                             | 26        | 25        | 51      |
| Female                           | 11        | 22        | 33      |
| Major                            |           |           |         |
| Chemical Engineering             | 26        | 29        | 55      |
| Bioengineering                   | 7         | 10        | 17      |
| Environmental Engineering        | 4         | 8         | 12      |
| GPA                              |           |           |         |
| 3.50 - 4.00                      | 18        | 30        | 48      |
| 3.00 - 3.49                      | 15        | 15        | 30      |
| 2.50 - 2.99                      | 2         | 2         | 4       |
Activities
Two variations of an inquiry-based activity were developed for the comparison study. They both addressed the Rate vs. Amount misconception where students conflate the factors that affect amount of energy transferred in a given physical situation with the factors that affect the rate of transfer.29 The variations were adapted from an inquiry-based activity developed by Prince and colleagues.19 However, while the original inquiry-based activities of Prince rely on either a physical experiment or simulation, the activities studied here employed only a thought experiment requiring neither a physical set-up nor a simulation for delivery. In that sense, they require less overhead for the instructor to deliver, but may not be as effective.

Two worksheets were developed: one corresponding to a cognitive conflict strategy and the other to an analogy strategy. Both worksheets led students through a scaffolded set of short answer questions where they made initial predictions, were presented results which they discussed with other students in small groups and evaluated their predictions. Worksheets for both strategies were designed to be completed in a 50 minute class section. Students in both conditions were given identical post-class analysis and reflection activities.

The cognitive conflict strategy worksheet was developed based on the design of Laws and colleagues.17 Students were asked to design two experiments the first of which considered the cooling of a beverage by comparing crushed ice to cubed ice. Elements of that task are shown in Figure 1. They were asked to consider the effects of initial temperature, surface area, and mass on the rate of energy transfer and, separately, on the amount of energy transfer. They were then shown simulated data from an experiment (on the right of Figure 1) and asked to assess their predictions. The worksheet followed with a second thought experiment where students predicted the effect of immersing hot metal blocks in a container of ice-water. This second thought experiment was not performed by students in the analogy strategy.

The analogy strategy was based on the design of Brown and Clement.27 Students were presented with the first experiment from the cognitive conflict strategy, in which surface area and mass were varied. They made initial predictions in this target domain before being introduced to a source analogy of fans entering a stadium. The number of entrance gates provides an analogy for surface area, the number of seats for mass, and the number of fans for energy. Here they made initial predictions, as shown in Figure 2, and then were asked to identify the analogic correspondence between the two representations The rate of fans entering is analogous to the rate of energy transfer while the number of fans entered is analogous to the amount of energy transferred (and corresponds to temperature). Finally, as in the cognitive conflict strategy, they were asked to assess their initial predictions in the target representation.
On the graph below plot the number of fans inside the stadium vs. time for the following cases:

A. 25,000 seat stadium with 5 gates
B. 25,000 seat stadium with 25 gates
C. 50,000 seat stadium with 5 gates
D. 50,000 seat stadium with 25 gates

Label each case with its corresponding letter.

**Figure 1.** Part of the worksheet instructions for the cognitive conflict strategy (left). Results presented to the students by the instructor (right).

**Figure 2.** Part of the worksheet instructions for the analogy strategy.
**Measurement instrument**

The Heat and Energy Concept Inventory (HECI) was used to measure conceptual learning gains. The HECI addresses the four following misconceptions relating to heat transfer:

1. **Rate vs. Amount**: The factors that affect amount of energy transferred given some physical situation and factors that affect the rate of heat transfer are the same (Rather, factors that increase the amount of heat transferred are not necessarily the same as those factors that increase rate of heat transferred.)

2. **Radiation**: Confusion regarding the effect of surface properties on the rate of radiative heat transfer

3. **T vs. Feeling**: Temperature is a measure of how hot/cold something feels (In actuality, other factors such as rate of heat transfer, affect how hot or cold something feels)

4. **T vs. Energy**: Temperature is a direct measure of energy of an object (However, higher temperature does not necessarily mean more energy. Further, change in temperature is not directly proportional to change in levels of energy.)

Content validity was addressed in the development of the instrument by asking panels of engineering faculty who teach an undergraduate heat transfer course to critique whether the questions clearly assessed the targeted concept area. Several cycles of feedback from this panel and subsequent revision were used to refine questions. For the final version of the HECI used, 10 faculty in chemical and mechanical engineering who teach the relevant undergraduate heat transfer course were used to assess content validity. All of the ten faculty experts agreed that each question on the instrument assessed the targeted concept, suggesting a high level of content validity.

Internal consistency reliability was determined using the Kuder-Richardson Formula 20 (KR20). Reliability was determined for the instruments as a whole and for each specifically targeted concept area. The internal reliability of the entire instrument was 0.85 and the reliability of the Rate vs Amount and Radiation scales were 0.76 and 0.75, respectively. Thus, the HECI has suitable validity and reliability for the study.

**Data collection and analysis**

During the first week and next to last week of the term, the HECI was administered. All students in the class were requested to complete it, but it was not a graded activity. During the third week, the six different studio sections were divided evenly between the cognitive conflict strategy and the analogy strategy of the Rate vs. Amount inquiry-based activity. Sections began with the analogy strategy and alternated strategies throughout the day. In week 9, all studio sections completed a cognitive conflict inquiry-based thought experiment activity on Radiation. This latter activity is included in the study design to serve as a control and compare gains of students in the different Rate vs. Amount strategies for an identical strategy. The same instructor delivered all the activities in studio, but was different than the professor who taught lecture.

Data were only collected for students who completed both the pre- and post- HECI, who participated in both the comparison and control inquiry-based activities, and who signed informed consent forms. Data are reported for average ( $\bar{x}$ ) and standard deviations (SD) of
number (or percentage) of HECI items correct. Two other statistics are reported: The normalized gain, $G$:

$$G = \frac{\bar{x}_{\text{post}} - \bar{x}_{\text{pre}}}{x_{\text{max}} - \bar{x}_{\text{pre}}}$$

and the effect size, $ES$. The effect size evaluates the magnitude of the difference between the means of two groups. Typically a threshold of value of 0.50 or greater is considered important.\(^{30}\) A One-way Analysis of Variance (ANOVA) and an Univariate Analysis of Covariance (ANCOVA) which controlled for pre-test scores were performed to determine the effect of the intervention condition, the difference between gender, and their interaction.

**Results**

**Comparison of cognitive conflict and analogy groups**

Table 2 presents the average scores for the 8 items in the HECI that correspond to the scale for the *Rate vs. Amount* misconception. While both groups, on average, performed similarly on the post-HECI (50% cognitive conflict; 48% analogy), the students who experienced the cognitive conflict strategy scored lower on the pre-HECI (42%; 47%), leading to higher normalized gains (15%; 2%) and a higher effect size (0.31; 0.04). In Prince et al.,\(^{19}\) the typical mean pre-test score in this concept area is 36.9% (n=373) and post-test is 42.6% (n=344) in engineering heat transfer courses with no intervention.

Table 3 presents the average number of correct answers from the post-HECI and the pre-HECI for items that correspond to scales for each of the four misconceptions, as well as the entire HECI. The number of items in each scale represent the maximum possible score and is reported in the last column.

### Table 2. HECI results for the cognitive conflict and analogy inquiry-based activities

<table>
<thead>
<tr>
<th></th>
<th>Cognitive conflict (n = 37)</th>
<th>Analogy (n = 47)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (Post), $\bar{x}_{\text{post}}$</td>
<td>50%</td>
<td>48%</td>
</tr>
<tr>
<td>Mean (Pre), $\bar{x}_{\text{pre}}$</td>
<td>42%</td>
<td>47%</td>
</tr>
<tr>
<td>St. Dev (Post), $SD_{\text{post}}$</td>
<td>27%</td>
<td>27%</td>
</tr>
<tr>
<td>Normalized Gain, $G$</td>
<td>15%</td>
<td>2%</td>
</tr>
<tr>
<td>Effect Size, $ES$</td>
<td>0.31</td>
<td>0.04</td>
</tr>
</tbody>
</table>

### Table 3. Number of correct items for each of the misconception scales in the HECI

<table>
<thead>
<tr>
<th>Misconception</th>
<th>Post HECI Mean, $\bar{x}_{\text{post}}$</th>
<th>Pre HECI Mean, $\bar{x}_{\text{pre}}$</th>
<th>Max Possible (Number of Items), $x_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate vs. Amount(^*)</td>
<td>4.0</td>
<td>3.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Radiation(^++)</td>
<td>7.5</td>
<td>7.2</td>
<td>5.0</td>
</tr>
<tr>
<td>T vs. Feeling(^+++)</td>
<td>6.2</td>
<td>5.5</td>
<td>5.8</td>
</tr>
<tr>
<td>T vs. Energy(^+++)</td>
<td>6.6</td>
<td>5.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Entire HECI</td>
<td>23.9</td>
<td>22.0</td>
<td>19.0</td>
</tr>
</tbody>
</table>

\(^*\) The comparison of cognitive conflict and analogy inquiry-based activities only addressed the rate vs. amount misconception

\(^++\) All studios participated in a cognitive conflict inquiry-based activity on radiation

\(^+++\) There were no inquiry-based activities of the type described in this paper addressing T vs. feeling or T vs. energy misconceptions.

\(^*\) 2 of the items are double counted as both T vs. Feeling and T vs. Energy; thus the individual items do not add up to the total
A One way Analysis of Variance (ANOVA), with intervention group as the independent variable, showed there was no significant difference between the two groups on either the pre-test or the post-test. However, ANCOVA results indicate a significant main effect for intervention group with a small effect size $F(1, 84) = 4.99, p < .05$, partial $\eta^2 = .06$. The covariate of pretest score significantly influenced the dependent variable of post-test with a large effect size $F(1, 84) = 61.74, p < .01$, partial $\eta^2 = .42$. The adjusted mean post-test scores indicated that the cognitive conflict group had a significantly higher mean post-test score than the analogy group.

Table 4 presents the associated normalized gains and effect sizes. Both groups completed the same cognitive conflict inquiry-based activities for radiation the week of the post-HECI and both show similar large positive gains. There were no inquiry-based activities intentionally directed at the other two misconceptions (T vs. feeling, T vs. energy) and the results of the two groups are different. The students in the analogy strategy actually show negative gains in both.

**Table 4.** Normalized gain and effect size for each of the misconception scales in the HECI

<table>
<thead>
<tr>
<th>Misconception</th>
<th>Normalized Gain, $G$</th>
<th>Effect Size, $ES$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cognitive conflict</td>
<td>Analogy</td>
</tr>
<tr>
<td>Rate vs. Amount</td>
<td>15%</td>
<td>2%</td>
</tr>
<tr>
<td>Radiation</td>
<td>42%</td>
<td>37%</td>
</tr>
<tr>
<td>T vs. Feeling</td>
<td>14%</td>
<td>-4%</td>
</tr>
<tr>
<td>T vs. Energy</td>
<td>5%</td>
<td>-31%</td>
</tr>
<tr>
<td>Entire HECI</td>
<td>29%</td>
<td>14%</td>
</tr>
</tbody>
</table>

**Differences in gender**

A One way ANOVA with gender as the independent variable showed that there was a significant difference between males and females on the post-test with a small effect size $F(1, 119) = 6.24$, $p < .05$, $\eta^2 = .05$. Males had a significantly higher mean score on the post-test than females (23.96 as opposed to 20.98). However, an Univariate ANCOVA which controlled for pre-test scores indicates no significant main effect for gender. The covariate of pretest score significantly influenced the dependent variable of post-test with a moderate effect size $F(1, 85) = 54.96$, $p < .01$, partial $\eta^2 = .39$. This result suggests the differences between genders arise from pretest score. Finally, a 2 x 2 ANCOVA was performed to determine the effect of gender and intervention group on post-test scores when controlling for pretest scores. ANCOVA results indicate a significant main effect for intervention group with a small effect size $F(1, 82) = 5.14$, $p < .05$, $\eta^2 = .06$. There was no significant main effect for gender and the interaction between gender and intervention group was not significant. The covariate of pretest score significantly influenced the dependent variable of post-test score with a moderate effect size $F(1, 82) = 56.61$, $p < .01$, $\eta^2 = .41$.

Table 5 presents results for the average number of items correct for the Rate vs. Amount HECI scale by gender and strategy.

<table>
<thead>
<tr>
<th></th>
<th>Post HECI $\overline{x}_{post}$</th>
<th>Pre HECI $\overline{x}_{pre}$</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cognitive conflict</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>3.2</td>
<td>1.3</td>
<td>11</td>
</tr>
<tr>
<td>Male</td>
<td>4.4</td>
<td>4.2</td>
<td>26</td>
</tr>
<tr>
<td><strong>Analogy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>3.9</td>
<td>3.5</td>
<td>21</td>
</tr>
<tr>
<td>Male</td>
<td>3.8</td>
<td>3.9</td>
<td>26</td>
</tr>
</tbody>
</table>
considered to be male oriented (football stadium), there is little evidence that males preferentially benefited.

Discussion
As shown in Table 3, students’ Rate vs. Amount scale HECI score improves from 46.3% to 47.5% (analogy) and from 42.5% to 50% (cognitive conflict); these numbers are similar, but slightly higher to the “normal instruction” group discussed in Prince et al.,30 36.9% to 42.6%. Aggregating the numbers from radiation in this study (in which all sections used a cognitive conflict strategy), Radiation scale HECI scores improved from 45.3% to 66.7%, which compare favorably to the “normal instruction” condition of the Prince study 44.6% to 50.8% and are similar to the score with physical and simulation inquiry-based activities of 41.0% to 63.8%. The study presented here controls for attrition (i.e., we only use pre-HECI scores for those students who took the post-HECI) which is believed would likely raise the pre-HECI scores as compared to the comparison studies cited above.

While these results suggest that the cognitive conflict strategy may be slightly more effective than the analogy strategy, the improvement level (gain) in both conditions is similar to change observed in “normal instruction” with no special intervention. However, the gains of the radiation activities are similar to that observed with inquiry-based activities. Several explanations are suggested to contribute to these observations.

Radiation is one of the final topics discussed in the course. High gains in the radiation activity suggest a temporal component where learning gains are stronger in proximity to the activity. This temporal effect has been observed previously in the laboratory-based work on cognitive conflict in these conceptual areas. Students’ recall is greatest in the immediate aftermath of the activity, and then tends to fall somewhat by the end of the term, although not usually to pre-test levels.31

This course has a prerequisite course, “Energy Balances,” which is taught using concept-based instruction32 and would cover concepts related to both rate of energy transfer and amount of energy transfer. Thus the higher pre-HECI scores on the Rate vs. Amount scale could actually be from learning gains in this prior course. To clarify the effect of each approach, we suggest to use both strategies in the “radiation” concept area (pending creation of a suitable analogy). Such data should provide a good basis for comparison as students have significantly less prior experience with radiation.

The interventions presented in this study consisted of thought experiments rather than hands-on or simulation activities. We conjecture that the students in Energy Balances who are better abstract thinkers would be disproportionately likely to conceptualize the differences in rate vs. amount from that prior course. Thus, the more concrete thinkers would impact the measurement (learning gains) most in this context. The medium of the activity (physical experiment, simulation, thought experiment) may be amplified with this prior knowledge consideration. Moreover, work is needed to characterize the nature of the concepts in Rate vs. Amount and in Radiation, themselves. We conjecture that the radiation concepts are inherently more accessible for concrete thinkers.
Unobserved effects such as similarities in problem structure and visual representations provided in the cognitive conflict strategy activities and the HECI may also be influencing students’ response to the questions. Examination of the HECI reveals that the first four questions of the inventory directly refer to melting ice with hot metal blocks. The cognitive conflict worksheet included a second thought experiment where students predicted the effect of immersing hot metal blocks in a container of ice-water while the analogy strategy did not. The contextual alignment in the cognitive conflict group may bias the collected data.

Finally, the gains in the analogy condition depend critically on the activity design. Blanchette and Dunbar propose that is desirable “to contrast teacher-generated analogies with self-generated analogies, where the learner him- or herself is asked to come up with analogies to a phenomenon. For teacher-generated analogies, the learners have to confront the double challenge of understanding the given source domain (do all children actually understand the structure and dynamics of a planetary system?), and the particular ways in which it is supposed to be similar to the unknown target domain.” The analogy activities in this study may be improved by having students generate their own analogies. However, such a task would take additional time.

Acknowledgements
The authors gratefully acknowledge support from the National Science Foundation under the grants TUES 1225221 and 1225031. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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