122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11522

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

Dr. Milo Koretsky, Oregon State University

Milo Koretsky is a Professor of Chemical Engineering at Oregon State University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley, all in Chemical Engineering. He currently has research activity in areas related engineering education and is interested in integrating technology into effective educational practices and in promoting the use of higher-level cognitive skills in engineering problem solving. His research interests particularly focus on what prevents students from being able to integrate and extend the knowledge developed in specific courses in the core curriculum to the more complex, authentic problems and projects they face as professionals. Dr. Koretsky is one of the founding members of the Center for Lifelong STEM Education Research at OSU.

Mr. Samuel Alexander Mihelic, Oregon State University

Samuel Mihelic is a research asistant in Dr. Yantasee's lab in the Biomedical Engineering Department at Oregon Health and Science University. He received a B.S. in chemical engineering and a B.S. in mathematics from Oregon State University in 2014. He worked as an engineering education researcher with Dr. Koretsky at Oregon State University in 2013 and 2014 where he helped develop and deliver student worksheets for flipped classroom teaching of undergraduate junior-level heat transfer concepts. He was a tutor for a sophomore level physics course at Oregon State University in 2013 and a freelance tutor of highschool mathematics in 2010.

Dr. Michael J. Prince, Bucknell University
Dr. Margot A Vigeant, Bucknell University

Margot Vigeant is a professor of chemical engineering and an associate dean of engineering at Bucknell University. She earned her B.S. in chemical engineering from Cornell University, and her M.S. and Ph.D., also in chemical engineering, from the University of Virginia. Her primary research focus is on engineering pedagogy at the undergraduate level. She is particularly interested in the teaching and learning of concepts related to thermodynamics. She is also interested in active, collaborative, and problem-based learning, and in the ways hands-on activities and technology in general and games in particular can be used to improve student engagement.

Dr. Katharyn E. K. Nottis, Bucknell University

Dr. Nottis is an Educational Psychologist and Professor of Education at Bucknell University. Her research has focused on meaningful learning in science and engineering education, approached from the perspective of Human Constructivism. She has authored several publications and given numerous presentations on the generation of analogies, misconceptions, and facilitating learning in science and engineering education. She has been involved in collaborative research projects focused on conceptual learning in chemistry, chemical engineering, seismology, and astronomy.

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.[1] 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,[2,3] or the effectiveness of a flipped classroom relative to traditional instruction,[4-6] 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.[7] In order to do so, students must learn with understanding.[8] 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.[9] However, traditional lecture-based instruction often reward students more for rote learning and algorithmic substitution than for conceptual understanding.[10] As a result, many of our classes are ineffective for developing students' understanding of fundamental concepts.[11]

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[12] 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[12] 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,[13] stem from a constructivist perspective of learning in which the learner's active part in reorganizing their knowledge is critical.[8,14] Posner and colleagues[15] 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.[16-18] Building on this success, engineering educators have adopted this strategy for instruction in heat transfer,[19] thermodynamics,[19] and dynamics.[20]

However, questions have arisen about the effectiveness of the cognitive conflict strategy for promoting conceptual change for several reasons.[21] 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[22] 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.[23] 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[24] 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[25] 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[26] 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[27] 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.[28] Clement[21] 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[12] 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.[29] 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

		Conflict Strategy	**Analogy Strategy**	**Total**
Gender	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.

Design an experiment to compare the rate of cooling and final temperature. Draw your experimental set-up on your worksheet. Describe what data you would collect.

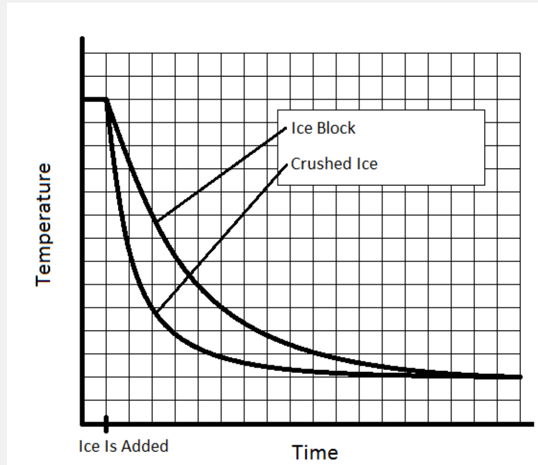
Objective: Investigate the cooling of a beverage by comparing crushed ice to cubed ice. Consider both the *rate* of cooling (i.e., how fast it cools) and the *amount* of cooling, as indicated by the final temperature.

Materials:
- beverage (mostly water) at room temperature
- crushed ice
- cubed ice
- thermometers
- stirrers
- stopwatches

Questions:
1. Consider adding the same mass of ice, either as a single block or as fine crushed ice particles, to a beverage. Which option will cool the beverage to a *lower* temperature? Why? (Answer on your worksheet)
2. Which option, if either, will cool the beverage more *quickly?* Why? (Answer on your worksheet)

Experiment 1

Ice Block vs. Crushed Ice: Temperature vs. Time



How do your predictions compare with these data?

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

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.

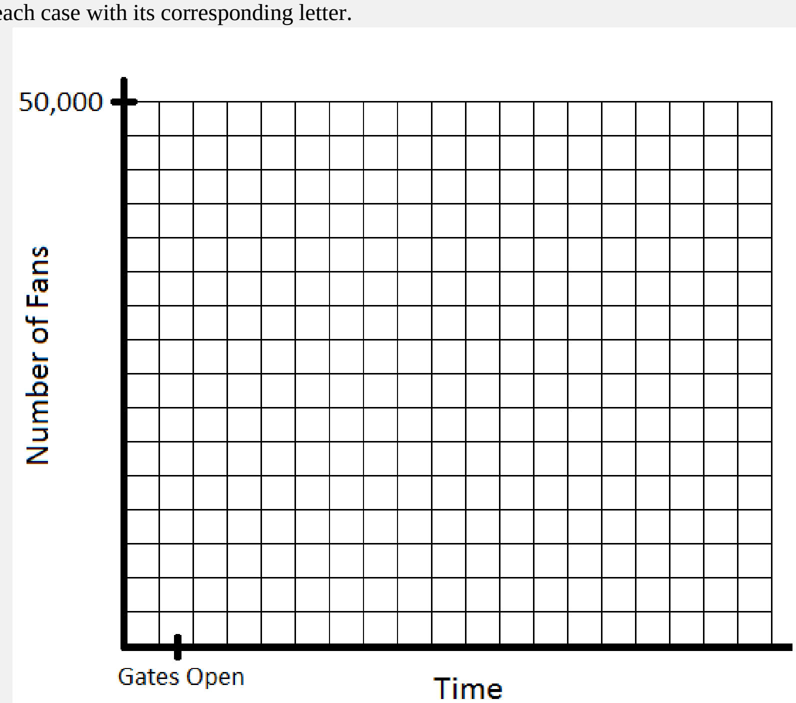


Figure 2. Part of the worksheet instructions for the analogy strategy.

Measurement instrument
The Heat and Energy Concept Inventory (HECI) was used to measure conceptual learning gains.[29] 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*:

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

and the effect size, *ES*. The effect size evaluates the magnitude of the different between the means of two groups. Typically a threshold of value of 0.50 or greater is considered important.[30] A Oneway 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 2. HECI results for the cognitive conflict and analogy inquiry-based activities

	Cognitive conflict (n = 37)	Analogy (n = 47)
Mean (Post), $\overline{x}_{post}$	50%	48%
Mean (Pre), $\overline{x}_{pre}$	42%	47%
St. Dev (Post), SD_{post}	27%	27%
Normalized Gain, *G*	15%	2%
Effect Size, *ES*	0.31	0.04

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

Misconception	Post HECI Mean, $\overline{x}_{post}$		Pre HECI Mean, $\overline{x}_{pre}$		Max Possible (Number of Items), $x_{\max}$
	Cognitive conflict R vs. A Studio	Analogy R vs. A Studio	Cognitive conflict R vs. A Studio	Analogy R vs. A Studio	
Rate vs. Amount[+]	4.0	3.8	3.4	3.7	8
Radiation[++]	7.5	7.2	5.0	5.0	11
T vs. Feeling[+++]	6.2	5.5	5.8	5.7	9[*]
T vs. Energy[+++]	6.6	5.8	6.4	6.8	10[*]
Entire HECI	23.9	22.0	19.0	19.8	36

[+] 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 Oneway 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 η^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 η^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

Misconception	Normalized Gain, *G*		Effect Size, *ES*	
	Cognitive conflict	**Analogy**	**Cognitive conflict**	**Analogy**
Rate vs. Amount	15%	2%	0.31	0.04
Radiation	42%	37%	1.08	0.97
T vs. Feeling	14%	-4%	0.24	-0.07
T vs. Energy	5%	-31%	0.08	-0.44
Entire HECI	**29%**	**14%**	**0.77**	**0.36**

Differences in gender

A Oneway 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, η^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 η^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, η^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, η^2 = .41].

Table 5 presents results for the average number of items correct for the post-HECI and pre-HECI items that form the *Rate vs. Amount* scale in terms of teaching strategy, gender, and number of students. The 11 females in the cognitive conflict strategy condition had an unusually low pre HECI and also demonstrated the largest gains. Although the analogy presented may be

Table 5. Average items correct for the *Rate vs. Amount* HECI scale by gender and strategy.

		Post HECI $\overline{X}_{post}$	**Pre HECI** $\overline{X}_{pre}$	**Number of students**
Cognitive conflict	Female	3.2	1.3	11
	Male	4.4	4.2	26
Analogy	Female	3.9	3.5	21
	Male	3.8	3.9	26

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 instruction[32] 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[33] 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.

References

1. A guide to the flipped classroom, the chronicle of higher education, January 2015. http://chronicle.com/article/A-Guide-to-the-Flipped/151039/ Accessed 01/31/2015.
2. Falconer, J.L., deGrazia, J., Medlin, J.W., & Holmberg, M.P. (2009). Using screencasts in ChE courses. *Chemical Engineering Education*, *43*(4), 302-305.
3. Ankeny, C.J., & Krause, S.J. (2014). Flipped biomedical engineering classroom using pencasts and muddiest point web-enabled tools. *ASEE Annual Conference and Exposition, Conference Proceedings*.
4. Bishop, J. L., & Verleger, M.A. (2013). The flipped classroom: A survey of the research. *ASEE Annual Conference and Exposition, Conference Proceedings*.
5. Berrett, D. (2012). How 'flipping' the classroom can improve the traditional lecture. *The chronicle of higher education*, *12*.
6. Mason, G.S., Shuman, T.R. & Cook, K.E. (2013). Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper-Division Engineering Course. *IEEE Trans. Educ. 56*, 430–435.
7. Phase, I. I. (2005). *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. National Academies Press.
8. Bransford, J., Brown, A. & Cocking, R. (2000). *How People Learn: Brain, Mind, Experience and School*. Washington, D.C.: Commission on Behavioral and Social Science and Education, National Research Council.
9. Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*, 141-58.
10. Elby, A. (1999). Another reason that physics students learn by rote. *American Journal of Physics 67*, S52
11. Streveler, R. , Litzinger, T., Miller, R., & Steif, P. (2008). Learning conceptual knowledge in the engineering sciences: Overview and future research directions. *Journal of Engineering Education 97*(3), 279-94.
12. Scott, P.H., Asoko, H.M., & Driver, R.H. (1991). Teaching for conceptual change: A review of strategies. *Connecting research in physics education with teacher education*, 71-78.

13. Driver, R., & Erickson, G. (1983). Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science, 37-60.
14. Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher, 23,* 13–20.
15. Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, *66*(2), 211-227.
16. Sokoloff, D. R., Laws, P. W., & Thornton, R. K. (2007). RealTime Physics: active learning labs transforming the introductory laboratory. *European Journal of Physics*, *28*(3), S83.
17. Laws, P., Sokoloff, D., & Thornton, R. (1999). Promoting active learning using the results of physics education research. *UniServe Science News*, *13*, 14-19.
18. Thornton, R. K., & Sokoloff, D. R. (1998). Assessing student learning of Newton's laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. *American Journal of Physics*, *66*(4), 338-352.
19. Prince, M., Vigeant, M., & Nottis, K. (2012). *Using inquiry-based activities to repair student misconceptions related to heat, energy, and temperature*. *Frontiers in Education Conference*, Seattle, WA.
20. Self, B.P. & Widmann, J. (2014). Learning Fundamental Mechanics Relationships Using Inquiry-Based Learning Activities. *Frontiers in Education Conference*, Madrid, Spain.
21. Clement, I. I. (2013). Roles for explanatory models and analogies in conceptual change. *International Handbook of Research on Conceptual Change*, 412.
22. Smith III, J. P., Disessa, A. A., & Roschelle, J. (1994). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences*, *3*(2), 115-163.
23. Duit, R. (1991). On the role of analogies and metaphors in learning sciences. *Science Education*, *75*(6), 649–672.
24. Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, *7*(2), 155–170.
25. Brown, D.E. (1993). Refocusing core intuitions: A concretizing role for analogy in conceptual change. *J. Res. Sci. Teach.*, *30*, 1273.
26. de Almeida, M. J. B., Salvador, A., & Costa, M. M. R. (2014). Analogy for Drude's free electron model to promote students' understanding of electric circuits in lower secondary school. *Physical Review Special Topics-Physics Education Research*, *10*(2), 020118.
27. Brown, D.E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science*, *18*(4), 237–261.
28. Dagher, Z. R. (1995). Review of studies on the effectiveness of instructional analogies in science education. *Science Education*, *79*(3), 295-312.
29. Prince, M., Vigeant, M., & Nottis, K. (2012). Assessing the prevalence and persistence of engineering students' misconceptions in heat transfer. *Journal of Engineering Education*, *101*(3), 412-438.
30. Fraenkel, J.R., Wallen, N.E., & Hyun, H.H. (2012). *How to design and evaluate research in education* (8^{th} ed.). NY: McGraw-Hill Co. Inc.
31. Heckler, A.F., & Sayre, E.C. (2010). What happens between pre-and post-tests: Multiple measurements of student understanding during an introductory physics course. *American Journal of Physics*, *78*(7), 768-777.
32. Koretsky, M.D. (2015). Program Level Curriculum Reform at Scale: Using Studios to Flip the Classroom. *Chemical Engineering Education*, *49*(1), 47-57.
33. Blanchette, I., & Dunbar, K. (2000). How analogies are generated: The roles of structural and superficial similarity. *Memory & Cognition*, *28*(1), 108–124.