Can structured reflection enhance learning in a heat and mass transfer course?

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Abstract

This paper presents a quantitative and qualitative study of written reflective exercises and normalized gain scores from a concept inventory assessment in a junior-level heat and mass transfer course for chemical engineers. The primary purpose of this research is to determine to what extent written reflection activities are successful at adjusting commonly-held misconceptions students have about heat transfer.

As described in a previous ASEE paper (Chenette and Ribera, 2016), the authors conducted a series of prediction activities in several course sections, each with approximately 25 junior-level chemical engineering students, with either a structured follow-up reflection assignment or no structured reflection assignment after each prediction activity. The Heat and Energy Concept Inventory (HECI) was administered to students of all sections at the start and the end of the course. The overall HECI score along with HECI subcategory (Temperature vs Energy, Temperature vs Feeling, Rate vs Amount, Radiation) scores were used to evaluate learning gains. Archived data from classes with no prediction activities and no reflection activities served as a control group. To explore if the quality of reflection is related to learning gains, student reflections were ranked according to a validated rubric and compared with quantitative data on learning gains. Qualitative contributions include student responses from focus groups and student surveys. Key highlights will be discussed to provide a better understanding how the students’ perception of learning is affected by these activities.

Preliminary results showed a weak correlation between the normalized gain score of individual students in the Rate vs Amount subcategory and the quality of reflection displayed by each student in the follow-up reflection activity. This paper analysis of another HECI subcategory relevant to the in-class prediction activity on radiation. This analysis also includes an additional cohort of students in an effort to increase the sample size to address limitations of the preliminary results. The goal of this study is to better direct the role of prediction and reflection activities in fundamental engineering courses.

Introduction

As other scholars have shown, including prediction activities in university-level heat transfer courses enhances conceptual understanding of heat transfer concepts among chemical engineering students. Additionally, guided reflection is being used in engineering education to elicit deeper understanding from an experience. This study compares students among different classes to determine to what extent reflective activities in combination with prediction activities impact shifts in conceptual knowledge of heat and mass transfer.

The theory upon which this study is founded includes literature on conceptual change, inductive-learning as a form of active-learning, and reflection. A detailed literature review of
these subjects can be found in a previously published work-in-progress ASEE paper (Chenette and Ribera, 2016)\textsuperscript{1}.

**Methodology**

This study expands upon a preliminary study that aimed to uncover the extent to which structured written reflection activities play a role in facilitating conceptual change for students in a fundamental heat transfer course. Established instructional methods based on inductive-learning guided the prediction activities used in this study\textsuperscript{5,9}.

This experimental design is an extension of the preliminary work, and is considered quasi-experimental (students were not randomly assigned to different sections). It includes traditional instruction (X1), in-class prediction activities (X2), and written reflection activities (X3), across various cohorts, as shown in Table 1. A pre- and post-test HECI (O1) and an optional focus group (O2) provide quantitative and qualitative evidence to describe the effect of these activities on student experience. Students in the control group (Class A) did not participate in the prediction nor reflection activities. Class C all received the same experimental conditions, however distinctions are made for the following reasons: Class C2 and C3 were not a part of the preliminary study (REF omitted), and a different instructor taught Class C3.

Three 25-minute prediction activities were spaced throughout the 10 week course. As mentioned earlier, established instructional methods guided the structure of these activities (REF omitted). Briefly, the three activities centered on the topics of conduction, convection, and radiation. Sample lesson plans can be found in the Appendix of this paper.

Each prediction activity began with the instructor explaining the demonstration and asking a question about what would happen in the system. Students wrote down their predicted answer with some justification. A brief demonstration followed, allowing students to observe what actually happened. The instructor concluded the activity with a 5 minute explanation of the theory governing the system. Within a week of the in-class activity, students in Class C completed a brief set of structured questions, aimed to engage students in reflection. These follow-up activities are in the Appendix.

**Table 1: Experimental Design.** The same HECI test was administered pre- and post-instruction as a quantitative form of observation (O1). In addition to traditional instruction (X1), the instruction received by Class B also included prediction activities (X2) and instruction in Class C also included reflection activities (X3). A voluntary focus group was assembled of students from Class B and Class C. The classes were all taught by the same instructor except for Class C3.

<table>
<thead>
<tr>
<th>Sample</th>
<th>HECI test</th>
<th>Traditional instruction</th>
<th>Prediction activities (3)</th>
<th>Reflection activities (3)</th>
<th>HECI test</th>
<th>Focus group (optional)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A (control)</td>
<td>O1</td>
<td>X1</td>
<td>-</td>
<td>-</td>
<td>O1</td>
<td>-</td>
</tr>
<tr>
<td>Class B</td>
<td>O1</td>
<td>X1</td>
<td>X2</td>
<td>-</td>
<td>O1</td>
<td>O2</td>
</tr>
<tr>
<td>Class C (1,2,3)</td>
<td>O1</td>
<td>X1</td>
<td>X2</td>
<td>X3</td>
<td>O1</td>
<td>O2</td>
</tr>
</tbody>
</table>
Assessment

Assessment methods for this study are the same as those published previously (REF omitted). Here, a brief overview of these methods is presented, and the reader is encouraged to review the prior work for justification details and supporting references.

Quantitative learning gains were assessed using the Heat and Energy Concept Inventory (HECI), which was selected for its relevant subject categories and its established internal consistency reliability and content validity. The HECI was administered pre- and post-instruction for all students in this study.

Witten follow-up reflective exercises were ranked using a four-category rubric developed by Kember and colleagues that has since been validated. The four levels of reflection identified in this rubric are: habitual action/non-reflection, understanding, reflection, and critical reflection. Each reflection activity (student name and course information removed) was independently reviewed and ranked by 2 or 4 faculty members. To facilitate this process, an online survey was created specifically for this study in the form of an online survey. Moodle, an online learning management system, hosted the questionnaire, which is the name given to an activity which allows teachers to create questions and receive feedback from students. The questionnaire was developed specifically for this study and provided reflection response text, a reminder of the rubric definitions, and fields to enter their numerical ranking and additional comments, if so desired. Faculty were trained to use the rubric and reviewed sample reflections to assist with inter-rater reliability. The developers of the rubric indicate that intermediate categories may be used. For this study, faculty reviewers did not assign intermediate categories, however average rankings across the multiple reviewers were rounded to fall into the four categories.

To complement quantitative assessment, qualitative responses from a survey administered by the Consortium to Promote Reflection in Engineering Education (CPREE) were gathered to provide supplementary qualitative data obtained in earlier work from a focus group. Nine students from Class C1 completed the survey, which asked about the impact of these activities on students.

Results and Discussion

One-way ANOVA (analysis of variance) tests were conducted to compare differences in the mean overall pre-test and post-test scores for the HECI among each student cohort. Differences were significant at a p < 0.001 level for every class except Class A (p > 0.05). Figure 1 displays mean pre- and post-instruction scores on the HECI for each class.
Figure 1: Overall HECI Score Comparison. Mean HECI score is plotted for each class: Class A: X1 (traditional instruction); Class B: X1 and X2 (prediction activities); Class C1, C2, C3: X1, X2 and X3 (reflection activities). Error bars represent SD.

Average normalized gain scores for this assessment were also calculated for each class for the overall HECI as well as individual subcategories, as shown in Table 2. Defined as the ratio of actual average gain to the highest average gain possible, student scores that increase significantly between the pre- and post-assessment show a high normalized gain. A decrease in an assessment score results in a negative normalized gain. Normalized gain scores may be further classified as “high-g” where \(<g> \geq 0.7\), “medium-g” where \(0.7 > <g> \geq 0.3\), and “low-g” where \(<g> < 0.3\).

Table 2: Average Normalized Gain Scores by Category and Overall. Normalized gains for individual students were averaged among each class.

<table>
<thead>
<tr>
<th>Class</th>
<th>Temp v Energy (10 items)</th>
<th>Temp v Feeling (9 items)</th>
<th>Rate v Amount (8 items)</th>
<th>Radiation (11 items)</th>
<th>Overall (36 items)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A (n=34)</td>
<td>0.01</td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
<td>0.08</td>
</tr>
<tr>
<td>Class B (n=27)</td>
<td>0.21</td>
<td>0.40</td>
<td>0.23</td>
<td>0.44</td>
<td>0.33</td>
</tr>
<tr>
<td>Class C1 (n=18)</td>
<td>0.19</td>
<td>0.12</td>
<td>0.39</td>
<td>0.42</td>
<td>0.34</td>
</tr>
<tr>
<td>Class C2 (n=20)</td>
<td>0.32</td>
<td>0.41</td>
<td>0.36</td>
<td>0.54</td>
<td>0.44</td>
</tr>
<tr>
<td>Class C3 (n=14)</td>
<td>0.23</td>
<td>0.32</td>
<td>0.18</td>
<td>0.44</td>
<td>0.32</td>
</tr>
</tbody>
</table>
These data support the conclusions drawn from analysis of the raw HECI score, and show that no distinguishable difference is observed between classes B and C for average overall normalized gain scores. While there are some observed differences among subcategories (for example, Class C1 has a lower average normalized gain score for Temperature vs Feeling than the other classes), it is noted that the Radiation category showed the highest average normalized gain score among all categories.

Reflective student responses from Class C were scored (1 = non-reflection to 4 = critical reflection) and compared with that student’s normalized learning gain for the relevant sub-category in the HECI. Of the three in-class prediction activities, two aligned well with the established subcategories of the HECI. The prediction in Activity 1 related to the rate at which ice melted under different scenarios, and was linked to the conceptual sub-category Rate vs Amount. Activity 3 focused on the material properties of different surfaces related to radiative heat transfer, and thus was linked to the HECI sub-category of Radiation.

While the working hypothesis is that students who exhibited more critical reflection, thus making strides to adapt and change their way of thinking, were the students with the highest normalized learning gains, preliminary work was inconclusive1. It was shown that for Activity 1, there was “a weak correlation between the normalized gain score of individual students in this category and the level of reflection displayed by each student in the follow-up activity”1. This was attributed, in part, to few numbers of students exhibiting critical reflection.

With the addition of more students, one can better see the relationship between the quality of reflection and normalized gain scores. Do students who demonstrate a deeper level of reflection tend to show greater improvement on the HECI? This can be explored within the context of one prediction activity and the associated HECI subcategory. Table 3a shows average normalized gain scores (\(<g>\)) for each reflection ranking (1.0, 1.5, etc.), along with the number of students in each ranking category (N) for Prediction and Reflection Activity 1. Table 3b shows the same representation for Prediction and Reflection activity 3. These data include students from Class C1, C2, C3 (total N = 48). Average normalized gains scores for the associated HECI subcategory are given at the bottom of the tables.
Table 3: For each reflection ranking the number of students (N) in that category and their grouping’s average normalized gain score \(<g>\) is reported. The two charts show data for (a) Prediction and Reflection activity #1 and HECI subcategory, Rate vs Amount, (b) Prediction and Reflection activity #3 and HECI subcategory, Radiation. Color scheme: red = low \(<g>\ < 0.30, yellow = medium 0.30 \leq <g> < 0.70, green = high \(<g> \geq 0.70

<table>
<thead>
<tr>
<th>Reflection #1</th>
<th>N</th>
<th>Rate vs Amount &lt;g&gt;</th>
<th>Reflection #3</th>
<th>N</th>
<th>Radiation &lt;g&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 (non-reflection)</td>
<td>2</td>
<td>0.67</td>
<td>1.0 (non-reflection)</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>1.5</td>
<td>7</td>
<td>0.26</td>
<td>1.5</td>
<td>4</td>
<td>0.29</td>
</tr>
<tr>
<td>2.0 (understanding)</td>
<td>12</td>
<td>0.36</td>
<td>2.0 (understanding)</td>
<td>15</td>
<td>0.47</td>
</tr>
<tr>
<td>2.5</td>
<td>7</td>
<td>0.37</td>
<td>2.5</td>
<td>16</td>
<td>0.39</td>
</tr>
<tr>
<td>3.0 (reflection)</td>
<td>12</td>
<td>0.28</td>
<td>3.0 (reflection)</td>
<td>6</td>
<td>0.42</td>
</tr>
<tr>
<td>3.5</td>
<td>3</td>
<td>0.36</td>
<td>3.5</td>
<td>4</td>
<td>0.75</td>
</tr>
<tr>
<td>4.0 (critical reflection)</td>
<td>2</td>
<td>0.51</td>
<td>4.0 (critical reflection)</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>total</td>
<td>45</td>
<td>0.34</td>
<td>total</td>
<td>45</td>
<td>0.45</td>
</tr>
</tbody>
</table>

These data indicate that the students who demonstrated critical reflection (ranking of 3.5 or 4) show medium to high learning gains in the associated subcategory. However, these two activities show distinct trends.

In looking at Table 3a, there were two students who exhibited non-reflection after completing Activity 1, which relates to the melting of ice and the difference between heat rate and amount of heat transferred, that showed, on average, moderate learning gains. Again, this data may be not be suitable for this analysis because of the small sample size. Upon closer inspection, the raw data show that one of these student scored a normalized gain score of 1.00, a perfect post-test score on this subcategory.

In the case of the Radiation activity, it is clear that students who exhibited a lesser degree of reflection exhibited lower learning gains. The Pearson’s correlation was found to be \(r = 0.22\), and a significance of \(p = 0.14\), indicating a weakly positive relationship that is not statistically significant. While the sample size is larger than in the preliminary study, the low statistical significance of this correlation may still be affected by a small sample. Another observation worth noting, is that it is the instructor’s perception that the concept at the core of Activity 3, pertaining to radiation, was more unfamiliar to these junior-level students at the start of this course than the concept of Rate vs Amount. As such, it may be that the majority of students were open to a shift in their understanding about radiation. It should be noted that negative gain scores are possible when a student earns a lower score on a post-test assessment. While this is in
frequent, it does happen, such as in the case when students earn a high score on the pre-test assessment.

Previous work related to this study found that the qualitative data from a student focus group supported the hypothesis that “the prediction activities were memorable in the student learning experience”\(^1\). Unfortunately, there was little insight into the retention of concepts, and the practice of reflective thinking in the future education of the individual students.

Nine students completed a voluntary CPREE (Consortium to Promote Reflection in Engineering Education) survey, which prompted students to answer what they took away from the reflection activity. Student comments fell into two categories: practical feedback to the instructor about the logistics of the activities themselves, thoughtful expressing of personal growth as a result of these activities. Below are example responses representative of the two themes:

Either incorporate it in class or make it shorter because although it is helpful, having a class discussion about it beforehand or doing it as a class would be more efficient.

The reflection activity did help with comprehension however it was more extensive than I expected it to be. However it was helpful and it did allow me to learn the material better.

These responses support the results of the quantitative data. Students found the reflection exercises helped with their learning, but figured their learning would be effected to a similar degree if a discussion occurred in class. This may very well be true, as students are likely reflecting in a general sense, revisiting the experience, on their own, without a structured written exercise.

Limitations of the preliminary study were the same for this work, with the exception that there were multiple evaluators of the written reflections and larger number of student participants.

**Conclusions and Future Work**

This quasi-experimental design revealed the extent to which prediction and reflection activities can have an impact on student conceptual understanding in the context of a junior-level heat and mass transfer course for chemical engineers. Although overall concept inventory scores alone do not capture any effect the reflection exercises may have had on the student, it should be emphasized that students who exhibited critical reflection had average \(<g>\) scores categorized as “medium” to “high” for the relevant concept sub-category.

Qualitative feedback from students indicated ways to improve the in-class activities and acknowledged the impact the reflections had on their learning. This is in agreement with preliminary work. Little information was explicitly gathered on the perception of the reflection exercises, but students expressed their dislike for additional work outside of class, albeit a 10-minute assignment.

As was mentioned in the concluding remarks of the preliminary study, the question remains, to what extent are students reflecting on their own after these prediction activities? A separate observational assessment method, such as the Reflective Thinking Test (RTT)\(^{10}\) may help explore the effect of the reflective process has on the student’s shift in conceptual understanding.
While there is still much to explore, this study is a small but important contribution to the community of engineering educators working to establish best practices for reflection, with the purpose of making meaning from experiences and facilitating conceptual change.

Acknowledgements

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References


Appendix

PREDICTION ACTIVITY 1

Name: _______________________________________________

Section (Circle one): 5th period / 6th period

Make a prediction...

Both cups contain the same volume of water at room temperature. To one you add regular ice cubes, and to the other one you add SONIC® ice (crushed ice). Each cup will contain the same mass of ice. Assume no heat is gained/lost to the surroundings and no bulk-motion.

On your own, make the following predictions:

Which scenario will have a higher rate of heat transfer? What will you observe (visually see or measure) that confirms this? Explain why you made this prediction.

Once all the ice has melted, which scenario will have transferred more heat? What will you observe (visually see or measure) that confirms this? Explain why you made this prediction.

Note: Prediction activities based on previously-developed inductive-teaching activities[^4]
PREDICTION ACTIVITY 1 FOLLOW-UP

Question 1
Recall the prediction activity in-class. Re-state your initial prediction below, including written explanation why you made this prediction. (2-3 sentences)

Question 2
What happened in the activity? Describe the result you observed in 2-3 sentences.

Question 3
Compare your initial prediction to what actually happened in the activity. Were your predictions completely correct? Yes / No

Question 4
Please explain your selection from Question 3. In your explanation, you should pay particular attention to why your original predictions were correct or not correct and how you revised your thinking to explain what happened. If you made a correct prediction and revised your justification as to why you made that prediction in any way to include new ideas, mechanisms, models, or parameters, be sure to explain this.

Question 5
Do the factors that increase the rate of heat transfer always increase the amount of heat transfer? Yes / No

Question 6
Please explain your selection in Question 5. (2-3 sentences)

Question 7
Given what you learned from this activity, answer the following question related to mass transfer: Do the factors that increase the rate at which a sugar cube dissolves in water always increase the final amount of sugar dissolved in water at equilibrium. ? Yes/ No

Question 8
Please explain your selection in Question 7. (2-3 sentences)

Question 9: What, if anything, did you learn from this activity?

Note: These prompting questions based on the on the “Rate vs Amount Misconception Survey” found on the AIChE Concept Warehouse.
Prediction Activity 3

Name: _______________________________________________

Section (Circle one): 5th period / 6th period

Make a prediction...

All three pipes are identical in size and material except for the outer coating. Pipe #1 is painted black, Pipe #2 is painted white, and Pipe #3 is coated with a thin sheet of aluminum. Each pipe has a thermometer displaying the internal temperature. All three pipes are initially at thermal equilibrium with their surroundings, and then are exposed to the same radiative heat source.

On your own, make the following predictions:

What will happen to the temperature in each pipe? Briefly explain.

The temperature in the black pipe will...

The temperature in the white pipe will...

The temperature in the aluminum-coated pipe will...

Which mechanism(s) and material properties will affect the result you observe? Briefly explain.
**Prediction Activity 3 Follow-Up**

**Question 1**
Recall the prediction activity in-class. (What will happen to the temperature in each pipe?) Re-state your initial prediction below, including written explanation why you made this prediction. (2-3 sentences)

**Question 2**
What happened in the activity? Describe the result you observed in 2-3 sentences.

**Question 3**
Compare your initial prediction to what actually happened in the activity. Were your predictions completely correct? Yes / No

**Question 4**
Please explain your selection from Question 3. In your explanation, you should pay particular attention to why your original predictions were correct or not correct and how you revised your thinking to explain what happened. If you made a correct prediction and revised your justification as to why you made that prediction in any way to include new ideas, mechanisms, models, or parameters, be sure to explain this.

**Question 5**
Does the absorptivity and emissivity have an effect on the rate of heat transfer? Yes / No

**Question 6**
Please explain your selection in Question 5. (2-3 sentences)

**Question 7**
Given what you learned from this activity, answer the following question related to radiation: Consider two hot pipes in a cool room. Each pipe is made of a different material but is otherwise the same (size, temperature, etc.). One material has a high emissivity and one has a low emissivity. If all other conditions are the same, does the pipe with the high emissivity always lose heat at a higher rate? Yes/ No

**Question 8**
Please explain your selection in Question 7. (2-3 sentences)

**Question 9:** What, if anything, did you learn from this activity?

**Note:** These prompting questions based on the on the “Rate vs Amount Misconception Survey” found on the AIChE Concept Warehouse.