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Prediction and Reflection Activities in a Chemical Engineering Course: Fundamentals of Heat and Mass Transfer

Dr. Heather C. S. Chenette, Rose-Hulman Institute of Technology

Heather Chenette is an Assistant Professor of Chemical Engineering at Rose-Hulman Institute of Technology. Her professional interests include enhancing student learning in the classroom and creating opportunities for students to learn about membrane materials and bioseparation processes through research experiences.

Dr. Tony Ribera, Rose-Hulman Institute of Technology

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Abstract

This paper presents a quantitative and qualitative study for discovering how written reflective exercises following in-class prediction activities enhance learning gains in a heat and mass transfer course for chemical engineering undergraduate students. The primary purpose of this research is to determine if and to what extent written reflection plays a role in adjusting commonly-held misconceptions students have about heat and mass transfer. To study this, three 30-minute prediction activities were planned throughout a ten-week course. The study participants included two sections of a course with approximately 20 junior-level chemical engineering students each. Based on their course section, students were broken into two groups. One group was asked to complete a follow-up reflection assignment after each prediction activity, guiding them through the reflective process, while the other group completed no structured follow-up reflection activity. The HECI (Heat and Energy Concept Inventory) was administered to students of all sections at the start and the end of the course. The HECI was used to evaluate learning gains. Archived data from classes with no prediction activities and no reflection activities served as a control group. Correlations between quantitative assessment performance and student group (prediction activities and practicing reflection, prediction activities only, no prediction and no reflection) are discussed. To explore if the quality of reflection is related to learning gains, student reflections were ranked according to a validated rubric and compared with data on learning gains. Additionally, to further understand how students' perception of learning is affected by these activities, a focus group of 5 students was organized and interviewed in a semi-structured format after the conclusion of the course. Key insights from the qualitative interviews are discussed. The goal of this work in progress is to aid in directing the role of prediction and reflection activities in future courses.

Introduction

The motivation for this work is driven by the conclusions that that even after successful completion of college-level engineering courses, some students still hold common misconceptions about heat and mass transfer. This has been documented in the form of post-instruction assessments, such as concept inventories, that target assessing conceptual knowledge. Beyond calculations and problem-solving, conceptual knowledge seems particularly difficult to adjust using traditional classroom techniques. This study explores the use of reflective activities in combination with prediction activities to better understand if and how reflection plays a role in shifting conceptual knowledge of heat and mass transfer.

The theoretical foundations for this study include literature on conceptual change, inductive-learning as a form of active-learning, and reflection. This literature review will give a brief overview of conceptual change and inductive-learning, but will focus on reflection, particularly in the context of reinforcing scientific content in university-level engineering education.

Conceptual change

Over three decades ago, science education researchers developed theories for conceptual change. Posner et al. state that scientists have "central commitments" that require modification with new concepts or information[10]. To achieve accommodation of new ideas into central concepts, the authors state there must be (1) dissatisfaction with the original concept, (2) an intelligible new concept that also (3) appears plausible, and (4) give way to expansion of ideas and interest. The authors also emphasize that the type of original concept (anomaly, analogy and metaphor, epistemological commitment, metaphysical belief, other) indicates the direction of conceptual change[10]. In her work in cognitive science, Chi further explores the idea of shifting mental categories to accommodate conflicting information[3]. This may occur over several levels (and is best changed with certain techniques): simple (refutation by contradiction), higher level (sometimes refutation), and highest level (resists normal instruction). Chi describes two distinct miscategorizations: lateral (related categories, i.e. mammal vs fish) and ontological (no common characteristics, i.e. entity vs process). The latter requires students to recognize that the category itself that needs adjusting[3]. A more detailed overview of conceptual change within the context of engineering and science is given by Streveler et al.[16] Among suggestions for future work, the authors identify one research question that remains is "how can one construct learning experiences that help students learn difficult concepts in engineering science?" Fortunately in the field of thermal science, just in the last five years strides have been made to identify and assess conceptual knowledge, and learning activities have been developed to facilitate conceptual change. This will be discussed in the following section.

Inductive-learning as a form of active learning

The incorporation of active learning into a course is a technique that has shown to affect conceptual change in the context of engineering and science courses. Laws et al. highlight significant learning gains in university students who participated in active learning classrooms (30% vs 75% of students who understood fundamental acceleration concepts)[7]. According to Laws et al., the elements that improved student learning include using peer instruction and collaborative work; using activity-based guided-inquiry materials; using a learning cycle beginning with predictions; emphasizing conceptual understanding; letting the physical world be the authority; evaluating student understanding; making appropriate use of technology; and beginning with the specific and moving to the general[7].

Inductive-learning is a method of learning which exposes the learner to an observation or experience first, and then later, once the need for knowledge has been established, does the teacher provide instruction. Prince and Felder provide detailed descriptions and definitions of inductive teaching and learning methods, and review research studies on the subject[11]. They found that these methods are just as effective as, and more often more effective than traditional deductive methods.

With these elements in mind, Prince et al. developed multiple inquiry-based demonstrations and tested their effectiveness in facilitating conceptual change among students in a heat transfer and thermodynamics course[12]. Of their many significant findings, one striking result is that the longterm normalized gain in overall heat transfer concept inventory scores ranged from over 50% to 70% for cohorts that engaged in the inquiry-based activities as compared to only about 20% for students who had no activities. As a part of these activities, students answered extension questions to demonstrate their ability to apply acquired knowledge to new settings, and open-ended questions so the researchers could use another lens through which to view potential changes in student's understanding of course concepts. It is noted that the final element of active teaching (according to Laws and colleagues) is to "begin with the specific and move to the general,"[7] which suggests asking the student to step away from the experience and try to apply their newly acquired knowledge to a new situation. This final element greatly resembles the practice of "reflection," and is worth exploring to better understand how the act of reflection plays a role in shifting student's conceptual knowledge. How important is it to include reflection into these exercises in order to bring about conceptual change?

Reflection

What constitutes reflection? The definition of reflection and how it is used in an educational context can vary widely. Generally, according to Rogers' analysis of Dewey's work on the subject, reflection is a meaning-making process occurring systematically, in a community, involving personal and intellectual growth[14]. For reflection to occur, Dewey's ideas can be condensed down to the following sequence of steps. One must be present to the experience; describe the experience holding self-consciousness, judgements, and interruptions at bay; analyze the experience; and then take intelligent action. Distinctions have been made between reflection for the purpose of developing as a learner, making-meaning in the form of defining one's identity, and learning content[4]. This work falls under reflection in the form of the latter category.

Within the context of engineering education, reflection can be a tool to assign meaning to an experience, and facilitate further action in engineering students[18]. Recognizing the potential for reflection in engineering education, Sepp et al. conducted a systematic review of literature pertaining to reflection in engineering education[15]. They found that the use of reflection is a growing trend in ASEE publications. Within articles that mention reflection, the authors of this review recognize that the scope of reflection varied. They categorized the use of reflection in engineering education as being one of the following scopes: casual mention, serious thread, or main focus. Of the articles reviewed, the authors also categorized the types of activities that used reflection: activity using portfolios, activities using reflective essays, other types of activities (such as surveys or discussions), and non-activities; essays constituted the most numerous form of reflective activities[15].

The noted variation in the way reflection was used in engineering education, as well as the scope to which it is emphasized within the engineering education setting is consistent with how reflection is used in education in a broader context. However, unlike in engineering education, the use of reflection in other disciplines, such as educating medical practitioners, has been established for quite some time.

Here, a small selection of previous studies within engineering education that incorporate reflection as a main focus will be discussed. Specifically, the following studies aim to measure gains in student knowledge of content (not sense of identity, or development as a learner) as a result of experiencing reflection through activities other than portfolios or essays. This sub-set shares goals in common with those of this study. Namely, exploring how, and to what extent, the inclusion of relatively short reflective assignments enhance student's knowledge of specific concepts within a content-based course. The reader is directed to work of Sepp et al., for more extensive review of reflection in engineering education across the range of activity types[15].

Castellanos and Enszer incorporated 200-word weekly reflective assignments guided by prompts with the hypothesis that these exercises might enhance students understanding of thermodynamic concepts[2]. Reflections were scored and were found to show a positive correlation with course grade. Additionally, there was a statistically significant difference between average final grades from the cohort that completed the reflection assignments as compared to a cohort that did not engage in guided reflection; grades were higher for the class that performed the reflection exercises. Student attitudes were surveyed using a Likert scale, and indicate that attitude, increased learning potential, and sentiments on continuation of the activities all received mediocre rankings (about 6, on a scale from 1 to 10). The authors acknowledge possible reasons for their observed correlations. One possibility is that motivated and high-performing students may be more skilled at reflective writing.

In a study conducted by Benson and Zhu guided reflection exercises were administered to students in an Introduction to Engineering course and a Solid Mechanics course (approximately 40, and 70 students, respectively)[1]. These guided reflections included identifying error types, a form of self-assessment, as well as self-reflection in the form of short written responses to reflective prompts. Among other takeaways, the researchers found that students who did poorly on earlier exams and chose to participate in the reflective exercises all improved the subsequent exam score. It can be difficult to discern whether this reflection exercise may be facilitating a student's understanding of content, or promoting student growth as a learner, or both. Nonetheless, the findings in this study support the use of reflection in a content-based course as students who complete these exercises may be more likely to perform better on subsequent exams.

In the context of an introductory materials science course, Meneske and colleagues evaluated daily reflective assignments, pre- and post- instruction concept tests, and exam scores of 27 undergraduate students[8]. The reflection questionnaire, administered daily at the end of each class period, prompted students to reflect on the "muddiest points" of that day's course content. For one unit exam, students with higher quality reflection scores performed better on the unit exam, however they did not perform significantly better on the associated concept test. The authors conclude that their results indicate that there is some support for the practice of encouraging students to authentically reflect on confusing concepts in order to better understanding of content, and that this area is worth further exploration to better understand the relationship between quality of reflection and learning outcomes.

Methodology

The purpose of this work is to quantitatively and qualitatively study how written reflection plays a role in facilitating a change in conceptual understanding of identified concepts in heat and mass transfer. Instructional approaches based on inductive-learning have been identified that lead to a change in student's understanding of these concepts[19] and were used as a guide for the prediction activities used in this study.

The experimental design (shown in Table 1) of this work is a quasi-experiment where the sections are not randomly assigned. In addition to traditional instruction (X1), treatments applied consisted of three in-class prediction activities (X2) spaced throughout the course, and three reflection activities (X3) that followed within a week of the prediction activities. Prediction activities consisted of in-class demonstrations that involved students making a prediction and were based on prediction activities developed by established researchers in this arena[12,13]. Reflection activities included an assigned follow-up worksheet that lead students through a set of reflective questions, encouraging them to revisit the in-class experience, describe changes in their thinking, and answer a related question in a different context. Examples of both prediction activities and reflective prompts are given in the Appendix. The effect these instruction methods had on student learning was based on an observation of HECI (Heat and Energy Concept Inventory) score (O1) pre- and post- instruction. The control group had only traditional instruction (X1) and no prediction or reflection activities. A focus group of students was assembled from those who participated in the prediction activities to further observe the impact of the activities on student learning.

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.

Sample	HECI test	Traditional instruction	Prediction activities (3)	Reflection activities (3)	HECI test	Focus group (optional)
Class A (control)	O1	X1	-	-	O1	-
Class B	O1	X1	X2	-	O1	O2
Class C	O1	X1	X2	X3	O1	O2

Assessment

To quantitatively assess learning gains, the Heat and Energy Concept Inventory (HECI) was used. This inventory was selected because the four concepts tested (rate vs amount, temperature vs the sense of feeling hot, energy vs temperature, and radiation) were topics that aligned with the course objectives. Additionally, the development and use of this instrument has been well documented, and has been tested for internal consistency reliability and content validity, both of which were acceptable[12,19,13]. All students included in this study took the HECI both as a pre-test (within the first two weeks of the course) and a post-test (during or after the tenth and final week of the course). Statistical analysis of student scores in each of the three groups as conducted after course grades were assigned.

To assess the written follow-up reflective exercises a four-category rubric developed by Kember and colleagues was used[6]. The four levels of reflection identified in this rubric are: habitual action/non-reflection, understanding, reflection, and critical reflection. This rubric, developed by researchers in education and applied professional learning in a medical setting, was validated using writing samples from students in the process of clinical placement[5]. It was selected because in addition to being theory-informed, with acceptable agreement among evaluators, it offers simple descriptions relevant to the reflection assignment in this study. Another rubric considered was the four-category REFLECT rubric, developed by Wald et al. which also contains five criterion categories[20]. While this rubric was also theory-informed with acceptable reliability and validity, the author was looking for a simple scheme that was familiar to other colleagues who were implementing reflection exercises in their courses at the same institution. Additionally, as this study is considered preliminary work, a more detailed rubric could always be adopted for future work if the need is established.

It is worth mentioning that there is a set of literature dedicated to the discussion of how written reflection should be assessed[9], and whether or not written reflections should be assessed at all[17]. In this study, points were assigned to students who completed the reflection exercises, but the reflections were not scored for the purpose of assigning students a grade. Reflections were only *scored* for the purpose of this research study. At this point, scoring the reflective exercises and subsequent analyses has been completed for one of the three in-class reflection activities. As this study is considered a work-in-progress, the analyses of the remaining activities is the focus of future work.

In addition to an analysis and review of the HECI data and written reflections, qualitative data were collected to better understand the quantitative results and identify future improvements to the course. This included interviews and a focus group with students in the two treatment groups, both containing in-class prediction activities. In total, 5 undergraduate students provided qualitative data.

Results and Discussion

One-way ANOVAs were conducted to compare differences in concept inventory scores between three student cohorts. No significant differences between classes emerged at the $p<.05$ level when looking at the concept inventory administered at the beginning of the course. However, looking at the concept inventory administered at the end of the course, significant differences between classes emerged. Post hoc comparisons using the Scheffe's test revealed the score for Class A with no prediction activities (M = 0.52, SD = 0.18, N = 34) was significantly lower when compared to the classes that experienced in-class prediction activities, Class B (M = 0.70, SD = 0.18, N = 27) and Class C (M = 0.65, SD = 0.13, N = 18). Figure 1 displays mean pre- and post-instruction scores on the HECI for each class.

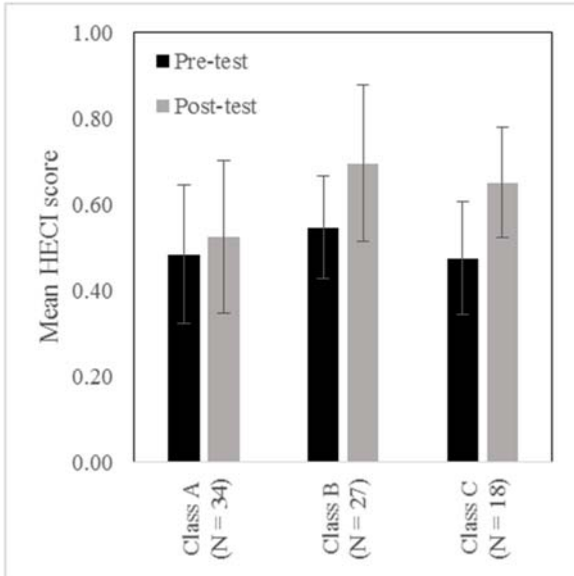

Figure 1: Overall HECI Score Comparison. Mean HECI score is plotted for each class: Class A: X1 (traditional instruction); Class B: X1 and X2 (prediction activities); Class C: X1, X2 and X3 (reflection activities). Error bars represent SD.

Average normalized gain scores for the HECI were also computed for the three classes. Average normalized gain scores have been used to measure the effectiveness of a course or activity in promoting conceptual understanding, most notably by Hake's evaluation of interactive learning environments in an introductory physics course[5]. Average normalized gain score, <g>, is defined as the ratio of the actual average gain to the maximum average gain possible (% post - % pre) / (100 - % pre). For context, in Hake's work (which analyzes gain scores for over six-thousand students from various institutions and a range of course settings), he classifies courses as "high-g" courses where (<g>) ≥ 0.7, "medium-g" where 0.7 > (<g>) ≥ 0.3, and "low-g" where (<g>) < 0.3. The concept inventory used in the present study contains four concept sub-categories (Temperature vs Energy, Temperature vs Feeling, Rate vs Amount, and Radiation), and the average normalized gain scores were computed for these sub-categories as well as the overall HECI. Results are shown in Table 2.

Table 2: Average Normalized Gain Scores by Sub-Category and Overall. Categories and the number of items in each category according to the developers of the HECI. The number of items indicate the number of HECI questions associated with each category. Some questions fell into multiple categories. Normalized gains for individual students were averaged among each class.

	Temp v Energy (10 items)	**Temp v Feeling (9 items)**	**Rate v Amount (8 items)**	**Radiation (11 items)**	**Overall (36 items)**
Class A (N = 34)	0.01	0.06	0.09	0.12	0.08
Class B (N = 27)	0.21	0.4	0.23	0.44	0.33
Class C (N = 18)	0.19	0.12	0.39	0.42	0.34

These data support the conclusions drawn from analysis of raw HECI score. However, this offers a deeper look into which students, on average, demonstrated changes in conceptual understanding of within these sub-categories. Class B improved their conceptual knowledge of Temperature vs Feeling compared to Class C, and Class C demonstrated a greater improvement in understanding the concept of Rate vs Amount than Class B, and yet both Class B and Class C showed similar average normalized gains for the entire HECI. One wonders, what factors might influence these results? Since both classes were exposed to the same in-class prediction activities, why else might one group of students exhibit greater improvement in one category? Is it something that an instructor can control or facilitate? Or does this have to do with the nature of the student, and how each student responds to a particular activity?

To explore how the reflection activities impacted the normalized learning gains, the reflective responses for each participating student from one prediction activity were scored (1 = critical reflection to 4 = non-reflection) and compared with that student's normalized learning gain for the relevant sub-category in the HECI. This comparison was completed for the first in-class prediction and reflection activity, where students were asked to predict in which water-filled beaker would ice melt faster: a beaker with cubed ice, or a beaker with the same mass of crushed ice (see Appendix). This activity is connected to the conceptual sub-category Rate vs Amount. As seen in Table 3, there is 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. Additionally, these data indicate that there is no statistically significant correlation between the two variables. It is worth noting that among the 18 students in this sample, the number of students demonstrating critical reflection or reflection were few (just three students in each of these categories). While this is expected—the literature indicates that instances of critical reflection are rare[6]—there are few data to analyze.

Table 3: Correlation between Sub-Category Normalized Gain Score and Reflection. This table examines the correlation between reflection scores and <g> scores on sub-categories of 18 students. The Kember et al. (2008) four-category scheme was used by the instructor to assess written reflections.

		Reflection
Rate v. Amount	Pearson Correlation	0.02
	Sig. (2-tailed)	0.94

Further information was sought from students enrolled in Class B and Class C to better understand their perceptions of the course and the in-class prediction activities. In total, 5 undergraduate students volunteered to share their insights in a semi-structured interview format, all of whom had favorable perceptions of the course and the in-class prediction activities in particular. One student shared,

> *"I really liked the in-class prediction activities. For me particularly, they were helpful to visualize what we were talking about in class. It made it much easier*

for me to grasp some of the topics in the class when I could see them actually happening."

From the focus group, students from Class B that did not do the follow-up reflection exercises expressed a desire for more opportunities to reflect on these activities, and indicated that more follow-up could ensure that these activities better prepare students for quizzes and exams.

The qualitative data support the hypothesis that the prediction activities were memorable in the student learning experience. Given that students did not have much to say about the reflection component of these activities, it is difficult to know how students perceived this aspect of the activity, and whether they felt it had an effect on their ability to recall and apply concepts later on in the course or their career.

The quantitative data support what other researchers have observed, that demonstrations involving prediction activities had a significant impact on student's learning gains as measured by the HECI. Post-instruction raw scores from the control group and raw scores of students who participated in prediction activities were comparable with those in literature[19]. However, according to this analysis, concept inventory scores alone do not capture any effect the reflection exercises may have had on the student. This raises questions about the students who did not complete the follow-up prompt (Class B). Did these students engage in un-structured reflection on their own? Is the nature of these prediction activities such that students will experience conceptual change, and perhaps, reflection, on their own without guidance from an instructor?

There are several limitations of this study that should be highlighted. While the same instructor taught each of these classes, and effort was made to keep course content the same, archived data was used as a control group (Class A). A better study would include a control group that was given instruction at the same time as (or in parallel with) students in the "treatment" groups to account for possible changes in instructor's teaching style or effectiveness. Additionally, this was only a quasi-experiment where students were not randomly assigned "treatment." As mentioned earlier, the small class sizes may have limited the ability to establish a correlations between quality of reflections and normalized gain scores. This study only aimed to capture reflection in the form of written follow-up activities, while reflection may very well have occurred among students independent from these written activities. Finally, while done anonymously, and after grades were submitted for the course, the instructor was the only evaluator of the written reflections.

Conclusions and Future Work

This quasi-experimental design studied the role of prediction and reflection activities in the context of a heat and mass transfer course for junior-level undergraduate students in chemical engineering. While the inclusion of reflection activities as a part of instruction did not significantly affect students' post-instruction HECI scores, incorporating three 30-minute demonstrations that included prediction activities throughout a 10-week course had a significant impact on students' understanding of heat transfer concepts as observed in higher HECI scores ($p<0.5$) and greater average normalized gain scores ((<g>) > 0.3) as compared to a control group with no prediction activities ((<g>) = 0.08), shifting the course from a "low-g" course to a “medium-g” course. There was a weak correlation and no statistical significance between normalized gain scores for the relevant sub-category within the HECI and the level of reflection demonstrated by students on the reflection exercise that was evaluated. However, small samples sizes may have limited the ability to observe a correlation. Qualitative feedback from students was generally positive, supporting the argument that not only are these in-class activities valuable because they promote student learning, but that the students perceive them as having value. Little information was explicitly gathered on the perception of the reflection exercises.

Additional analyses needs to be performed to score and compare the written reflective responses from the two other prediction activities. While this rubric has been shown to have reasonable inner-rater reliability these reflections will be scored with a second and third evaluator to confirm the scoring. Another cohort of students with the same treatment as Class C (both prediction and reflection activities) will be analyzed which may help to alleviate limitations of this study. This will be the focus of future work.

Beyond the scope of this work, but certainly of interest, would be to assess students’ reflective thinking skills using a separate observational assessment method, such as the Reflective Thinking Test (RTT)[21]. This may aid in exploring the effect, if any, that participating in the reflective process—whether facilitated with written reflection activities, or independently without guidance from an instructor—has on the student’s shift in conceptual understanding. This would better inform the engineering education community about how practicing the reflective process through these types of activities might impact the engineer’s ability to reflect, and if there lies a connection to learning conceptual knowledge.

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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[12,13]

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.