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Self-paced, Active Problem-Solving Using Immediate Feedback (IF-AT; Scratch-off) Forms in Large Classes

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ABSTRCT

In-class example problems that students work out on their own using active problem-solving are typically well received and help the students better learn the material; however, they are difficult to enact in large classes with limited resources due to the number of questions received and the speed at which different students work through the problem. In a Junior-level mass transfer unit operations course, immediate feedback (IF-AT) forms were used to allow groups of four students to self-pace through in-class problems. The immediate feedback forms allowed students to check their progress, use cooperative learning to resolve their misconceptions, and ask the instructor questions only when truly stuck. In a class of 100 students, with one instructor and one teaching assistant, two problems were worked through, once in week 5 and the other in week 13, using the immediate feedback forms. Student and instructor feedback was highly positive.

Key words: IF-AT forms, Large class, self-paced learning

INTRODUCTION

Research has shown time and again that traditional lecturing does not allow students to actively choose and evaluate strategies, which is important for developing independent thinking.[1-2] When considering engineering majors, independent thinking is critical to their future careers. Unfortunately, due to increasing enrollments, it is becoming common to have class sizes of 100 plus students and a lone instructor, which often results in a traditional lecture-based class since it requires the least amount of work. To improve student's mastery of the subject material and conceptual understanding, many studies have proven that active learning helps engage students, which leads to meaningful learning.[2-3] Thankfully, many active learning strategies can be implemented with minimal resources such as ConcepTests,[4-5] think-pair-share,[6] one-minute papers,[7] and in-class problems.[8]

ConcepTests are multiple-choice questions that students typically respond to using a student response system, such as clickers. They are easy to implement in large classes since they require only a multiple-choice question and can even be responded to with a show of hands. During the class, a topic is presented and then a multiple-choice question is asked in which each student answers using their clicker. The students can answer on their own, or peer instruction/think-pair-share can be incorporated by allowing the students to discuss the answer before responding with the clickers.

Active learning using think-pair-share begins with a problem that the students individually work on for a few minutes and then discuss with another student to improve their answer. After some time, the instructor then randomly calls on an individual to share their response.[6, 9] Since the students first individually think about the problem, the students can improve their metacognition.[9]

One-minute papers can take many forms from having students recap the important learning objective of the class to finding out what lingering questions students may have on a topic that can be addressed in the following class. Typically at the end of class, the instructor hands out note cards or students use a sheet of paper to write their response to the posed question. The responses are then reviewed and addressed in the next class if necessary.

These active learning techniques can be easily implanted in large, and even mega-sized,[10] classes using single component questions (stand-alone and do not rely on answering a previous question correctly), but do not easily allow for scaffolded (depends on a previous answer), analytical problems to be worked through, which is critical for future engineers. Both ConcepTests and minute papers are excellent ways to gauge student learning and receive feedback, but are not applicable to problems requiring scaffolded, analytical solutions. Think-pair-share works well for short, one question problems, but, again, scaffolded questions do not work as well due to differences in student pacing and the difficulty in addressing student questions as they work through the problem. In-class problem-solving[9, 11-13] promotes active learning that can build confidence[14] in the subject material and leads to higher student motivation.[15] Additionally, having students work through problems on their own and providing immediate feedback is a benefit to the students,[9, 16] but large class sizes can lead to a lack of accountability[17] making in-class problems difficult to carry out when a high student to instructor ratio exists.

A novel, active learning method presented here uses Immediate Feedback–Assessment Technique (IF-AT) forms to allow students to complete scaffolded problems in-class. The IF-AT forms are a multiple-choice answer form with a thin, opaque film covering the answer options (Figure 1), which were developed in 2001 by Epstein et al.[18] to facilitate immediate feedback on multiple-choice exams. The students read a multiple-choice question, select an answer, and then scratch off the film covering for the corresponding answer. If they answered the question correctly, a star is shown in the answer rectangle. If answered incorrectly, the box is empty and the students should re-do the

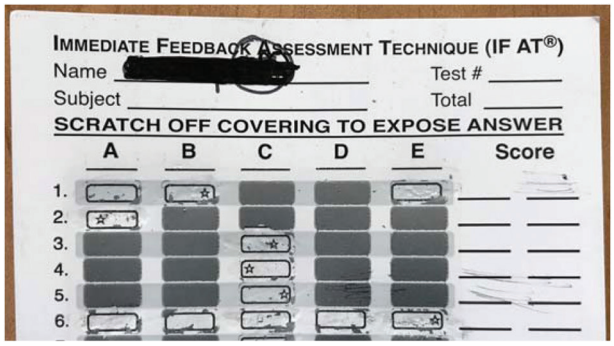


Figure 1. A used IF-AT form from week 5. Line 1 shows that the students incorrectly answered both A and E prior to choosing the correct answer, B while line 2 shows the students correctly answered A on their first attempt.

problem and scratch off another box. This process provides immediate feedback to the students. The IF-AT forms have a perforated bottom tab that contain a code that directs the instructor to the solutions for that form. Prior to handing out the forms, the tab is removed so that students cannot search for an answer key.

The IF-AT forms have been studied as a replacement to Scantrons for testing/exam purposes[18-20] and for team-based learning where students individually take quizzes and then use an IF-AT form in a group to complete the same quiz.[21-23] Research found that the use of IF-AT forms led to more confidence and higher recall compared to questions asked with a traditional Scantron form.[20]

The novelty in this work was having students use the IF-AT forms to work through scaffolded problems with minimal instructor interaction due to the high student to instructor ratio. In-class problems allow students to take problems step-by-step and apply the knowledge they have to determine a solution on their own or in groups, but in large classes, scaffolded questions may prevent students from moving forward if they get stuck. This can lead to the problem being fully worked through by the instructor, and the students, effectively, check out and do not attempt the problem. Additionally, students that incorrectly solve the problem move on and may not realize that the solution was incorrect. IF-AT forms allow students to know their answer is correct or immediately correct their mistake, which has been shown to increase retention of the correct information for procedural knowledge and difficult tasks.[24] Additionally, questions that result in the most incorrect answers, as evidence by multiple scratches for a problem, can be reviewed by the instructor as a form of Just in Time Teaching since the students focus on the relevant (i.e., the topics that lead to the most errors) material.[25]

In order to allow students to self-pace and check their answers as they progressed through scaffolded, higher-order cognitive problems, Immediate Feedback Assessment Technique (IF-AT) forms were used for two problems in a large class of 100 students. This paper describes the student and instructor feedback of using the IF-AT forms and recommendations for implementing the forms in a class.

METHOD

Classroom

As with many engineering programs, the class size of the mass transfer unit operations class at Montana State University has increased over 50% from Spring 2013 (64 students) to Spring 2017 (100 students). The class has been taught in a blended fashion[9, 26] using lecture, in-class videos, clickers, and example problems done by the instructor who had taught the course three previous times in a similar fashion since 2013. This core course is taken by all chemical engineering majors typically during the Junior-year. Mass transfer unit operations begins to take concepts from previous courses, such as mass and energy balances, thermodynamics, and heat transfer, and combines them in order to solve problems on evaporation, distillation, absorption/stripping, and other mass transfer unit operations.

Problem Topics

The two topics chosen for the IF-AT in-class problems were evaporation, which is the first time the students need to recall several concepts from previous courses in week 5, and distillation, which is an important unit operation in the chemical engineering field, in week 13.

The first IF-AT problem was implemented during week 5 of the course and used a slightly modified version of problem 17.39, single-effect evaporator (Figure 2), from the Separations Process Principles textbook.[27] For this class, the evaporation section of the course is the first time students have to use mass and energy balances and steam tables to solve a problem during the semester. A sample problem had been worked out previously in the class by the instructor, but this problem was the first time the students need to put the pieces together themselves, which leads to cognitive recall issues.

Based on Bloom's revised taxonomy,[28] the evaporator problem in week 5 was designed for students to remember, understand, apply, and analyze what they know (Table 1). The students were given the problem separated into eight different parts (i.e., a, b, c, etc.; Figure 2) and 10 multiple-choice questions on an attached sheet of paper (Figure 3). For example, after completing part a of the problem, there was a corresponding multiple-choice problem that the students answered prior to moving to part b; in this case, questions 3-a and 4-a (Figure 3). One source of confusion was the

Single-effect evaporator problem

Fifty thousand lb/h of a 20. wt% aqueous solution of NaOH at 120°F is to be fed to an evaporator operating at 3.72 psia, where the solution is concentrated to 40. wt% NaOH. The heating medium is saturated steam at a temperature of 40°F higher than the existing temperature of the caustic solution. The heat transfer coefficient is 300. BTU/lb. Assume the tubes are 30' long and have a diameter of 2".

Determine the:

Variable	
	a. Boiling point rise of the solution
	b. Saturated-heating-steam temperature and pressure
	c. Evaporation rate
	d. Heat-transfer rate
	e. Heating-steam flow rate
	f. Economy
	g. Heat-transfer area and number of tubes needed

i) Determine what variables you will be calculating and add them to the table above

a) BPR and b) incoming steam T and P

c) Evaporation rate: The evaporation rate will have units of_____; therefore, mass or energy balance?

d) Heat-transfer rate: The heat-transfer rate will have units of_____; therefore, mass or energy balance?

e) Heating steam flow rate: The heating steam flow rate will have units of_____

f) Economy – steam economy is the mass of water vaporized divided by the mass of steam fed

g) Heat-transfer area needed and the number of tubes required:

Figure 2. Text of in-class problem from week 5 with blank space removed.

Table 1. Multiple-choice questions from the IF-AT problem for week 5 and the level of learning required to answer the question.

Question (all with multiple-choice answers)	Level of learning[28]	Question type
1-i) What variable is going to be the evaporation rate?	Remembering	Single comp.
2-i) What variable is going to be the heating-steam flow rate?	Remembering	Single comp.
3-a) What is the boiling point of the water?	Understanding	Single comp.
4-a) What is the BPR of the solution in degrees F?	Applying	Scaffolded
5-b) What is the P of the incoming steam in psia?	Understanding	Scaffolded
6-c) What is special about the vapor in the evaporator?	Analyzing	Scaffolded
7-e) What is the approximate steam flow rate needed (lb/h)?	Applying	Scaffolded
8-f) What is the estimated steam economy?	Applying	Scaffolded
9-g) Approximately how surface area will you need for the evaporator?	Applying	Scaffolded
10-g) Approximately how many tubes will you need in the evaporator?	Applying	Scaffolded

1-i) What variable is going to be the evaporation rate?
A. S B. V C. L D. F E. q
2-i) What variable is going to be the heating-steam flow rate?
A. S B. V C. L D. F E. q
3-a) What is the boiling point of the water?
A. 100 B. 130 C. 150 D. 200 E. 240
4-a) What is the BPR of the solution in degrees F?
A. 0 B. 25 C. 50 D. 75 E. Not given
5-b) What is the P of the incoming steam in psia?
A. 3.722 B. 11.53 C. 24.97 D. 29.82 E. None of the above
6-c) What is special about the vapor in the evaporator?
A. It is at its vapor pressure B. It is superheated C. The steam tables can be used to determine H_v D. A and C E. B and C
7-e) What is the approximate steam flow rate needed (lb/h)?
A. 10,000 B. 20,000 C. 30,000 D. 40,000 E. 50,000
8-f) What is the estimated steam economy?
A. 0% B. 20% C. 50% D. 80% E. 100%
9-g) Approximately how surface area will you need for the evaporator?
A. 2,000 B. 2,100 C. 2,200 D. 2,300 E. 2,400
10-g) Approximately how many tubes will you need in the evaporator?
A. 10 B. 20 C. 40 D. 80 E. 160

Figure 3. IF-AT multiple-choice questions for week 5 that were listed on a separate page.

multiple-choice questions being listed on a separate page. This led to a change that the multiple-choice questions being in-line for the next IF-AT-based problem.

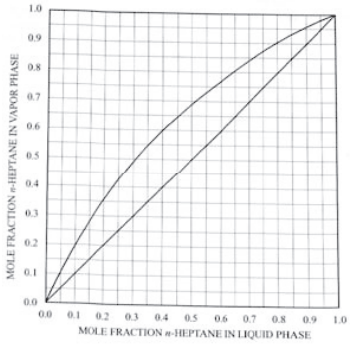
The questions started in the lower cognitive process categories of Taxonomy (Table 1), such as variable identification, to get students accustomed to the IF-AT form. Then, the questions became more complex in the middle and end (Table 1). Additionally, the first three questions were single component (stand-alone and do not rely on answering a previous question correct) and the last six questions were scaffolded, meaning that in order to get those answers correct, the students had to have answered a previous question (or questions) correct.

For the McCabe-Thiele distillation problem, which was from the National Council of Examiners for Engineering and Surveying (NCEES) 2017 FE Chemical Practice Exam, in week 13, the students were in the same base groups as they were for the first problem. In this case, the problem was changed so that the multiple-choice questions were in-line with the problem (Figure 4). Having seen this format before in combination with the in-line questions seemed to significantly decrease the confusion amongst the groups. Additionally, this problem was shorter with three required questions (16–18) and four optional ones (19–22; Table 2) that were in the lower cognitive levels of Bloom's revised taxonomy with the most difficult questions being in the "Apply" category.[28] The optional questions were used to provide hints for completing the problem and to check their final answer. The only clarification needed for this problem was that the questions begin at 16 on the IF-AT form because the forms from the week 5 problem were reused.

In-class Implementation

Students were placed in base groups of four assigned by the instructor that were also class project groups, given one IF-AT form per group, and a problem sheet each. The directions given were to

FE exam sample problem: A distillation system is used to separate a mixture of n-heptane and n-octane. A mixture containing 40 mole% n-heptane and 60 mole% n-octane is fed to the distillation column to produce one product containing 99 mole% n-octane and another containing 5 mol% n-octane. The feed enters the column at its dew point. Data are provided in the figure below. Determine the minimum reflux ratio (L_0/D).



Numbers correspond to IFF (scratch-off form).

16) The q-line will be:
a) Outside of 90° b) In-between horizontal and vertical c) Horizontal d) Vertical

17) Will the q-line intersect the $x = y$ line?
a) Yes b) No

18) Will the q-line intersect the equilibrium line?
a) Yes b) No

Calculate the R_{min} and look at the next page **if you get stuck and need a hint or to confirm your answer.**

19) Which equation will you need to determine R_{min}?
a) $R = \frac{L_n}{D}$ b) $y_{m+1} = \frac{L_m}{V_{m+1}} x_m - \frac{W x_W}{V_{m+1}}$ c) $y = \frac{q}{q-1} x + \frac{x_F}{q-1}$ d) $y_{n+1} = \frac{R}{R+1} x + \frac{x_D}{R+1}$

There are 2 ways to solve this problem (A and B below):

A- 20) Determine the y-intercept:
a) 0.22 b) 0.77 c) 0.85 d) 0.98
e) -0.16

B- 21) Determine the slope of the line:
a) 0.22 b) 0.77 c) 0.85 d) 0.98 e) -0.16

22) What is approximately the minimum reflux ratio:
a) 0.22 b) 0.77 c) 1.8 d) 3.3 e) 4.5

Figure 4. Text of IF-AT in-class problem from week 13 with blank space removed. The IF-AT multiple-choice questions were in-line.

Table 2. Multiple-choice questions from the IF-AT problem for week 13 and the level of learning required to answer the question.

Question (all with multiple-choice answers)	Level of learning[28]	Question type
16) The q-line will be:	Remembering	Single comp.
17) Will the q-line intersect the ***x=y*** line?	Remembering	Single comp.
18) Will the q-line intersect the equilibrium line?	Understanding	Single comp.
19) Which equation will you need to determine $\boldsymbol{R_{min}}$?	Remembering	Single comp.
A- 20) Determine the y-intercept:	Applying	Scaffolded
B- 21) Determine the slope of the line:	Applying	Scaffolded
22) What is approximately the minimum reflux ratio:	Applying	Scaffolded

work through the problem, answer the multiple-choice question(s) that correspond with that part of the problem, and scratch the corresponding box on the IF-AT form. If the IF-AT form showed they were wrong, they were told to reattempt the solution until correct. If they could not understand why they were wrong, then the group should raise their hand for instructor or teaching assistant (TA) help. The students received immediate feedback as to whether their answer was correct and move on to the next question, or to spend more time on the current question. No points were given for attendance or effort and the IF-AT forms were not labeled with group numbers to keep their answers anonymous. Questions where the most wrong answers occurred (as indicated by multiple scratched boxes) were discussed in detail by the instructor in the next class.

Assessment

In the class following the IF-AT problem, a series of clicker questions were asked for feedback. Additionally, for week 5's problem, several anonymous short-answer feedback questions were asked as a minute paper on a half sheet of paper. The TA collected and compiled the answers to the following questions: 1) "What did you like about the set-up?" 2) "What would you have changed about the set-up?" and 3) "Any other comments about the sample problem we did last class:". Items mentioned by three or more students and more were listed as common suggestions/feedback. It should be noted that the clicker and survey responses were not graded and that students did not receive credit for completion.

DISCUSSION AND RESULTS

Question Completion

As the students worked through the evaporator problem in week 5, no broad issues came up for the first five questions as evidenced by the high number of groups only requiring one attempt to answer the questions correctly (Table 3). Question 6 was asked about by several groups and therefore, class was interrupted after 10 min or so to ensure students were up to this point. Students were then given about 5 min to work on part c and answer question 6-c. The class was then interrupted, and the solution was discussed. It was clear when reviewing the 21 IF-AT forms that question 6 was a sticking point since the majority of the 17 groups (81%) that got to problem 6 had to make multiple attempts in order to get the correct answer. This can also be seen by the high average number of attempts to correct in Figure 5. Three groups (14%) required all choices (A-E) to be scratched (Table 3). Question 6 required students to find the temperature of the steam entering the evaporator and then use steam tables to determine the steam quality. It was

Table 3. The number of attempts the students made in order to determine the correct answer during week 5. Attempts scored as "0" had a scratch for the incorrect answer and no other scratches.

		Number of attempts						
Question	Learning level	1	2	3	4	5	0	Total groups
1	Remembering	20		1				21
2	Remembering	21						21
3	Understanding	17	1			2	1	21
4	Applying	20	1					21
5	Understanding	16		2		2		20
6	Analyzing	3	3	3		3	5	17
7	Applying	13		2				15
8	Applying	12					2	14
9	Applying	10	2			1	1	14
10	Applying	9					4	13

expected that the students would have more difficulties with this question since it was a higher level of learning (analyze).

Additionally, question six was the first problem in which several groups (5 (24%)) did not scratch off the correct answer. (This is denoted by the "0" column meaning the group scratched incorrect answers off for the question but did not scratch off the correct answer.) The lack of correct answer

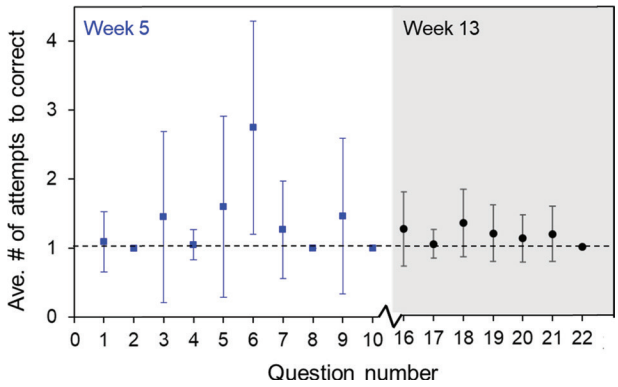


Figure 5. The average number of attempts made before obtaining the correct answer and standard deviation for each problem in weeks 5 and 13. The dashed line represents answering the question on the first attempt.

scratches could have resulted from: 1) the instructor providing the answer to the class before the group reached the correct answer and so, they did not scratch it, 2) group frustration with the problem and after several wrong answers that led to giving up on the question, or 3) lack of time. Three (14%) of the five groups continued answering questions on the IF-AT form, so, likely, in the instructor providing the correct answer, those groups just did not complete the IF-AT.

Besides the two groups mentioned above, two other groups (total of 19%) no longer attempted to scratch off any answers on the IF-AT after problem 6. Since after providing the answer for question 6 the groups continued to work on the problem, groups should have been able to work through at least 1, if not the rest, of the questions. Scratching an incorrect answer did not seem to discourage students since 71% of groups had incorrect answers and only two (10%) of those groups stopped scratching after an incorrect answer on problem 6. Therefore, it is assumed that the students became disengaged due to the difficulty of question 6. During the last 10 minutes of class, questions 7 through 10 were worked through by the instructor. For question 10, where four groups did not scratch the correct answer, but made incorrect scratches, lack of time was likely the issue. In total, 13 groups (62%) completed the problem during class based on the IF-AT responses.

For week 13's problem, 21 groups of 23 (91%) worked through the required questions and 16 groups (70%) completed all optional questions as well (Table 4). For this second problem, there were fewer questions that had an incorrect answer scratched without a correct answer scratched (as noted by the "0" columns in Tables 3 and 4), which was attributed to clarifying the directions that you scratch until get the correct answer. The problem ran smoothly in-class and no interruptions were made since no major issues arose. After about 15 min, class was stopped, and the problem was worked through.

Table 4. The number of attempts the students made in order to determine the correct answer during week 13. Attempts scored as "0" had a scratch for the incorrect answer and no other scratches.

		Number of attempts						
Question	**Learning level**	1	2	3	4	5	0	**Total groups**
16	Remembering	18	4	1				23
17	Remembering	22	1					23
18	Understanding	13	7				1	21
19	Remembering	16	4					20
20	Applying	14	2					16
21	Applying	13	3					16
22	Applying	16						16

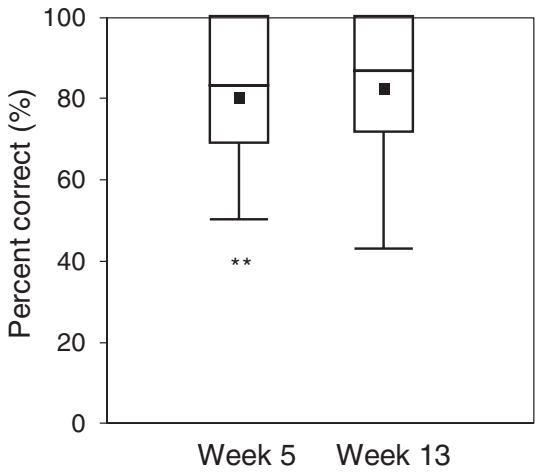


Figure 6. Comparison of the percent correct of attempted questions for the IF-AT problems. The filled squares represent the mean scores. n=21 in week 5 and n=23 in week 13. Outliers are indicated by an asterisk.

Attempts and Score Discussion

Even though week 13 had a higher percent of lower-order questions, when comparing the scores for the two problems (Figure 6), no significant differences were noted indicating that the problems were of similar difficulty for the students. (Note that Figure 6 shows the data for only the questions that were attempted by a group as to not skew the data for questions that groups may have ran out of time for.) However, when comparing the number of attempts it took for groups to get the correct answer (Figure 5), for week 5, the standard deviation was higher on questions 3, 5, 6, 7, and 9. For week 13, the standard deviation was relatively consistent across all questions.

Looking deeper into the subject material of the questions with higher standard deviations for week 5, the common thread is using steam tables to gather data and make calculations. Additionally, the same seven groups (33%) answered incorrectly for multiple questions, as shown by their high standard deviation of average number of attempts to get the correct answer in Figure 7. Two groups in particular struggled the most. Since it was the same groups missing the steam table-based problems, it would have been helpful to know the group numbers so that the instructor could follow up with additional information. Another option would be to assign a homework problem specific to that topic for the entire class to get more practice. As with the question standard deviation in week 13 (Figure 5), the average number of attempts to correct for groups was less as well (Figure 7).

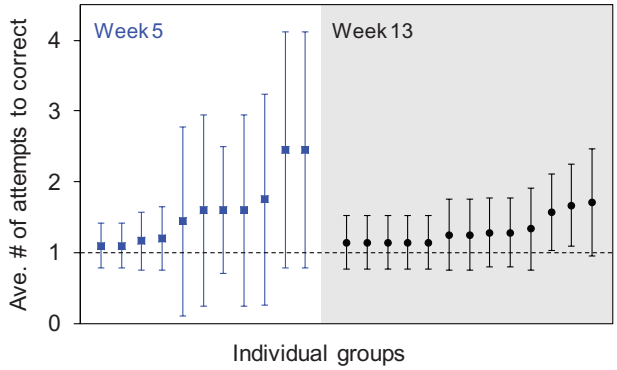


Figure 7. The number of attempts required per group for all attempted questions in weeks 5 and 13. Not shown in both weeks are the 10 groups (~45%) who answered all answers correctly resulting in a "1" score with no standard deviation. Note, the scores do not include questions that they scratched an incorrect answer, but not a correct answer ("0" scores) and the order of groups in week 5 is not necessarily the same as week 13.

Student Learning

A student learning comparison could be made between a course taught in 2015 and this one taught in 2017 since in both years a clicker quiz was given on the topic of distillation, week 13's IF-AT problem topic. The clicker quiz was set-up in a game show format entitled "Are you smarter than a sophomore?–distillation edition" and included approximately 12 multiple-choice questions (mainly obtained from the CU LearnChemE ConcepTests inventory at www.learncheme.com) that the students had to use their clickers to answer. The students were not in their base groups for the quiz and were allowed to discuss the question with students seated nearby before selecting their answer. Figure 8 shows a box and whiskers plot comparing the scores from the quizzes for each year and shows there was no statistically significant difference (p-value of 0.75 with an α of 0.05) in quiz scores when the IF-AT forms were used. However, there was less variability in 2017, indicating that working through the problem in groups using the IF-AT forms may have helped the students having difficulties with distillation understand the problem better.

Student Feedback

In the class period after the IF-AT problem was worked, a series of multiple-choice questions were asked to get student feedback using clickers. For the week 5 problem, 90-92 answers were received for each clicker question and for week 13, 78 responses were received. Students were told to only answer if they took part in the in-class problem, but some students present for the problem may not have attended the next class.

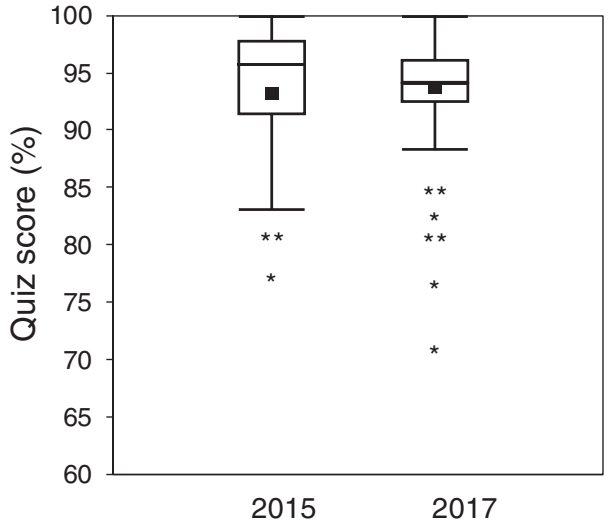


Figure 8. Comparison of the quiz scores for a clicker based distillation quiz in year 2015 (no IF-AT problem) and 2017. n=84 in 2015 and n=93 in 2017. Outliers are indicated by an asterisk.

The responses from both in-class problems showed an overwhelming positive response to working out the problem in-class with over 60% of the students responding "Really liked" or "Liked" (Figure 9). Only 11% of students for both weeks responded "Disliked" or "Really disliked." When asked about using the IF-AT forms, approximately 34% of students were positive for both weeks, while 39% in week 5 and 49% in week 13 were "Neutral." In week 5, 28% of students responded that they "Disliked" or "Really Disliked" using the IF-AT forms, but the percentage dropped to 17% for

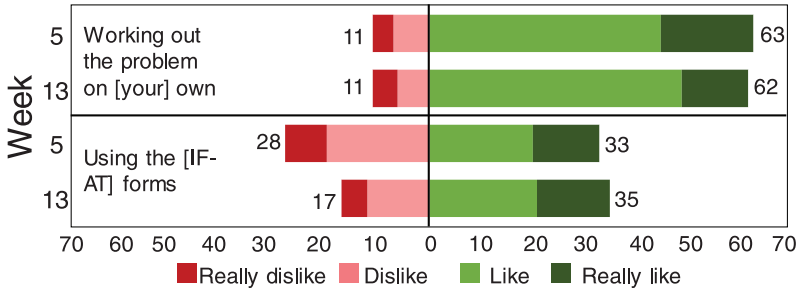


Figure 9. Clicker feedback shown as percent from the class period following a problem using the IF-AT forms.

Table 5. Student responses (%) as to whether they would want to do more IF-AT based problems.

	Week 5	Week 13
Yes, the more the better!	27	26
Yes, but individual/work with those around me	55	41
Doesn't matter to me	10	20
No, it was too difficult when I got stuck	2	6
No, I prefer to watch you work it out	5	7

week 13. The reduction of negative feedback is likely due to inserting the multiple-choice questions in-line (week 13) versus as a separate page (week 5), previous exposure to the forms, and better oral directions. When asked if they would like to do problems like this [using IF-AT forms] again, students overwhelming responded positively (Table 5).

In the short-answer survey after the week 5 IF-AT problem, students were asked what they liked about the setup and the common responses were (number of respondents):

- How it walked you through a complicated problem step-by-step (30%)
- Working on a problem in-class/good practice (19%)
- Working in groups (15%)
- The scratch-offs [IF-AT forms] (9%)

The common student responses for what they did not like were:

- Questions/instructions were unclear (33%)
- Not enough time/felt rushed (22%)
- Not working in groups (10%)
- Pick their own groups (7%)
- Not using scratch-offs [IF-AT forms] (7%)

The most common open-ended "Other comments" was that they would like to do this again (13%).

The feedback from the week 5 survey was used to improve the week 13 IF-AT problem. To reduce confusion, the multiple-choice questions were placed in-line with the problem. That way students did not have to flip between pages and knew exactly when they needed to respond to a question. Additionally, a shorter problem was selected and ample time was allowed to finish the problem. This resulted in all of the groups completing the week 13 problem in-class. A small fraction of students preferred to not use the scratch-offs, but it was clarified that the problem could be completed without using the IF-AT form during week 13 and that the IF-AT form was there to check answers and make sure the students were on track.

Instructor Feedback

Comparing to previous experiences of in-class problems without the IF-AT forms, the forms made in-class problems significantly smoother and less chaotic. Previously, fast working students would want to go through the solution before most the class was ready leading to many questions. Also, when students would get a wrong answer, they did not realize it and would continue working on the problem or compare with a different group then ask the instructor or TA which answer was correct. The IF-AT form allowed the students to check their own answer and then try again before asking for help. Additionally, the students could discuss solutions with other groups that correctly answered the question to find where their mistake occurred. This allowed for peer-to-peer learning, which results in greater knowledge for both students.[9, 29]

Students also benefited from in-class time to work with their group. As previously mentioned, the student groups for the IF-AT problems were the same as the semester project groups. Not one group requested a group member to leave and peer evaluation scores were, on average, higher than in other classes the instructor has taught. This could be due to the in-class problems allowing a team member to participate and discuss what they know about a topic leading to more respect their teammates. A final benefit to the IF-AT forms were the audible cheers when students scratch off the correct answer which happened both weeks.

Additional Instructor Workload

In terms of instructor workload, there is an increase due to writing the multiple-choice questions and ensuring that the correct answer aligns with the IF-AT correct answer. With a multiple part problem, like from week 5 (Figures 2 and 3), the work was minimal since the answers for each of the section became the multiple-choice question. For week 13 (Figure 4), slightly more thought was required, but after determining the important concepts from the problem, the time required was not significant (less than 1 h for each problem). Reviewing the IF-AT forms took less than 15 min to determine where the majority errors occurred and discussing the errors in the following class required minimal prep work and benefited the students.

RECOMMENDATIONS

Based on the findings of the student feedback and thoughts of the instructor, several recommendations were noted to implementing IF-AT forms for in-class work out problems:

- It is recommended to start with a short exposure to the IF-AT forms through a multiple-choice quiz or perhaps a “things you should know” problem set early in the semester. Then, the exercises could become increasingly more rigorous and higher-order throughout the semester.

- Have the multiple-choice questions in-line so that the students know where to stop and check their solutions.
- Students were placed in groups of four, which would be the recommended minimum number due to the discussion generated while working through the problem.
- Complete an in-class example problem on the topic covered in the IF-AT problem so the IF-AT problem is not the first time the students see a problem of that nature.
- The IF-AT forms should be collected and reviewed at the end of a class to determine where students were having difficulties in the problem (as indicated by multiple scratches for a question) and those questions reviewed in the following class.

CONCLUSIONS

Based on student feedback and instructor experience, using IF-AT forms to solve work out problems in-class with large student numbers was a success and will be used in future classes. By having the students check their answers as they worked through a problem dramatically reduced the amount of questions asked of the teaching assistant and instructor and seemingly led to less frustration of students in a large class where wait times for an instructor could be long. Additionally, the IF-AT forms allowed the instructor to determine where the students had the most difficulties and address them in the following class. The students were engaged in the problems, self-paced through the exercises, and the feedback was overwhelming positive for using the IF-AT forms for problems students work out in-class.

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