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Mini-Lab Activities to Stimulate Students' Conceptual Learning

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Abstract

Courses and labs commonly reinforce learning through activities that explore applications, but it remains vital to promote deeper conceptual understanding. Also, with increasing class sizes, it has become more difficult to monitor the conceptual understanding of individual students. To address these issues, we have developed a framework for implementing short and individualized activities that focus on bridging the gap in conceptual understanding of a key topic. The framework involves administering a demonstration in a fun and exciting way while connecting independent concepts first introduced in the classroom. Specifically, we designed a demonstration for a mechanics and materials lab to aid in understanding a material's behavior during loading and failure and how temperature can affect a material's response. The demonstration requires students to think critically and draw connections in the interplay among mechanical loading, material behavior, and failure behavior, as opposed to simply assuming that failure behavior is always correlated with the material type itself. The demonstration consists of two mini activities: in the first activity students break chalk and observe failure surfaces expected for a brittle material and in the second activity a polymer is cooled with liquid nitrogen, a torsional load is applied until failure, and the failure surface is compared to that of chalk. Students' understanding gained from this demonstration can easily be applied to other topics involving failure behavior in the course. These types of short demonstrations could be used in any lab or even as a quick way to grasp concepts during classroom lectures. Students were split into a study group (n=155) who attended the activity and a control group (n=162) who did not attend. Three assessments were conducted: an initial impression survey, a quiz on the concepts targeted, and a final extensive feedback survey. Surveys show that students had an overwhelmingly positive attitude toward the activity with perceived improvements in their learning. The study group's performance in the quiz was found to be statistically significantly better using a one-tailed t-test with a significance level of $\alpha=0.05$, $t(315) = 3.428$, $p<.001$. A second demonstration using the established framework was added in the second run of the study and focused on the connection between the intrinsic coefficient of thermal expansion and the interatomic energy potentials of a pair of bonded materials. The preliminary results of the second run show comparable results for students' initial impressions. The results demonstrate that the framework developed for implementing short, low-cost, and engaging demonstrations had a positive impact on student's performance and learning.

Introduction

Classroom demonstrations are a common tool used to convey concepts in challenging subjects. They help reinforce and stimulate students' learning [1-4] as well as increase their engagement [2, 5]. Engaging students in an interactive demonstration can aid in establishing an active learning environment, which has been shown to have many benefits such as increased performance [6]; development of independent learning skills, critical thinking, and problem-solving skills [7]; and increased equity in higher education [8]. Indeed, greater enjoyment and a positive impact on learning can be achieved by adding demonstrations [4, 5]. While teaching a laboratory course in mechanics of materials, our instructors have found that students often exhibit a lack of understanding or have misconceptions regarding concepts that our experiments had targeted. Additionally, experiments can often be problematic when the results are not completely aligned with what they learned in the course, which can contribute to a lack of conceptual understanding and confusion about the underlying theory. To bridge the gap between theory and experiments and combat misconceptions, we proposed to introduce short demonstrations/activities that can be implemented with typical experiments. The goal of these demonstrations is to increase student engagement, enhance learning, and increase the retention of concepts. These demonstrations can also be used as a tool to enhance critical thinking skills.

When designing the demonstrations, we surveyed the literature for best practice guidelines [9-11]. Milner et al. discussed the importance of observing a demonstration correctly to result in conceptual understanding. For instance, a lack of learning/understanding can occur when experiments do not go as expected. An essential element in an effective demonstration is in allowing the students to predict the outcome [2, 12]. In addition to implementing this approach, we also strived to review the underlying physics and, where possible, include a hands-on element to actively engage the students and make the demonstration more interactive. Other elements we implemented included having the demonstrations be short, attention-grabbing, and performed in small groups. Using this framework, we developed a short demonstration as a case study to evaluate the effectiveness of this approach.

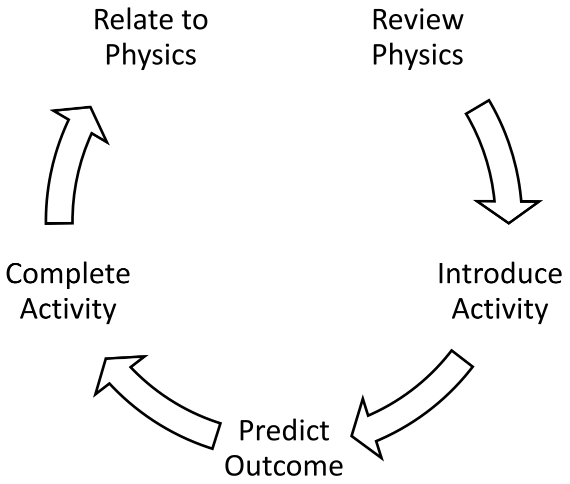


Figure 1 Proposed framework for implementation of demonstrations.

Proposed Demonstration

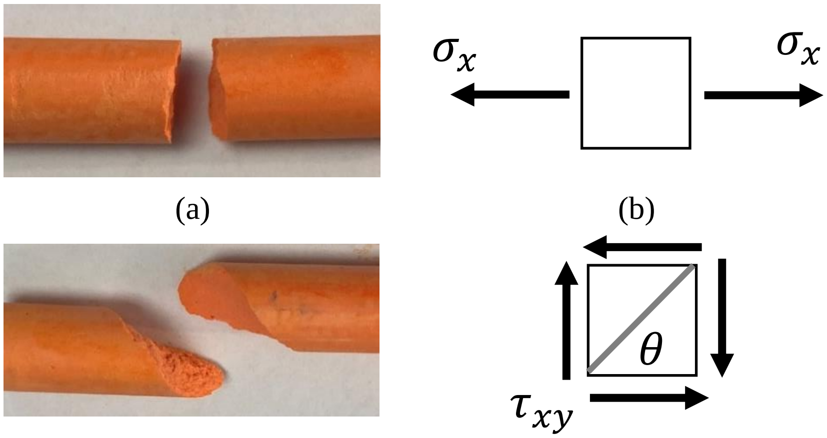
We found that students often displayed a lack of understanding of failure modes due largely to an emphasis on ductile material behavior under loading in our courses. Many students had a disconnect between how a material behaves under loading and how the material fails. In a lab that involves loading a material until failure, identifying the failure type is crucial. Additionally, by examining the failure surface students can understand why a material behaved in a certain way if it deformed unexpectedly during loading. These observations motivated the development of our first demonstration which focused on brittle failure.

A common misconception that students have is that failure of brittle materials always produces a flat surface. This is, however, not the case in torsion. Indeed, in torsion, it is a ductile material that is expected to fail with a flat surface. More accurately, one must relate loading and material behavior to predict how the failure surface will appear. Students are typically introduced to these concepts separately, which may be why there is some disconnect in relating them. We hypothesized that introducing a small activity that connects concepts that students already know in an interactive and engaging manner would increase intuition, such that students can make better predictions of failure behavior going forward in their studies/careers.

An established experiment in a material testing laboratory course aiming to exhibit brittle material failure is the three-point bending test using chalk as a test specimen. Since chalk is brittle, easily broken, and cheap, it is indeed an excellent material to use. Based on Crouch *et al.* [2] an essential element in demonstrations is that students predict the result to produce greater understanding in a shorter time frame. Using this approach, we designed the demonstration to include a brief introduction of the concepts to refresh students and then asked them to predict the fracture surface after a load is applied to the piece of chalk. Within the demonstration, an activity is introduced for students to validate their assumptions. To make the activities more personalized, students were given a piece of chalk and applied the load themselves. This approach gave a more visceral element to the activity, making it a more memorable experience. Testing their predictions, the students were able to directly and immediately verify their understanding or challenge what they understood. Afterward, we gave a brief explanation of why the chalk failed as it did while referring to the concepts that we had introduced earlier.

Since the concept of brittle failure was introduced in the first activity, we decided that connecting this concept to polymers would help reinforce their understanding and see for themselves some (likely) unexpected behavior. Indeed, polymers are typically expected to behave in a ductile fashion. However, polymer behavior depends on the temperature at which it is tested relative to its glass transition temperature. If cooled well below their glass transition temperature, polymers behave in a brittle manner. Using liquid nitrogen, we cooled very flexible polymer cylinders well below their glass transition temperature and then applied a torque load in a manner similar to that applied to chalk. The polymer failed in the same manner as chalk and regained its ductility once it had warmed up.

The total duration of the demonstration was on average 10 minutes. Within that time, we reviewed concepts of the relationship between loading and stress transformation, introduced failure theory for brittle materials, predicted the outcome of loading a piece of chalk, validated or challenged students' understanding of brittle failure with the first activity, reviewed students' understanding of the glass transition temperature, and then finally loaded a cold and brittle polymer cylinder to failure. Our hypothesis was that the activity would engage students and affect their learning positively. All students were introduced to the concepts mentioned in the demonstration by the traditional method of a passive lecture. Approximately half the students then attended the activity the following week in groups of 10 or fewer.

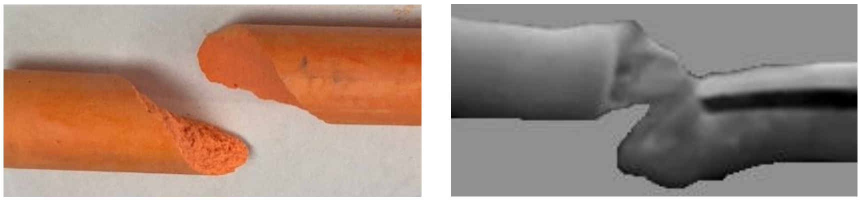


(a) (b)

(c) (d)

Figure 2 Brittle failure of chalk due to tension (a) and a schematic of the corresponding loading (b). Brittle failure of chalk due to torsion (c), and a schematic of the corresponding loading (d).

To evaluate the effectiveness of the activities for this study, we performed three assessments. The first assessment evaluated students' initial perceptions. Immediately after they attended the demonstration, students were asked to provide at least three adjectives to describe their experience. The purpose of this evaluation was to determine what the main takeaways were for the students, as a favorable first impression will more likely make the activity more memorable. The second assessment was a concept quiz that consisted of 12 multiple-choice questions. The questions fell into three categories: (1) questions related to loading and stress transformation, (2) questions related to brittle failure behavior, and (3) questions related to the glass transition temperature; one question was considered as falling into both the brittle failure behavior and the glass transition temperature categories. With this assessment, we looked at how students have performed in the independent concept categories as well as in questions where concepts overlap. The last assessment was a survey in which students shared their opinions on their experiences attending the demonstration, which was distributed the week following attending the demonstration. In this survey, students expressed their thoughts on the demonstration to evaluate and continually improve the activities.



(a) (b)

Figure 3 Comparison of failure surfaces of brittle failure due to torsion of the chalk (a) and the polymer (b).

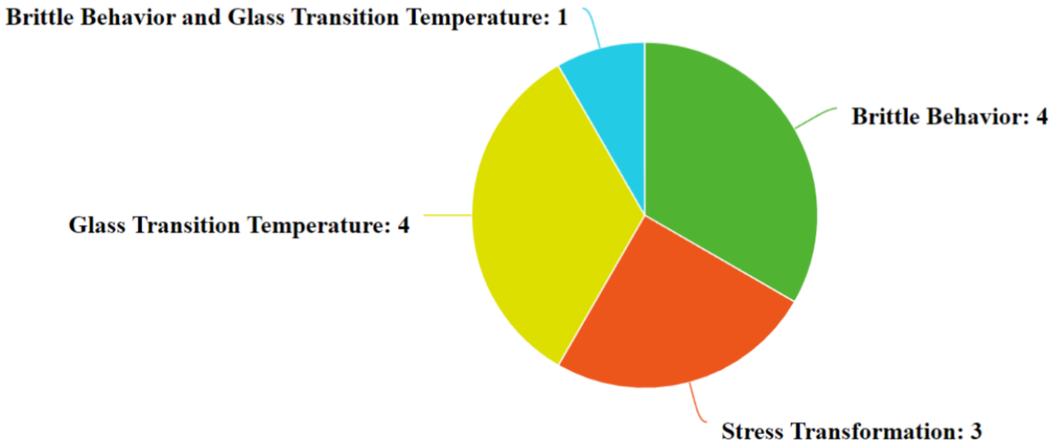


Figure 4 Breakdown of questions categories in the concept quiz.

Results

For the first assessment, students were asked to provide at least three adjectives they would use to describe the activity. Adjectives that belonged to the same theme were grouped, and any words that did not repeat were ignored. Table 1 shows the results of the students' initial thoughts on the demonstration which are overwhelmingly positive. Students generally found the activity enjoyable, considered it engaging, and reported a perceived benefit to their understanding.

Table 1 Word frequency for initial impressions of the activity (n=155).

Word	Frequency	Word Cloud
Fun	94	
Interesting	70	
Engaging	60	
Informative	50	
Helpful	35	
Exciting	22	
Cool	22	
Hands-on	21	
Educational	18	
Useful	13	
Intriguing	11	
Fast	10	
Visual	6	
Messy	5	

Based on the findings of the initial impressions survey we expected higher performance on this quiz from students who attended the activity than in the control group. A one-tailed t-test was conducted to ensure statistical significance with a significance level of 0.05. The 155 students that attended the activity (*M*=68%, *SD*=9%) compared to the 162 students in the control group

(*M*=61%, *SD*=12%) demonstrated significantly better scores on the quiz with t(315) = 3.428 and p<.001. We also subdivided the results based on the question category. Table 2 shows that the average score for the study group is significantly greater than the control group for questions in the brittle behavior and glass transition categories, while the stress transformation questions showed that there was no significant difference between the groups. The activities performed during the demonstration specifically targeted brittle behavior (with the breaking of the chalk) and the glass transition temperature (with the breaking of the polymer), while stress transformation was merely a passive part of the demonstration.

Table 2 Results of the one-tailed t-test (α=0.05) for the quiz total and the question categories.

	Total		**Stress Transformation**		**Brittle Behavior**		**Glass Transition Temperature**	
	Study	*Control*	*Study*	*Control*	*Study*	*Control*	*Study*	*Control*
Mean	2.04	1.82	0.48	0.46	0.88	0.72	0.79	0.71
SD	0.27	0.35	0.05	0.05	0.07	0.08	0.08	0.09
***t*-value**	3.428		0.596		5.243		2.332	
***p*-value**	<.001		0.276		<.001		0.01	

Finally, a reflection survey was conducted to obtain more in-depth feedback from the students. The first part of the survey consisted of six Likert-scale statements to gain a better understanding of how students felt about demonstrations, as shown in Fig. 5. This section was administered to all students regardless of whether they attended the activity. Out of the 213 students who participated in the survey, 125 attended the demonstration. The statements asked how much students agree that (1) it is difficult to link the physical system with the theoretical understanding of the material, (2) it is difficult to use Mohr's Circle/stress transformation equations to predict the failure surface, (3) having *physical* demonstrations helps them understand the topic better, (4) having demonstrations helps me understand the topic better, (5) physical demonstrations are a waste of time, and (6) they prefer individualized to class demonstrations. A two-tailed t-test on the student responses showed that there was no significant difference between their responses. Both sets of participants felt strongly that demonstrations are not a waste of time and that demonstrations help them understand topics better. Participants were neutral about a preference for individualized over class demonstrations. Additionally, they were more inclined to disagree that it was difficult to link the theory with the physical phenomena.

The second part of the survey consisted of four short-answer questions asking the students who attended the activities about their experience. The questions asked the students (1) what they liked about the activities, (2) what they disliked about the activities, (3) how they feel about attending additional similar activities, and (4) suggestions for improvement. To analyze the responses, we identified common themes and categorized how often a response falls within each theme. Each response can fall into multiple themes.

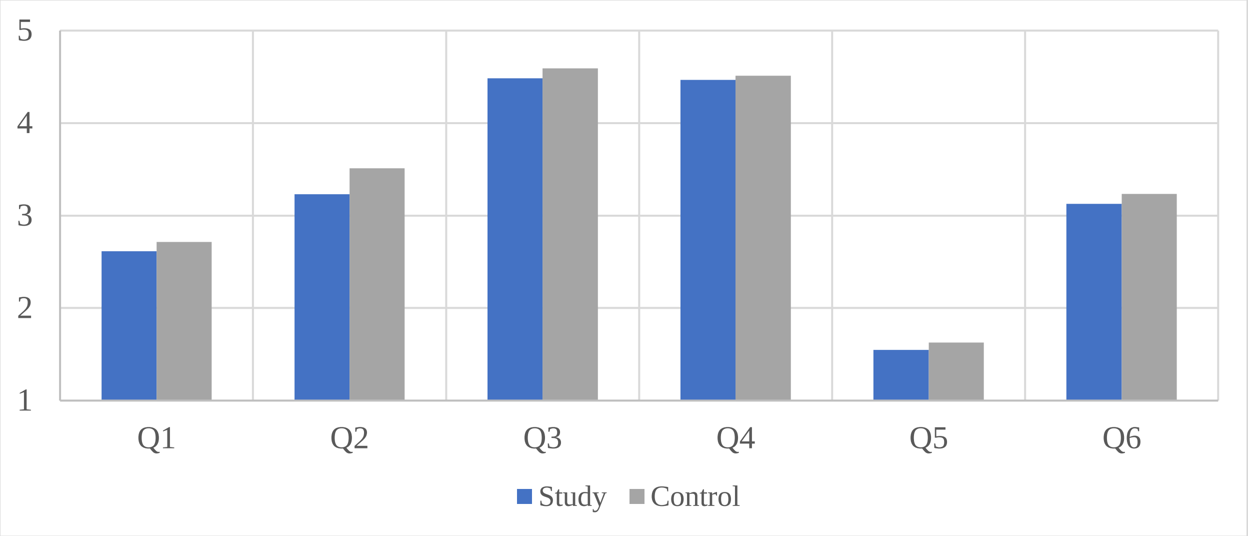


Figure 5 Average results of the six Likert scale statements on the feedback survey (n=125 for study, n=86 for control) (1=Strongly Disagree, 5=Strongly Agree).

Table 3 identifies the themes found for the first and second reflection question. Seven themes were identified for the first question, with the most frequent theme of “Educational.” Responses that referred to increased understanding, a feeling of enhanced learning, or reinforcement of their understanding are examples of responses included under the “Educational” theme. The second most frequent theme is “Entertaining” which includes references to fun, interest, and enjoyment. The next most frequent theme is “Connect to class or the real world” which included responses that referred to relating the concepts to daily activities, to the classroom, to theory, or to real-world applications. The next theme, “Visual,” included any references to seeing the concept and being able to verify the theory visually. The last two themes, “Engaging” and “Hands-on/Involved” had an equivalent number of responses. “Engaging” included responses that referred to their engagement and references to the interactive aspect of the activity. The theme “Hands-on/Involved” included responses where students elaborated on the hands-on aspect of the activity, as well as its being personalized. Additionally, there were several references to the small group size and the swiftness of the activity. A response can fall under multiple themes. A total of 113 students' responses were analyzed for the first reflection question referring to what students liked about the activity, and 55 responses were analyzed for the second reflection question about what students disliked. Some sample responses are as follows.

- “I enjoyed the small group and short demonstration that helped to reiterate materials learned in class.”
- “It did a very good job at explaining exactly what was happening with some of the things we have been learning in [the companion lecture course]. It helped me draw connections to real-world and theoretical ideas.”
- “It demonstrated a topic that can be hard to understand, which makes it easier to remember.”
- “It was fascinating and illustrated the concepts in a way which was memorable and easily comprehensible.”
- “I enjoyed seeing a physical demonstration and being able to interact as the demo was being given. It was extremely engaging and broke down concepts to a level of understanding that was comfortable and organized.”

Table 3 Frequency of themes of the responses correlating to what students liked about the activity (n=113) and what they disliked (n=55).

Frequency of themes about what students liked about activity		**Frequency of themes about what students disliked about activity**	
Theme	*Frequency*	*Theme*	*Frequency*
Educational	42	**Cleaning/ Mess**	13
Entertaining	34	**Extra time**	12
Connect to class/real world	30	**Rushed**	7
Visual	25	**Quiz**	7
Engaging	22	**Unprepared**	3
Hands-on/Involved	22		

For the second question asking students what they disliked about the activity, most opted to omit an answer or stated that there was nothing they disliked. The results were consolidated under common themes and the number of responses in each theme reported in Table 3. The main themes of the responses related to logistical issues such as an additional wait time or that they spent additional time beyond the expected. Due to time constraints, some students felt that the activity was rushed and could use additional explanation. The mess created by breaking the chalk and shattering a polymer tube was the most common nuisance. Some comments referred to study-specific concerns such as the administering of a quiz or the lack of preparedness before the activity. A minority of responses did not fall into one of the common themes. Several responses provided useful information for further development of future demonstrations.

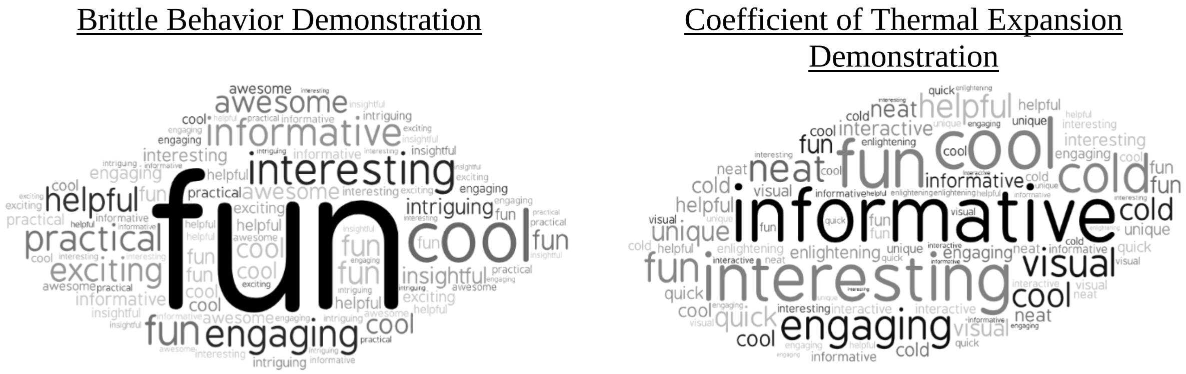
The third survey question asked students how they would feel about additional demonstrations. More than 85% of respondents were interested in demonstrations with a similar format to the one they attended. A short, engaging, and hands-on demonstration were the main aspects of the activity that the students praised, and they wanted to attend other activities that follow that format. The final reflection question asked for students' suggestions to improve the activity. Their responses have contributed to the current activity's continuous improvement for the next round of implementation.

The run of the study conducted in the fall semester of 2022 included a second demonstration. There were 48 participants from 3 sections. This demonstration focused on the interpretation of the intrinsic coefficient of thermal expansion (CTE) and its relationship to the asymmetry of interatomic energy potentials for two dissimilar materials bonded together. The demonstration was based on the experiment setup presented in [13]. Three components made up of two dissimilar materials bonded together were cooled by liquid nitrogen. All had a polycarbonate sheet attached to a thin plate of copper, aluminum, or stainless steel, as presented in Fig. 6-(a). The difference between each of these materials' coefficient of thermal expansion to that of the polymer causes each one to deflect at a different rate (i.e., per temperature change), thereby inducing the curvature as depicted in Fig. 6-(b). The activity was intended to help students relate the CTE with the interatomic energy potentials, as depicted in Fig. 6-(c). The high CTE of polymers is due to weak interatomic forces. An example is presented in Fig. 6-(c) as curve C. Metals have a deeper bonding energy well that is more symmetric, thus causing the CTE value to be lower.

(a) (b) (c)

Figure 6 The difference between the bonded materials of (a) polycarbonate sheet with a thin plate of copper, aluminum, or stainless steel, (b) varying degrees of deflection upon cooling. (c) The relation between the CTE and the interatomic energy potentials is represented in.

The CTE demonstration followed the same general flow of the first demonstration as presented in Fig. 1. This activity had the same assessments, namely an initial impression survey, a concept quiz, and a reflection survey. Fig. 7 depicts the word cloud representation for the initial impressions for both demonstrations, which shows similarities to that presented in Table 1. The data for the quiz and reflection survey is yet to be processed.



(a) (b)

Figure 7 Word Cloud representation of initial impressions (a) Brittle behavior, (n=155), and (b) second run of the study, CTE, (n=48).

Discussion

The demonstrations were beneficial to the students by engaging them and increasing their performance and conceptual understanding. The initial impressions and the reflection questions show that students have an overwhelmingly positive attitude toward the activities and the perceived benefit. We should note that focusing solely on students' perceptions alone can inadvertently promote inferior methods. For instance, Deslauriers et al. [14] reported that active classrooms learned more, despite their perception of learning being worse than in traditional classrooms. The quiz, as shown in Table 2, shows that the average was about 7% greater for the students who attended the activity than those who only attended the traditional lecture. Additionally, the quiz indicated a greater increase in the students' understanding of brittle behavior and the glass transition temperature, with a more significant increase in questions related to brittle behavior. The passive aspect of the demonstration, stress transformation, showed no difference in performance between the study and control groups. Moreover, comparing the two mini-activities in the demonstration, the one on brittle behavior involved a hands-on exercise while the other involved an instructor-led demonstration on the glass transition temperature due to liquid nitrogen. Since the performance of students was greater for the hands-on activity, this may indicate that students gain more appreciation for increased knowledge when they are personally involved in their learning, as has been shown by Morgan *et al.* [4] and Miller *et al.* [12]. Furthermore, students mentioned that the interactive nature and their involvement in the activity contributed to their satisfaction and engagement in the activity, shown in Tables 1 and 3. By contrast, Self *et al.* [3] concluded that there was no significant difference between demonstrations that included hands-on aspects to ones that did not. Fig. 5 shows that students did not indicate a preference for individualized versus class demonstration. In addition to increased performance, our goal was to engage students' interest in their learning; therefore, including an interactive aspect can have other benefits. Accordingly, it may be important to consider including an interactive element in future demonstrations. Students' responses in the reflection survey indicate that they are willing to participate in additional demonstrations that follow the same format (short, engaging, and hands-on). While it may be difficult to always involve every student directly in demonstrations, finding an alternative that includes an interactive element is favorable to their engagement and learning.

Conclusions

In this study, we propose a framework to address gaps in understanding between independent concepts. The framework includes short demonstrations with interactive activities to improve students' conceptual understanding. Having short and engaging demonstrations can keep the students focused on their learning while gaining an intuitive feel for the concepts. The two metrics determining the design of the framework for the demonstrations are student satisfaction and performance. To evaluate these metrics, we implemented three assessment methods: an initial impression survey, a concept quiz, and a reflection survey. The quiz results show that students who attended the activity had a statistically significantly increased performance with $t(315) = 3.428$ and $p < .001$. The initial impression survey and reflection questions indicate that students enjoyed the activity and had a positive perception of their learning, increasing students' confidence in their understanding. The preliminary results of the second run of the study, the CTE demonstration, have shown comparable results regarding students' initial impressions. These results are very promising regarding the potential of using the established framework, which can be used to develop and conduct additional demonstrations to bridge conceptual gaps, thereby giving students the tools to better understand and apply what they learned in their future studies and careers.

Acknowledgment

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