2006-903: TEACHING CONCEPTS ON SOFTENING: OBSERVATIONS FROM ACTIVE VERSUS PASSIVE INSTRUCTION IN AN UNDERGRADUATE AND A GRADUATE LEVEL COURSE

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Teaching concepts on softening: Observations from active versus passive instruction in an undergraduate and a graduate level course

Introduction

Currently, engineering course content is a delicate balance between theory, problem-based learning, and hands-on experience. Controversy continues to exist regarding the merits of teaching mostly theory as opposed to incorporating significant amounts of problem-based and hands on strategies. However, most instructors concede that changes to traditional lecture-based courses are required to appeal to a student population with a wide variety of learning styles. The different ways that students receive and process information have been described in a variety of learning style models. In an effort to increase retention of engineering students and to appeal to a broader array of students, many engineering curriculums are being designed to address these models by incorporating active instructional methods.

This manuscript summarizes the experience of implementing active instructional techniques (including collaborative learning) in two courses being taught in the Department of Civil Engineering at the University of Toledo, an undergraduate water treatment course and a graduate level environmental chemistry course. Modifications to teaching strategies were made in an effort to improve student learning of and attitudes toward applied aquatic chemistry, specifically precipitative softening. In addition, the instructors were interested in determining student response toward active learning by comparing the experience in a graduate and an undergraduate course. Finally, instructors were interested in determining if learning outcomes of students involved in active learning would be markedly improved after only one class period as compared to students who were taught the same basic information in a passive lecture. Classroom assessment techniques included a background knowledge probe (pre-assessment), teacher designed feedback forms (post-assessment), teacher observation, and student performance on subsequent exams.

Background

Precipitative softening is used by many water treatment facilities in the United States to address hard water issues, which can result in clogged water transmission lines, shortened life of heaters and boilers, and poor lathering of water. Hard water is caused by an abundance of minerals in source waters, specifically polyvalent cations such as calcium (Ca) and Magnesium (Mg). Hard water is the most common water quality problem reported by US consumers, and it is typically attributed to ground water sources with high mineral content [1]. In the Midwest, water softening is a locally relevant issue since many of us live in individual homes and communities with groundwater sources that require softening. This concept is typically taught in undergraduate courses that focus on water supply and treatment as well as graduate courses that focus on applied environmental chemistry. Many undergraduates in civil engineering departments express both apprehension and discomfort with learning principles of chemistry. It was anticipated that incorporating active learning techniques would result in improved learning outcomes for students in both the graduate and undergraduate courses.

Although there has been an emphasis on the incorporation of *active learning* in engineering courses, a precise definition of *active learning* does not exist. Most researchers agree that *active learning* involves student activity and engagement in the learning process in contrast to passively receiving information. In short, *active learning* involves students in doing things and thinking about what they are doing[2]. Although the qualitative benefits of active learning are widely accepted, quantitative data that suggests that active learning positively impacts learning outcomes is difficult to produce. Learning outcomes typically cover a broad range including factual knowledge, student attitudes, and retention[3]. To further complicate matters, active learning itself includes a wide array of instructional techniques such as hands-on experience, interactive visually-oriented multi media, and group learning processes[4].

Most college students expect to be evaluated on their individual work and envision limited interaction among students in the classroom. Since engineers typically work in teams during their professional careers, it is common for engineering courses to incorporate *collaborative learning*. In addition, the national organization for accreditation of engineering curriculums (ABET) requires a demonstrated ability to work in multi-disciplinary teams. Any activity that involves two or more students working together may be considered *collaborative learning*[5]. This style emphasizes learning through student interactions as opposed to learning as a solitary activity. In this work, collaboration was used as an active learning tool since students in designated as "active" were required to work in groups.

In order to determine if changes in instruction techniques to adapt to active learners, faculty must implement classroom assessment and evaluation techniques. Assessment is a process of developing hypotheses to solve problems related to learning. In order to test the hypotheses, data must be collected. The data collection method is guided by the selected hypotheses. Although the importance of assessment is well-documented, it is extremely difficult to design assessment methods that test the efficacy of active learning techniques[6]. A background knowledge assessment is often used to provide a basis for student's existing knowledge and preconceptions. This type of pre-assessment is required to assess student learning since students' concepts will likely develop and change with instruction. Depending on the specific hypotheses, post-assessment may include observation, measurements, experiments, and surveys.

Research on active learning, collaborative learning, and assessment is often based on long term studies performed over an academic semester or a period of years. Also, most studies focus on the assessment of undergraduate student performance in response to learning objectives. The original aspect of the present research is its focus on single instruction in one class period and its comparative analysis of teaching the same material in an undergraduate and graduate class.

Methods

Students involved in this study were members of either a requisite undergraduate water treatment course (n = 29 students) or a graduate level environmental chemistry course (n = 10 students) in fall semester of 2005. One faculty member was responsible for the undergraduate class, while the other faculty member instructed the graduate level class. Both courses were taught in the Department of Civil Engineering. Chemistry has traditionally presented problems to undergraduate students in our department who have received a broad education in civil engineering, including one semester of general chemistry, and are required to enroll in an undergraduate course focused on water treatment in their 3rd or 4th year. Until now, these students have not applied their knowledge in chemistry to address design problems, such as unit operations in water treatment. As a contrast, in our department we also offer a graduate level environmental chemistry course populated by students with a self-identified interest in chemistry and environmental engineering. In this study, we tested the effectiveness of two different teaching styles on student learning at the graduate and the undergraduate level.

Two broad learning objectives were identified for the instruction of the softening concept: (1) at the end of this lecture, the students should be able to describe to an intelligent high school student how to remove Ca hardness using precipitative softening; (2) students should demonstrate their interest in life-long learning of some of the key concepts of softening. It was anticipated that these learning objectives would be more likely to be achieved by implementing active instructional methods in both the undergraduate and graduate level class.

Assessment for this research included a background probe for pre-assessment, instructor observations, a survey for post-assessment, and subsequent student performance on exam questions on the topic of softening. The pre-assessment surveys consisted of two questions (Table 1). The goals of the pre-assessment survey were to determine students' current knowledge of and conceptions about softening prior to the instructional activities. This relates to the first learning objective. Responses to questions 1 and 2 were evaluated using a coding and scoring scheme where mention of a keyword or concept in response to the survey questions was counted[6]. Any concept that was relevant to the question and implied a correct statement was included in the count. Some keywords were lumped into an overarching theme and counted only once. For example, mention of both lather and taste counted as one keyword since the overarching concept for both of them was aesthetics. On the other hand, details about a concept were counted as separate keywords. For example, Van't Hoff equation is the relevant equation for calculating the effect of heating on solubility of Ca and is counted separately than heating. Similarly, names of specific chemicals used in precipitation, mention of the word 'salts', and the word 'precipitation' were treated as separate concepts and counted separately.

Table 1 Questions posed and relevant keywords

	Question	**Relevant Keywords/Concepts**
Question 1	Why do we care about hardness?	Geographic relevance
		Scaling/staining fixtures
		Aesthetics (lather, taste)
		Minimizing of corrosion
Question 2	How do we remove hardness?	Ion exchange
		Precipitation
		Add salts
		Names of specific chemicals used
		Boiling/heating
		Van't Hoff equation
		Filtration
		Membrane filtration
		Increase alkalinity

After the initial assessment, the classes were randomly divided approximately in half. One half of the class met and was instructed on the topic of precipitative softening using a passive lecture-style format with minimal class interaction. In each class, only a few students had questions regarding clarification of the presented issues during the passive lecture. Lecture notes presented by the instructors for the passive lecture were identical between the graduate and undergraduate courses. In addition, the graduate course instructor attended the undergraduate section prior to her class in an effort to closely duplicate the instruction material. There was no interaction amongst classmates in the passive groups. The second half of the class was instructed using active practices focusing mainly on collaborative brainstorming. In the active learning class, the instructors had four concept questions which they used in guiding the group brainstorming exercises. These questions were:

Concept question 1: Why do you care about softening?

Expected answers: A variety of answers were expected including the mention of hardness causing the formation of precipitates (resulting in problems in water distribution systems and hot water appliances). It was anticipated that recognition of 'precipitation' of polyvalent cations may lead students to consider implementing this process as a potential solution to remove hardness from the water.

Concept question 2: How can you remove hardness?

Expected answer: Precipitation is used to remove hardness.
Other correct answers: Ion exchange, reverse osmosis, membrane filtration, softening, and other relevant concepts.

Concept question 3: What do you know about precipitation?

Expected answers: A mineral is formed; must be a mineral that includes the polyvalent cations causing hardness (e.g., Ca); there may be a solubility limit.

Concept question 4: What are possible important variables affecting Ca precipitation?

Expected answers: Will changing the temperature make it precipitate? I sometimes see deposits in the water that I boil. Is contact time important? What else is in the water? Carbonates, dissolved CO_2, other background analytes, and pH may all affect precipitation. I may need a chemical reaction equation that includes these variables.

The instructors did not ask concept questions directly in class. Instead, the students were asked in groups to formulate their own questions on the topic of softening. Each group's questions were shared with the rest of the class and instructors encouraged further group discussion on only those questions that overlapped with the four concept questions. When the groups shared their responses to the four concept questions with the rest of the class, the instructors filled in the gaps in knowledge where appropriate.

Within a couple of weeks of the learning activity, post-assessment survey was distributed. Post-assessment included a repeat of the pre-assessment questions plus two additional formative questions developed by the instructors:

> Question 3: Did you seek any additional information about softening after the class (asked someone, went on-line, looked in a book)? Please elaborate.
>
> Question 4: Do you have any lingering questions about the topic of softening?

The pre-assessment questions were repeated in the post-assessment in an effort to measure changes in the students' knowledge related to softening and to evaluate the success of the first learning objective. The overall goal for Questions 3 and 4 were to assess the outcomes for the second learning objective. Question 3 assesses whether students had developed enough interest to search for additional information on the topic. Question 4 is similar to a muddiest point assessment where students identify areas that may not have been clearly communicated in the class. This question also aims to assess student interest since students who were actively engaged may have formulated some questions that were not addressed in class due to time limitations.

In the graduate level course, an additional in class discussion and open book final exam post-assessment question (assessing learning objective 1) focused on the topic of chemistry based mechanistic explanations for the success of precipitative softening. This topic is more in depth and was appropriate for graduate level students. At the end of this more in depth discussion, a few students were asked to rephrase what was discussed. If they could not make the links or missed a concept, they were teamed up with another student and received peer help. The various steps of knowledge and links between concepts in this topic were as follows:

Step 1: Lime ($Ca(OH)_2$) is a base.
    Linkage 1: Addition of lime raises the pH.
Step 2: Carbonates in water occur in various species (e.g., H_2CO_3, HCO_3^- and CO_3^{2-})
    Linkage 2: Raising the pH causes CO_3^{2-} to be the dominant species.
Step 3: Precipitation of $CaCO_3$ is based on solubility where the product of concentrations of Ca and CO_3^{2-} is always a constant.
    Linkage 3: When CO_3^{2-} becomes the dominant species, Ca concentration has to be smaller to satisfy the solubility rule whereby the product of concentrations is a constant.

Results

Assessment of Learning Objective 1

Active versus Passive Learning Keyword Count Results from Questions 1 and 2

Students provided 0, 1, 2, or 3 keywords in the pre- and post- assessment answers to questions 1 and 2 (Figures 1-4). On question 2, only a few replies from undergraduate students included 3 keywords, whereas, a greater percentage of graduate student responses included 3 keywords

(Figures 2 and 4). A clear trend did not exist for the effect of active learning on student performance when evaluated by keyword counts (Table 2).

Table 2 Performance of students in post-assessment compared to pre-assessment.

	Undergraduate Population				**Graduate Population**			
	Question 1		**Question 2**		**Question 1**		**Question 2**	
	active	*passive*	*active*	*passive*	*active*	*passive*	*active*	*passive*
Student population	14	15	14	15	6	4	6	4
% w/more keywords	42.9%	40.0%	30.8%	40.0%	33.3%	50.0%	50.0%	0.0%
% no change	42.9%	53.3%	42.8%	53.3%	50.0%	25.0%	33.3%	50.0%
% w/fewer keywords	14.2%	7.7%	30.8%	7.7%	16.7%	25.0%	16.7%	50.0%

The analysis of keyword counts can be summarized in two observations:

> (i) The active group generated more keywords than the passive group on question 1 in the graduate population and on question 2 in the undergraduate population; but generated almost the same amount of keywords as the passive group on question 1 in the undergraduate population; and generated fewer than the passive group on question 1 in the graduate population.
>
> (ii) Interestingly, some students performed more poorly after the 'learning' took place. That is, they included fewer keywords in their replies. For both question 1 and question 2, the percentage of students generating fewer keywords in the post assessment was higher in the active learning undergraduate group but lower in the active learning graduate population.

The first observation suggests that using active learning as the instruction method did not unequivocally improve learning. The second observation implies that active learning may result in consistent performance, as measured by generation of keywords, when used in graduate classes. This positive outcome for the graduate population is in contrast to the results attained through measuring undergraduate student performance by counting keywords. Undergraduate performance suggests that passive learning is more effective since active learners generated fewer keywords in post-assessments.

Our keyword analysis results should be interpreted with caution for several reasons. (i) While this approach has been used by other researchers[6], the keyword analysis (or coding) is not an exact or particularly accurate method. Students were not requested to nor given enough time to provide comprehensive answers to the survey questions, which may have affected the amount of keywords provided. (ii) Most of the prior research focuses on coverage of more material in multiple class meeting times. The approach in this work involved practicing the active and passive learning techniques and evaluating their effects on learning following a single class of instruction, which likely provided a single data point rather than time averaged data. (iii) The undergraduate students performed additional activities that focused on softening beyond the single class of instruction since they completed a design project which included softening. (iv) Finally, the population of students especially in the graduate class was relatively small.

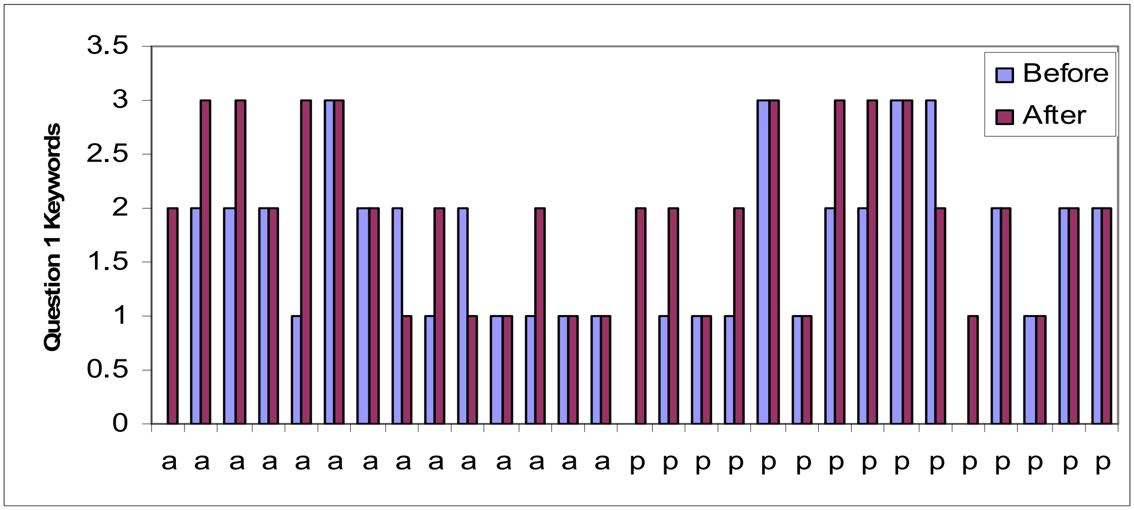

Figure 1: Number of Question 1 keywords generated by the active and passive groups in the undergraduate population before and after 'learning'. Each bar chart shows the performance of a different student in the active ('a') group or passive ('p') group.

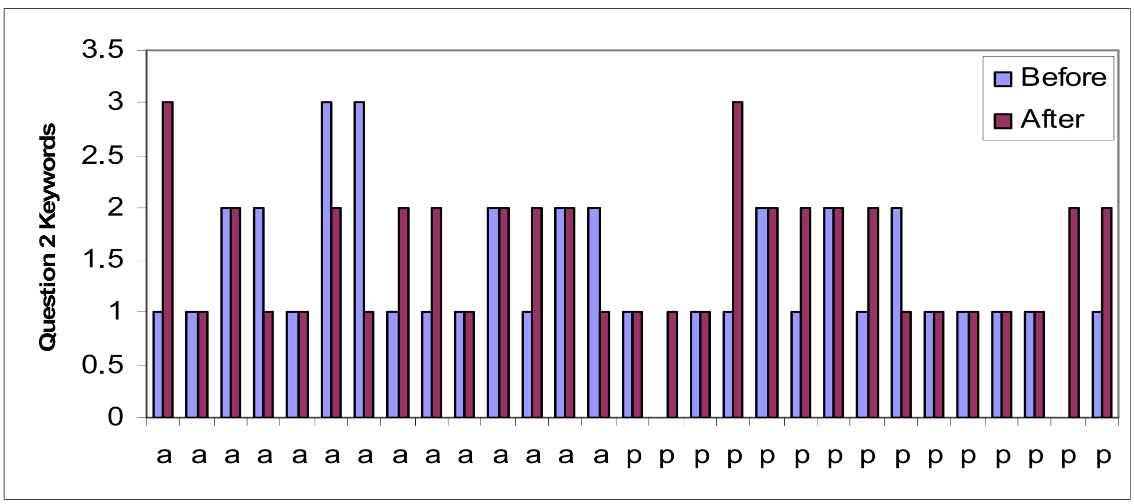

Figure 2: Number of Question 2 keywords generated by the active and passive groups in the undergraduate population before and after 'learning'. Each bar chart shows the performance of a different student in the active ('a') group or passive ('p') group.

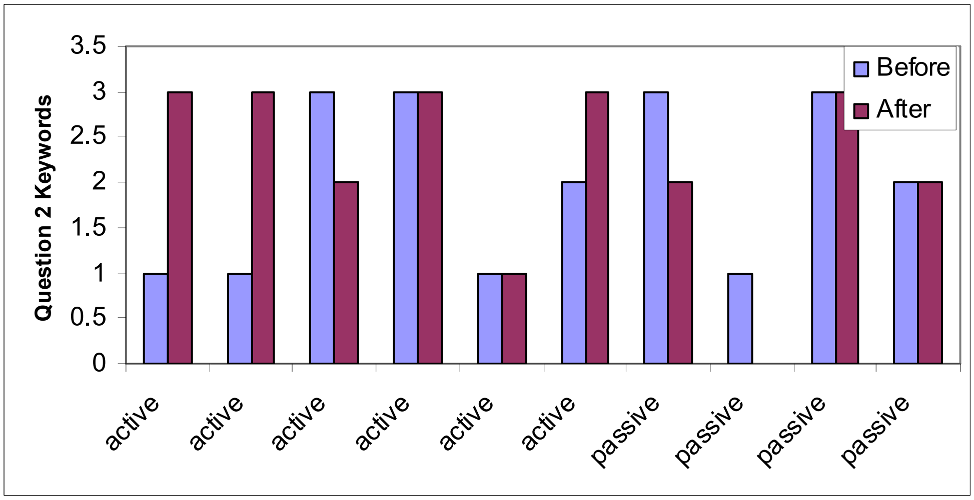

Figure 3: Number of Question 1 keywords generated by the active and passive groups in the graduate population before and after 'learning'. None of the students improved in the passive population and two out of six (33 %) students generated more keywords in the active population. Both in active and passive groups one student (17 % and 25 %, respectively) produced fewer keywords after 'learning'.

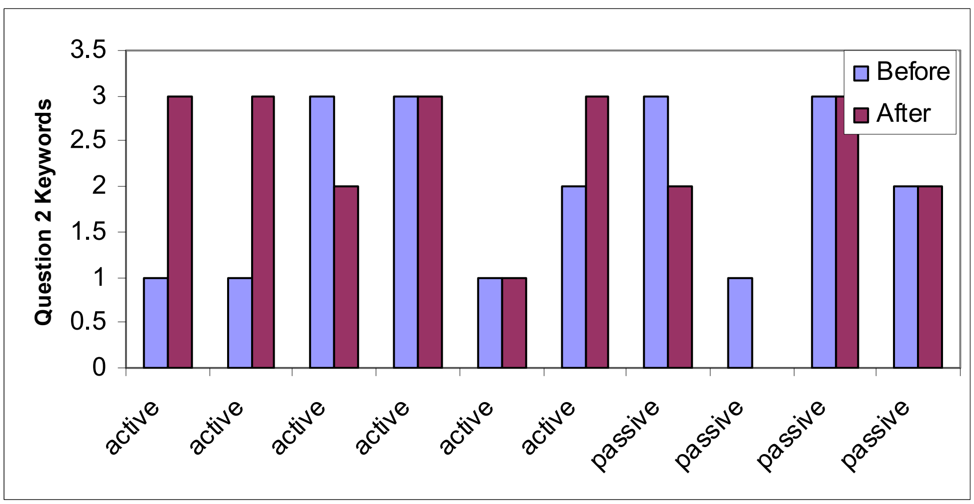

Figure 4: Number of Question 2 keywords generated by the active and passive groups in the graduate population before and after the 'learning' took place. Zero out of four students generated more keywords in the passive population, while three out of six students (50 %) generated more keywords in the active population after 'learning' took place. Both in active and passive groups, one student (17 % and 25 %, respectively) generated fewer keywords after 'learning'.

<u>Active versus Passive Learning Results from the Final Exam</u>

There also appeared to be some differences in active and passive learning groups when more in depth questions were asked. In the graduate student population, 5 out of 6 students in the active group could explain in depth the mechanistic reason for calcium precipitation. This is in contrast to zero out of three students that could explain the mechanism in the passive group. This result implies that students in the active group went through the learning steps and linkages between concepts during the course whereas the passive group simply listened to the instructor and did not recreate the steps and linkages on their own.

Pre and post Assessment Qualitative Results from Questions 1 and 2

The style of writing in pre- and post- assessments appeared to show some differences. For example, especially in the graduate student population, many answers collected prior to the lecture included words such as "I think", "I guess", "I would guess", "I am not sure how", and partial sentences with question marks indicating they had incomplete knowledge of what they wanted to write. These indicators for lack of confidence were missing in the answers collected after the lecture. Students' confidence in their answers was apparent in the assessment done after the learning.

Another difference in style between pre- and post- assessments was the language students used in their answers. After the lecture, students more frequently used specific and technical words used to describe the process of precipitative softening. Examples of these keywords were; soda ash, cations, lime, caustic soda, and precipitation. These words were in contrast to broader, non-technical words such as 'adding salt', 'treating with chemicals', and 'making ions drop out' that were provided in the pre-assessment.

The importance of students' backgrounds in facilitating learning was also apparent in analysis of pre- and post-assessments. Some students maintained preconceived ideas. For example, one student discussed temporary and permanent hardness and wrote the exact same answer in pre- and post- assessments, even though these words were not discussed during the lecture. Preconceived ideas can often be difficult to displace regardless of instruction methods. .

Assessment of Learning Objective 2

The active learning style appeared to have some effect on student inquiry and curiosity in the graduate population. Among graduate students, 5 out of 6 students in the active learning group had further lingering questions compared to 1 out of 3 students in the passive learning group. While it is difficult to interpret these numbers on a statistical basis, these results suggest that the active learning group was required to think and become engaged in class, which might have led to the development of new questions during or after the lecture as a result of the active learning process.

Question 3 of the post assessment requested that students identify lingering questions related to softening. In general, this question was posed in an attempt to determine if students were interested in softening beyond the material presented in the classroom and to gauge if course material was presented clearly. Students from both the passive and active group generated questions at both the graduate and undergraduate levels. However, the undergraduate students posed questions that were very specific to design and calculations related to precipitative softening, which was directly related to course material. On the other hand, graduate student generated questions that were broad and went beyond the presented material. For example, some of the questions focused on alternative methods to softening and their efficacy.

Students' and Instructors' Experience of the Active Learning Class

As expected, there were clear differences in the way the active and passive learning classes were experienced from an instructor's point of view. The chance to interact with students and our ability to engage them through activities is empowering as a 'facilitator' and keeps us as instructors engaged and dynamic. It was encouraging that in the active graduate student group, students participated in the learning process without hesitation. Graduate students that would otherwise lose attention were engaged when they were asked to work with their peers in both raising and answering the questions. Collaborative learning as part of active learning appeared to work well in practice.

The graduate and undergraduate students reacted differently to the active learning experience. We observed that undergraduate students were resistant to active learning techniques, particularly in-class collaborative learning which required full participation of students. Since these students commonly experience lecture-style formats, apprehension developed which diminished the efficacy of the activities. In this research, this type of active learning was only incorporated for the lessons related to precipitative softening (e.g., for one class period). It is anticipated that student response and learning outcomes would improve markedly if these techniques were employed over a longer period of time. Felder and Brent suggest that student resistance may be encountered initially, but that perseverance will eliminate these problems[5].

Caution and careful planning should be practiced in active learning especially with respect to students' background knowledge, which may be completely different than what is anticipated by the facilitator[7]. When activities are misaligned with student interests and backgrounds, the material discussed in class can easily deviate from what was planned. For example, in the active graduate learning group, there were some very advanced students. When the students were asked to develop their own questions about softening, they posed in depth questions (e.g. How does ion exchange work to remove hardness? Where in the treatment process are chemicals added?), instead of the more basic questions we had anticipated (e.g., Where does hardness come from? How do we remove it? Why do I care about it?). Our active learning strategy was focused on having students raise their own questions and then helping them to answer their own questions. When we received unexpected questions and answers in the graduate level class, it became difficult to keep the lecture focused on the learning objectives. We suggest that facilitators be prepared to cover a broad array of topics if students are given freedom to raise and answer their own questions.

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