AC 2011-2394: IMPLEMENTATION OF DIFFERENTIATED ACTIVE-CONSTRUC INTERACTIVE ACTIVITIES IN AN ENGINEERING CLASSROOM

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Implementation of Differentiated Active-Constructive-Interactive Activities in an Engineering Classroom

Introduction

Over the past decades considerable attention has been given to "active learning" in different domains including the area of engineering education.[1,2,3,4,5] A broad array of modes of active learning have been described, implemented and assessed in these domains. Problem-based, inquiry-based, discovery, collaborative, cooperative, team-based and inductive learning methods have been classified as the modes of active learning in many studies.[4,6] Some exemplary research on active learning from the engineering education literature includes examination of student learning from inquiry-based real life problems,[7] use of multimedia to facilitate student interaction,[8] use of a teamwork based approach to solve complex problems,[9,10] use of activity oriented instruction to increase active engagement,[11,12] and from comparison of collaborative learning methods with traditional instruction.[13] Taken as a whole, active learning methods in current literature refer to innovative *student-centered* instructional approaches that dynamically involve students in the learning process. The main constructs of active learning include the participation and the engagement of students with concrete learning experiences, knowledge construction of students via meaningful learning activities, and some degree of student interaction.

Active learning is usually defined as the opposite of passive learning, in which *teacher-centered* methods favor direct instruction where students often learn through listening to and observing instructor initiated lectures. Active learning methods and activities have been contrasted with passive learning methods by using pair-wise designs in which students in one condition engage in an active intervention whereas students in another condition passively receive information from an instructor or expert. These contrasts include studies comparing inductive versus deductive reasoning,[5,14] inquiry-based instruction versus direct instruction,[15] discovery learning versus traditional methods,[16] and collaborative learning versus learning from lecture.[13]

The evidence from the learning sciences, educational psychology, science education, and recently, engineering education literature often support the notion that active learning methods are superior to passive methods in terms of student learning.[4,6,17,18,19] However, other studies found that active learning methods were not always better than more passive lecture based methods.[16,20,21] Also, some of the studies contain inconclusive findings or overstated evidence, which makes it difficult to reach a robust conclusion or understand the relative effectiveness of these methods.[28, 29, 30]

In the published literature, there are also problems with how to measure and judge the effectiveness of active learning methods.[4] Evidence for content validity and difficulty level of individual test items is typically not reported in the literature; these are important factors to consider before interpreting test results and making judgments about effective learning interventions. Evidence for content validity supports the premise that test items are accurate and cover a representative sample of content from a given domain.[22] Knowledge about item difficulty is necessary to understand the depth of student learning as evidenced by their test scores. If test items are easy and measure lower levels of cognitive processing, e.g. recall, test results may

easily favor active methods of learning and the results may not even differ significantly from more passive forms of learning. However, the effect of active learning methods on the higher cognitive levels needed to succeed in an engineering curriculum, e.g. knowledge synthesis, may point out more significant effects of active learning.

Another common problem in the literature is the lack of shared terminology for active learning methods. For example, some studies classify any "hands-on" activity as inquiry based intervention without stating the important aspects of inquiry, such as to what degree students will be responsible to generate research questions, or who is in charge (i.e., teacher or students) to decide data collection methods. Another example of the lack of shared terminology appears in team based learning. Teams and team-based learning are very popular in engineering schools. However, some studies classify any group of students working together for any length of time as a team. This ambiguity between definitions of small groups versus teams makes it confusing to generalize the results from team based learning studies as well.[10,23]

From the instructional perspective, the scope of active learning in the literature is very broad and includes all sorts of classroom activities that engage students with the learning experience in some manner. However, classifying all classroom activities as a mode of active learning ignores the unique cognitive processes associated with the type of activity. The lack of an extensive framework and taxonomy regarding the components and characteristics of these "active" activities makes it difficult to compare and contrast the value of conditions in different studies in terms of student learning. Recently, Chi [24] proposed a framework that differentiated overt learning activities as being *active*, *constructive*, or *interactive* based on their hypothesized underlying cognitive processes and their effectiveness on students' learning outcomes. The motivating question behind development of this framework was whether some types of overt engagement are better than the others. The review by Chi,[24] based on experimental studies in the learning sciences literature, revealed that all three modes are better than *passive* learning in terms of students' learning. Further comparison of the literature on the three modes indicated that interactive activities are more likely to be better than constructive activities, which in turn are better than active activities.

Our current study evaluated the differentiated overt learning activities framework in an engineering context. The introductory materials science and engineering course is one of the fundamental classes in an engineering curriculum; the course contains difficult, rich concepts such as atomic structures, interatomic bonding, crystal structures, phase diagrams, and material properties and processing. As a discipline, materials engineering is unique with its fundamental tenet of bridging nano-scale structural features (i.e., electronic structure, atomic bonding, lattice parameters, and grain size) to macro-scale properties (i.e., stiffness, strength, deformation, and functional properties). Therefore, materials science and engineering classes provide a rich domain in order to generate differentiated in-class activities and determine the relative learning effectiveness of these activities.

Active-Constructive-Interactive

Chi's [24] active-constructive-interactive hypothesis asserts that different types of overt learning activities have differential learning effectiveness because they have different attributes and

involve different cognitive processes (see Table 1). The claim here is that the activities designed as *active* are expected to engage learners more than *passive* instruction can do; the activities designed as *constructive* are expected to facilitate the generation of better and/or more new ideas and knowledge than the *active* activities can facilitate; and the activities designed as *interactive* are often expected to generate superior ideas and knowledge than constructive activities, but only when both students are contributing substantial joint intellectual effort.

Chi [24] discusses three main advantages of this framework as: 1) the classification of overt activities helps researchers and instructional designers decide what type of activity or intervention would be appropriate for the intended research or instruction; 2) the hypothesized causal cognitive processes of each type of activity make it easier to assess the potential effectiveness of the activities in terms of learning; 3) the differentiation of activities or interventions based on underlying cognitive processes may allow us to re-analyze the studies in the literature and to clarify the inconsistent findings in different studies.

Note that this framework differentiates and makes a claim about only overt or observable learning activities. Clearly, students may also covertly interact cognitively with information, e.g. construct knowledge while self-explaining silently, but this behavior is difficult to assess reliably and may only occur with a small portion of students in any given classroom. Similarly, it is possible that overt activities may be provided to students and they still do not cognitively interact with the information; their attention may be focused elsewhere at that moment. Despite these caveats, the studies suggest that learning activities, particularly ones that require knowledge construction by the student, are effective ways to increase learning.

Another barrier to results as predicted by Chi's [24] hypotheses is proper implementation of activities. In other words, even if researchers properly design and classify activities as active, constructive or interactive, there still may be obstacles to successful implementation of those activities in the classroom, and student learning outcomes may not match with the expectations. For example, in an interactive activity such as argumentation, if students are not actively challenging each other's claims or if only a few of the students participate in the discussion, the activity may not provide the anticipated benefits for those who do not contribute.

Being Active

The active mode refers to students undertaking overt activities that activate their own knowledge within the boundaries of the desired content. Chi [24] defines being active as doing something overtly, rather than passively waiting for information or instruction while learning or studying. Examples of the active mode include: following the procedure of a highly structured experiment, repeating sentences after hearing them, underlining or highlighting some sentences while reading, pointing at some sentences or part of a solution, copying and pasting some of the text, copying the solution of a problem from the board while the teacher is solving it, selecting from a list of choices as in matching tasks, looking and searching for specific information in a text or problem, or playing a video game without making strategic decisions.

Table 1

Characteristics, overt activities, and cognitive processes, for passive, active, constructive, and interactive activities, from the learner's perspective

	Passive	Active	Constructive	Interactive
Characteristics	Not engaged	Engaged: with the content	Generative: Go beyond what was presented	Dialoguing: Participate in dialog (or in other ways) with peer, expert, or systems
Overt Activities	No overt activity zoning out	Describe/Repeat Look/Attend Underline/Highlight Gesture/Point Summarize Paraphrase Manipulate tape	Explain/Elaborate Justify/Reason Connect/Integrate Answer Questions Reflect/Predict Self-monitor/Regulate Compare/Contrast	Question-Answer Reciprocal teaching Argue/Challenge Collaborate Peer tutoring Monitor/Feedback Responding to scaffold
Cognitive Processes	Storing new information directly, without assimilating it with relevant knowledge	Activate/retrieve search existing knowledge; Strengthen knowledge; Encode/assimilate new information	Create & infer new knowledge; Integrate with old knowledge; Re-Organize knowledge; Repair/Accommodate old knowledge	Co-construct new knowledge that is novel to both partners; Build on each other's knowledge; Resolve own conflicts based on partner's comment

For example, an in-class activity demonstrating the relationship of macroscopic properties to the strength of atomic bonding of pure metals could be implemented at an active level if students underline the text sentences explaining this topic in class notes, or if students flex 3 rods of 3 different metals to feel the stiffness of the each road with the associated melting points. Students may be able to link this experience to their prior hands-on "everyday experience" knowledge of materials when they see and feel the flexing of the rods. The cognitive processes hypothesized to correspond with *active activities* are activation of existing knowledge, searching for related knowledge, and encoding, storing, or assimilating new knowledge. Encoding new information by assimilating it with existing knowledge via "attending" processes helps learning because it activates prior knowledge, can strengthen it, and make it more salient, more stable and more retrievable. As such, Chi [24] predicts that students who engage in *active learning* activities will learn better than students who are more *passive*, and do not engage in any observable learning activities. At minimum, students engaged in *active* activities are paying attention, activating relevant knowledge, focusing on the materials, and optimally encoding new information.

Being Constructive

The constructive mode subsumes the active mode and refers to learners undertaking activities that develop knowledge and understanding of content in new ways that extend beyond the level of that being studied. The main difference between a constructive and an active mode is that in the latter case, learners do not produce outputs that go beyond the given information. For example, simply repeating a paragraph would be classified as active, but the following activities can all be considered to be constructive: drawing a concept map, constructing notes from a lecture, generating self-explanations, comparing and contrasting different circumstances, asking comprehensive questions, constructing meanings, solving a problem that requires constructing knowledge, justifying claims with evidence, designing a study, posing a research question, generating examples from daily lives, using analogy to describe certain cases, monitoring one's comprehension, giving strategic decisions in a video game, converting text based information into symbolic notation, drawing and interpreting graphs, or hypothesizing and testing an idea.

A constructive version of the metal rod activity described earlier could be offered if after flexing the rods of 3 different metals and finding the stiffest rod with the highest melting point, students then represented that macroscopic property by drawing a microscopic model of the stiffer metal, showing a small matrix array of small spheres (atoms) connected to each other by thick, strong, stiff springs. Thus, students will have provided information beyond what was observed; they will have created an explanatory model that is *constructive* because they produced additional outputs containing new content-relevant ideas that go beyond the information given. For example, *underlining* is not a *constructive* activity, but self-explaining of textbook text is *constructive* because it goes beyond the given content. Cognitive processes hypothesized to underlie *being constructive* are those that can generate new ideas, insights, and conclusions in a way that allows learners not only to infer new knowledge, but also repair or improve their existing knowledge. Repairing one's existing knowledge makes it more coherent, more accurate, and better-structured, which serves to deepen one's understanding of new information. Research has shown that constructive activities, such as explaining-to-oneself [25] and explaining-to-others [26] can improve learning.

Being Interactive

The interactive mode subsumes both the active and constructive modes. It refers to two or more learners undertaking activities that develop knowledge and understanding extending beyond the level being studied (similar to constructive) but the interaction of the learners enables them to creatively build upon one another's understanding in an innovative way. The main (but surface level) difference between the interactive and constructive mode is that learners in the constructive condition engage in activities alone.

Examples of interactive activities are studying/working in teams, peer teaching, interacting with feedback from a teacher, an expert or a computer agent, responding to scaffolding, or arguing or defending your position with evidence. Overall, interactive conditions are essentially co-construction of knowledge between pairs or group members. Chi [24] cautions that it is not appropriate to classify any group work as an interactive activity however. For example, if one group member dominates the discussion or if one group member does not contribute to the discussion or product, then the group is not fully interacting. The quality of discourse among group members is critical to determine the degree of interactivity in interactive activities. In addition to degree of interactivity, the effectiveness of interactive activities may also be dependent on the domain being studied, the particular topic within the domain, degree of student knowledge construction, and student characteristics such as age and prior knowledge.

An interactive version for the metal rod activity could be offered if two students worked together on the activity, questioning each other about rationale for suggested solutions and explanation of findings. Through this give-and-take discussion, students would be building knowledge in a way that would not have occurred if they had been working alone, thus resulting in new knowledge being created in an innovative way. As such, two or more partners build on each other's contributions sequentially, by refining or modifying an original idea in some way, so that the interaction can spiral and produce novel ideas or products. This has potential to be more beneficial than *constructive* learning, in which a single individual can only extend beyond given content with their own ideas; in *interactive* learning, two individuals can further enrich the topic of discussion through jointly extending on a given content topic from two different perspectives and sets of ideas.[24] Table 2 summarizes the above information.

Table 2
Example of 4 ways to present an in-class activity concerning the relationship of macroscopic properties to the strength of atomic bonding of pure metals

Passive	Active	Constructive	Interactive
Students **read** or **see** *a* video explaining that the higher melting point of pure metals gives them greater bond strength and higher elastic modulus than lower melting point metals.	Students **underline** the text sentences explaining this topic, or students **flex** 3 rods of 3 different metals to feel the stiffness of each rod with the associated melting points.	Students **flex** 3 rods and after finding that the stiffest rod has the highest melting point, they are then asked to **draw** a matrix array of small spheres connected to each other by thick strong stiff springs, showing the microscopic level.	Students discuss this topic collaboratively in pairs. Besides flexing rods, one partner is asked to **draw** the microscopic representation and the other partner is asked to **give feedback**, **guidance**, or **ask questions.**

Methods

Participants

The sample for this study included forty-two undergraduate engineering students enrolled in an introductory materials science and engineering class in a large public university located in the southwestern United States. Thirty-five of the students were male and **7** of the students were female. The mean age of the participants was 19 with a range from 18 to 21 years old. Each student enrolled in the class had already completed a college level general chemistry class as a prerequisite. Participation in the project was voluntary and students were assured that their participation would have no effect on their grades. Data collection was completed on five different days during the first three weeks of the semester. Participants were asked to stay for 15 to 20 minutes after the regular class hours during these five days. Student received $5 per day for their participation

Development of the In-Class Activities

One of the researchers attended the introductory materials science and engineering class for a semester prior to the study to document all learning activities already used in class, as well as to check the classroom resources such as computers, classroom space, and class materials. We gathered instructional materials used for each class (i.e. slides and handouts) as well as assessment measures that were used, (i.e. concept tests, unit tests, and homework assignments). In preparation for our research, we classified the nineteen overt activities that were used as being active, constructive or interactive and based on Chi's [24] framework.

We selected two units, atomic bonding and crystal structures, to be used for this study. After negotiating with the faculty, we agreed on the type of activities (active, constructive, or interactive) that would be offered within each unit. We planned only one type of activity per class period, regardless of how many activities were offered, so that we could test for learning that could be attributed to one particular type of activity. We planned the types of activities so that a contrast could be made between active and interactive learning in the atomic bonding unit, and between active, constructive, and interactive learning in the crystal structures unit (See Table 3). The final study design included three active, two constructive and three interactive activities for the two units (See Appendix A for detailed description of activities). Many of the activities used for the study were modified versions of ones already used by the faculty. For example, in previous semesters, students learned about features of a face centered cubic (FCC) structure via a constructive activity in which they used given indices to draw unit cell directions on a worksheet and also used a given set of directions to determine the indices of unit cells. We modified this activity to be active by having the instructor demonstrate both processes and having students copy the instructor's work. This activity then met the active mode criteria of having students manipulate the information in some way, without constructing new meaning from it.

In an effort to promote high quality productive interaction between students during the interactive activities, we devised written guidelines to help group leaders facilitate discussion. The guidelines included detailed directions for the task, timelines for completion of the activity, and ideas for probing questions that could stimulate knowledge construction by team members.

Table 3
Type and order of activities used

	Atomic Bonding		Crystal Structures		
	Day 1	Day 2	Day 3	Day 4	Day 5
Active	Materials selection activity			Drawing and indexing unit cell directions Unit cell families of directions	
Constructive					Drawing and indexing unit cell planes Unit cell worksheet
Interactive		Bonding concept map	Concepts in context Hidden treasurers		

Measures

Student learning from in-class activities was measured after each class period in which the two topics were studied. We chose to measure student learning after each class period in an attempt to differentiate between learning that may have resulted from the in-class activities and learning that may have resulted from homework or alternate learning strategies that students employed outside of class. Daily quiz questions for each activity were generated in order to measure students' learning and comprehension of the content covered in the activities. Because the content and activities were different each day, we had to measure knowledge gained from them on a common metric in order for the ANOVA significance tests to be meaningful. Due to our interest in examining the depth of processing and resultant knowledge associated with each activity, we chose level of quiz questions as the common metric. We adopted three guidelines for quiz question development: 1) quiz questions related to one activity included 2 two-tier questions, or four questions per activity. Two-tier questions are those in which the initial question is asked at a relatively low level, e.g. recall or application, and the following question requires a higher level of cognition, e.g. evaluation or synthesis. For this study, we had eight activities, and thus generated 32 new questions in total. 2) A consistent question format was used. Each daily quiz included two multiple-choice and two open-ended questions. The tier one (lower level) questions were multiple choice and the tier-two questions (requiring a higher level of cognition) were open-ended. A total of 16 questions were multiple-choice and 16 were open-ended. 3) A consistent framework was used for question development. The first question of each daily quiz was a *verbatim* type multiple choice question (tier 1), and the second question of this

set was a *knowledge inference* type open-ended question (tier 2); the first question in second question set of each daily quiz was a *comprehension inference* type multiple choice question (tier 1), and the second question in the second set was a *knowledge inference* type open-ended question (tier 2). We had two multiple choice and two open-ended questions for each quiz. All open-ended questions were *knowledge inference* type questions, half of the multiple choice questions were *verbatim* type questions, and the other half were *comprehension inference* type questions. Content validity evidence was obtained by having experts from the materials science and engineering department as well as an individual with expertise in measurement and test development provided continuous feedback and suggestions for improvement during question development. They approved the final version of each question. The quiz questions were closely aligned with the content covered in each activity, thus ensuring representative sampling of content in the assessment of student learning (See Appendix B for activity sample & Appendix C for quiz sample).

The categories in our framework used for question development represented different levels of cognitive activity required to respond to the question, which was also considered to be indicative of question difficulty.[27] The verbatim type questions were generated from ideas and information explicitly stated in the activity, and required students to merely recall the correct responses. For example, to correctly answer the verbatim question in the *concepts in context* activity, students needed to select a disaster/failure that occurred as a result of an incomplete phase transformation; this information was explicitly stated in the activity. The comprehension inference type questions were also generated from the ideas and information explicitly stated in the activity but they required students to integrate two or more different ideas from the activity. For instance, to correctly answer the comprehension inference question from the activity mentioned above, students needed to integrate the ideas of the most likely condition for phase change, properties of materials, and unit cell transformation. These three ideas are covered in the activity; however, the completion of activity does not require the integration of the three ideas explicitly. Finally, the knowledge inference type questions required students to generate ideas beyond the information presented in the activity. For example, one of the knowledge inference questions for the *concepts in context* activity asked students to specify recommendations to prevent disaster/failure based on the relationship between a component material's macroscopic properties and its atomic level structure. The activity itself did not include any discussion about recommendations to prevent disasters/ failures, so this question required students to think about these recommendations like a consulting engineer giving advice about failure prevention to a company. Accordingly, our question categories had an ordinal relationship in which knowledge inference questions were considered to be more difficult than comprehension inference questions, which in turn, were considered to be more difficult than verbatim type questions.

Procedure

The data was collected over five days in an introductory materials science and engineering class. The class topic was atomic bonding during the first two days and crystal structures during the last three days. Students completed one activity per day during the atomic bonding units and two activities per day during the crystal structures unit (See Table 3). The activities each took approximately 15 minutes of class time. On the first day, students completed the active version of the *materials selection activity* individually. An activity worksheet was provided for each

student. The instructor told students to work alone and not to interact with peers during this activity. After the regular class hour, participating students stayed in the classroom and completed the daily quiz questions individually, which took 10 minutes. The students were not allowed to use any instructional materials to answer the quiz questions. On the second day, students completed the interactive version of the *bonding concept map* activity in small groups. One activity worksheet was provided for each of the nine groups in the class. The students were encouraged to question each other's reasoning and reach a group consensus for their final answers before recording their responses on their group worksheet. Similar to the first day, participating students stayed after class and took the daily quiz questions individually. On the third day, students completed the interactive versions of the *concepts in context* and *hidden treasures-features of FCC* activities in small groups. Similar to the *bonding concept map* activity, they were encouraged to question each other and reach a consensus as a group before recording their responses on their group worksheets. After the regular class hour, participating students stayed in the classroom and took two daily quizzes (one for each activity) individually, which took a total of 20 minutes. On the fourth day, students completed the active versions of the *drawing and indexing unit cell directions* and the *unit cell families of directions* activities. Each student copied the activity answers given by the faculty onto their worksheet for each activity. After the regular class hour, the participants again took two daily quizzes individually, which took a total of 20 minutes. On the last day, students completed the constructive version of the *drawing and indexing unit cell planes* activity and *the unit cell worksheet* activity individually during the regular class hour. Again, an activity worksheet was provided for each student for each activity. After class, the participants stayed and took two daily quizzes individually, which took a total of 20 minutes. During these five days, the instructor did not provide any feedback or scaffolding to students about course content during about the activities.

Results

To evaluate the effectiveness of differentiated overt learning activities on students learning, we conducted a one way repeated-measure analysis of variance (ANOVA). The within-subject factor was type of activity, and the dependent variable was students' total scores on daily quiz questions. The means and standard deviations for students' scores are presented in Table 4.

Table 4
Means and standard deviations for students' scores for each type of activity by topic

	Atomic Bonding		Crystal Structures	
	M	*SD*	*M*	*SD*
Active	6.69	3.19	7.74	2.68
Constructive	NA	NA	9.11	1.65
Interactive	9.67	2.49	8.86	2.77

Because the topics, atomic structure and interatomic bonding and the crystal structures, have different characteristics and difficulty levels, the direct comparison of the effectiveness of activities across topics did not reveal meaningful results. Therefore, we chose to compare the students' achievement scores within each topic across different activities. Accordingly, the

analysis involved the comparison of active and interactive activities for the atomic bonding unit, and the comparison of active, constructive and interactive activities for the crystal structures unit.

Results for Atomic Bonding

For the first topic, atomic bonding, a one way repeated-measures ANOVA was conducted with the factor being type of activity (active, interactive), and the dependent variable being the students' achievement scores on daily quiz questions. The results for the ANOVA indicated a significant effect of activity type, Wilks' $\Lambda = .57$, $F(1, 38) = 28.69$, $p < .05$, multivariate $\eta^2 = .43$. These results suggested that students learned significantly more from interactive activities than they learned from active ones.

We were also interested in determining how students performed based on the type of questions (i.e., multiple choice, open-ended). Figure 1 shows students' mean scores for multiple choice questions, open-ended questions and total mean scores for each activity. A one-way repeated-measures ANOVA was conducted with the factor being type of activity and the dependent variable being the students' scores for multiple choice questions. The results for the ANOVA indicated a significant effect of question type, Wilks' $\Lambda = .70$, $F(1, 38) = 16.01$, $p < .05$, multivariate $\eta^2 = .30$. Another one-way repeated-measures ANOVA was conducted with the factor being type of activity and the dependent variable being the students' scores for open-ended questions. These results also revealed a significant effect of activity type, Wilks' $\Lambda = .62$, $F(1, 38) = 23.57$, $p < .05$, multivariate $\eta^2 = .38$. Overall, students performed significantly better both on multiple choice and open ended questions related to interactive activities than they did for the active activity questions.
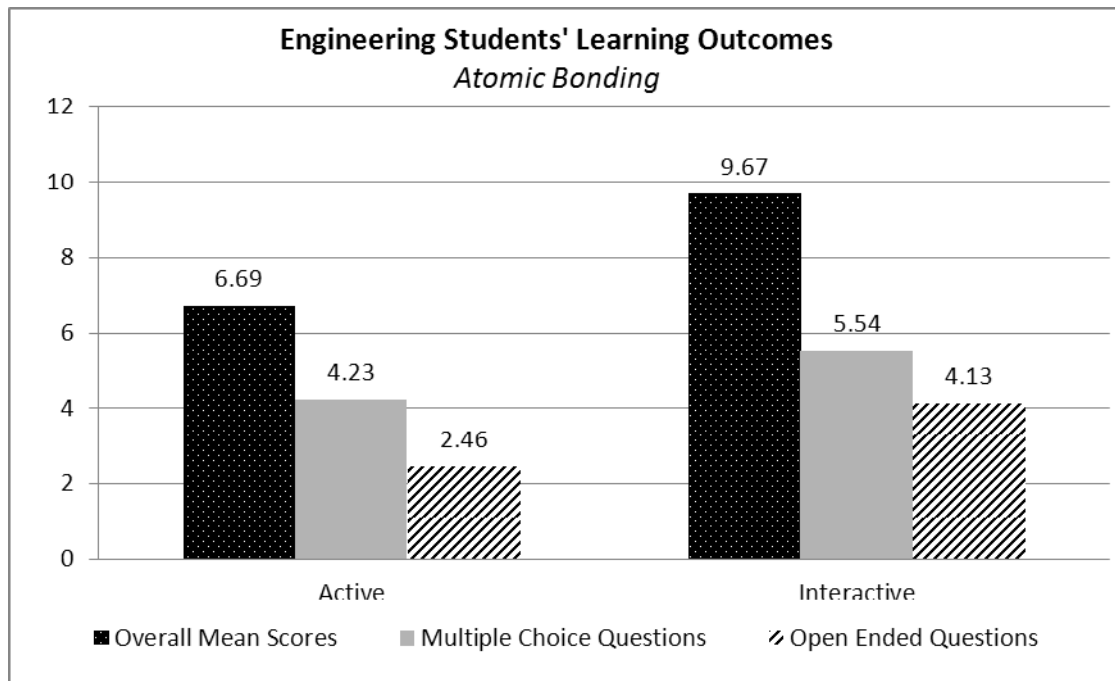

Figure 1. Students' total mean scores, mean scores for multiple choice questions, and mean scores for open ended questions by type of activity for atomic bonding.

Results for Crystal Structures

To evaluate the overall effect of the different types of activities on the students' daily quiz question scores for the crystal structures unit, we initially conducted a one-way repeated measures ANOVA with the activity type as a factorial variable, and students' total scores as dependent variables. The results showed a significant main effect for the type of activity on learning, Wilks' Λ = .79, $F(2, 34)$ = 4.40, $p < .05$, multivariate η^2 = .21.

Next, three unique pairwise comparisons were conducted among the means of students' scores for active, constructive and interactive activities. Two of the three pairwise comparisons were significant, controlling for familywise error rate across the three tests at the .05 level using the Holm's sequential Bonferroni procedure. The smallest p value was for the comparison of active and constructive, and its p value of .007 was less than α = .05/3 = .017; therefore, the difference between the means (7.74 vs 9.11) was significant. The next smallest p value was for the comparison of active and interactive and its p value of .021 was less than α = .05/2 = .025; therefore, this comparison of means (7.74 vs 8.86) was also significant. Lastly, the comparison of constructive and interactive was not significant. Taken as a whole, there were significant differences between the total scores resulting from interactive and active activities, as well as constructive and active activities, but not between interactive and constructive activities.

As we did for the atomic structure and interatomic bonding activities, we determined how students performed after the different activities in the crystal structures unit, based on the type of questions that were used (i.e., multiple-choice, open-ended). Figure 2 shows students' mean scores for multiple choice questions, open-ended questions and mean total scores for active, constructive and interactive activities. We conducted one-way repeated-measures ANOVAs for students' scores on the multiple choice questions and the open-ended questions separately. The results showed a significant main effect for the type of activity on the multiple choice questions, Wilks' Λ = .56, $F(2, 34)$ = 13.53, $p < .05$, multivariate η^2 = .44; and on the open-ended questions, Wilks' Λ = .83, $F(2, 34)$ = 3.60, $p < .05$, multivariate η^2 = .17, respectively.

In addition, pairwise comparisons were also conducted to determine how type of activity affected students' scores on the different question types. For the multiple-choice questions, two of the three pairwise comparisons were significant, controlling for familywise error across the three tests at the .05 level using Holm's sequential Bonferroni procedure. Mean scores after constructive activities were significantly higher than those following active activities (5.65 vs 4.33), and mean scores after constructive activities were significantly higher than those following interactive activities (5.65 vs 4.67). There was no significant difference between the mean scores of multiple choice questions following active and interactive activities. For the open-ended questions, after using Holm's sequential Bonferroni procedure, we found that mean scores following interactive activities were significantly higher than those following active activities (4.19.vs 3.41), and mean scores following interactive activities were significantly higher than those following constructive activities (4.19 vs 3.46), but there was no significant difference between scores following active and constructive activities. In sum, as questions became more difficult (open ended questions were more difficult in this study), students received higher scores following the interactive activities.
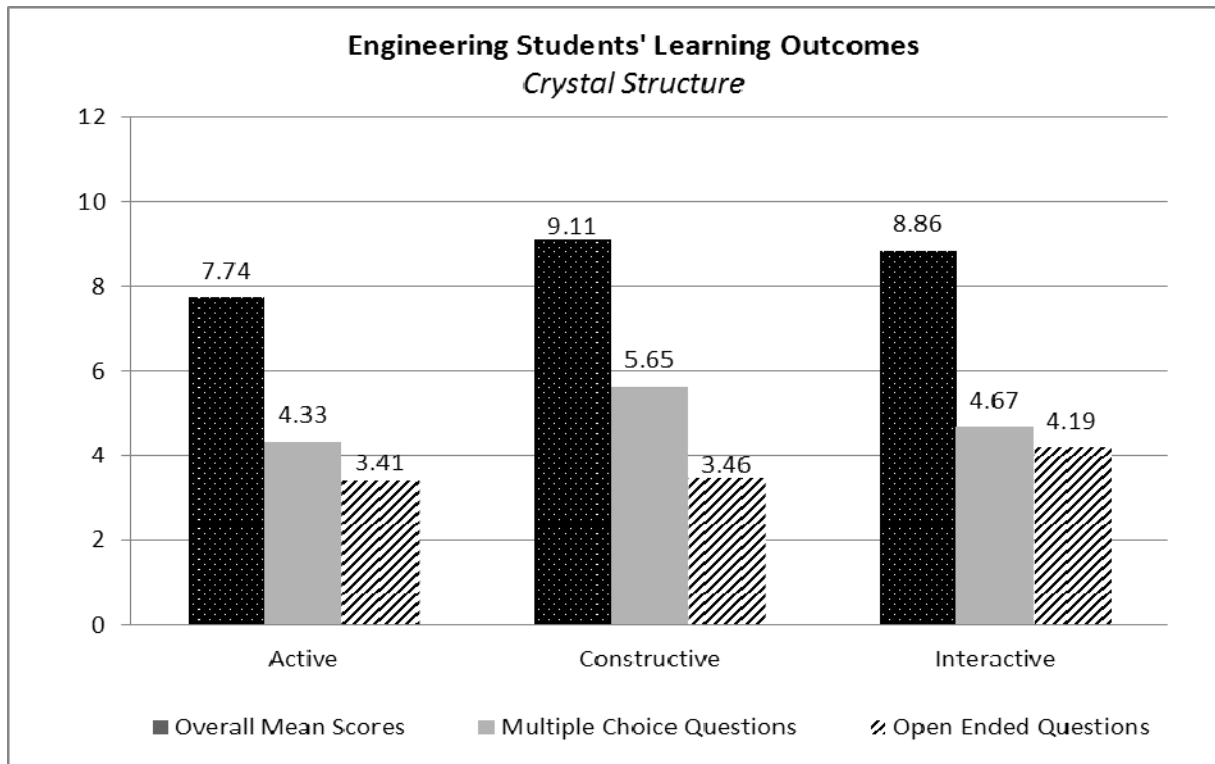
Figure 2. Students' total mean scores, mean scores for multiple choice questions, and mean scores for open ended questions by type of activity for crystal structures.

This is especially important for the comparison of constructive and interactive activities; although there were no significant differences in terms of total scores, the comparison of scores from open-ended questions revealed that following interactive activities, students were better able to respond to more challenging questions about their engineering course material. Students did learn enough during the constructive activities however, to perform well in the multiple choice questions, which tested verbatim recall and comprehension inferences from material directly given in the activities. An interesting finding from our analysis was that for this unit, students performed better on multiple choice questions after engaging in constructive activities than after engaging in interactive activities. This should not be the case, as interactive activities involve construction of new knowledge with the added enhancement of contributions from one's peers. However, this finding may be influenced by the quality of interaction that occurred between students during interactive activities. Despite our efforts to promote productive collaboration when students worked interactively, this may not always have been the case. Future research may need to involve more qualitative analysis of the ways in which students communicate during interactive activities and how this relates to subsequent learning.

Conclusion

Our study results provide preliminary evidence to support Chi's [24] hypothesis that constructive activities provide greater returns in terms of student learning than active activities, and that interactive activities provide greater returns than either constructive or active activities. Using a study design in which we tested student learning after each class, we compared the effects of three types of activities for two topic areas in an introductory materials science engineering class.

We found that the highest student scores followed interactive activities in the atomic bonding unit, and the highest scores followed constructive activities in the crystal structures unit. Additionally, when we examined effects of the type of activity on student scores for different types of questions, there was a significant effect of interactive activities on scores for the more difficult open-ended knowledge inference questions.

This study has several limitations which need to be considered before findings are generalized to other populations. Although we provided validity evidence for the content of our daily quiz questions, further validity evidence is needed to support our interpretation of student scores as representative of student learning for the respective class content areas. Current work is being done to examine the relationship between students' daily quiz scores and their course exam scores, which will provide evidence for their predictive validity. Students' retention of the material needs to be evaluated to provide evidence for the long term benefits of the different types of learning activities. Additionally, for content that is related, e.g. drawing / indexing cells and drawing/indexing planes, there is a possibility of order effects from the activities which may have influenced the degree of learning students experienced. Repetitions of the study are needed, varying the order of the type of activities, to control for these possible effects. Despite the limitations however, our study results initiate a line of inquiry that will supplement current literature on activities to increase student learning.

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Appendix A
Detailed description of in-class activities from the introductory materials science and engineering class

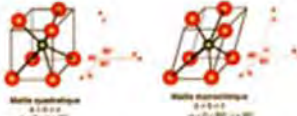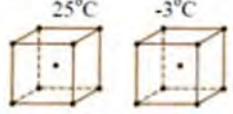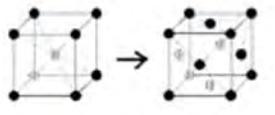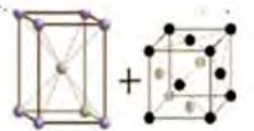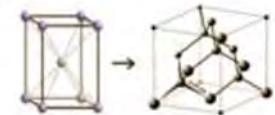| Name of the Topic	Name of the Activity	Description of the Activities
Atomic Bonding	Materials selection activity / Active	Select most likely material, property of that material, type of bonding, and processing method from a given list for the motorcycle parts such as motorcycle fender or seat.
	Bonding concept map/ Interactive	Complete the partially constructed concept map about atomic bonding. Also, students are asked to explain their reasoning for every single decision they make to complete this concept map.
Crystal Structure	Concepts in context / Interactive	Overall goal is matching the five different historical events (disasters involving failure of materials) with the scientific reasons for the occurrence. Task 1: Matching with the possible reason for change of materials. Task 2: Matching with type of transformation. Task 3: Matching for the condition for change. Task 4: Matching with the processing method.
	Hidden treasurers – Features of FCC / Interactive	Task 1: Calculating the number of atoms on faces, edges and corners of a FCC unit cell. Task 2: Calculating the length of cube edge, face diagonal and body diagonal in terms of atomic radius. Task 3: Calculating the coordination number and atomic packing factor of a FCC unit cell.
	Drawing and indexing unit cell directions / Active	Task 1: Drawing directions in the unit cell by using given Miller indices. Task 2: Determining the Miller indices of unit cells from a given set of directions.
	Unit cell families of directions / Active	Task 1: Specifying and drawing all directions in family of unit cell. Task 2: Identifying the unit cell directions that are equivalent in terms of properties and packing density.
	Drawing and indexing unit cell planes / Constructive	Task 1: Drawing the planes in the unit cell by using given Miller indices. Task 2: Determining the Miller indices of unit cells from a given positions of planes.
	Unit cell worksheet / Constructive	Task 1: Drawing atom locations in two-dimensions based on the given indices of planes and atomic packing factor. Task 2: Drawing and calculating the total number of atoms per area for various planes.

Appendix B
Active Version of Concepts in Context Activity

Concept Learning in Context: Materials Science of Unit Cell Disasters

Occurrence (Object)	Property & Change	Unit Cell Transformation	Condition for Change	Original Processing Method
Napoleon's failed winter invasion of Russia 1812 (tin button)	_____	_____	_____	_____
The World Trade Center 9/11 (steel girders)	_____	_____	_____	_____
The Titanic sank (steel rivets)	_____	_____	_____	_____
Helicopter Crash (steel gear)	_____	_____	_____	_____
Grandma's hip joint failed (ceramic ball cracked)	_____	_____	_____	_____

PROPERTIES & CHANGE

I. steel BCC to FCC higher temp

II. BCC loses ductility at low temp

III. ductile BCT (body center tetragonal) metal transforms to brittle powder with diamond cubic unit cell

IV. cracks form in BCT ceramic when it transforms to body center monoclinic

V. soft FCC phase is retained in hardened steel phase (BCT)

UNIT CELL TRANSFORMATION

CONDITION FOR CHANGE

A. 120°C sterilization phase change

B. incomplete phase transform

C. loses strength above 730C

D. iceberg cold environment

E. temp falls below 13°C

PROCESSING

a. sintered

b. forged

c. cast

d. machine & heat treat

e. hot rolled in steel mill

Appendix C
Sample Quiz for Concepts in Context Activity

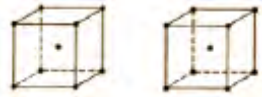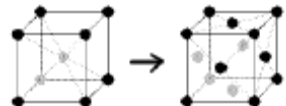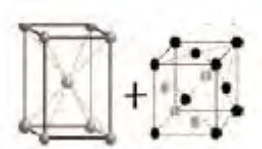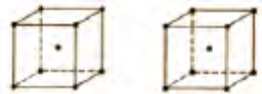### Concepts in Context: Materials Science of Unit Cells in Disasters

1. A. Which of the following disasters/failures has occurred as a result of an incomplete phase transformation?

    a) Helicopter crash (steel gear)
    b) Napoleon's failed winter invasion of Russia 1812 (tin button)
    c) The World Trade Center 9/11 (steel girders)
    d) Grandma's hip joint failed (ceramic ball cracked)
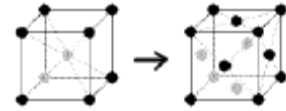   e) The titanic sank (steel rivets)

B. Using your understanding of macroscopic properties and atomic level structure, explain what could have been done to avoid the disaster that you choose above?

2. A. A steel skeleton chemical processing plant collapses due to a steel beam failing prematurely a short time after a chemical explosion and a fire.

Choose the most likely condition for change, properties and change, and unit cell transformation for this disaster.

Condition for change	Properties and Change	Unit cell transformation
a) 140^0 C sterilization phase change	Ductile metal to brittle powder	
b) Loses strength above 730^0 C	Steel BCC transforms to FCC at higher temperatures	
c) Incomplete phase transformation	Ductile metal to brittle powder	

d)

    140^0 C sterilization phase

    change

Steel BCC transforms to FCC at higher temperatures

e)

    Loses strength above 730^0 C

BCC loses ductility at low temperature

B. As a consulting engineer giving advice to the company, specify your recommendation to prevent this failure and justify it based on your understanding of the relationship between macroscopic properties and atomic level structure.