AC 2012-4513: THE USE OF DIFFERENTIATED LEARNING ACTIVITIES TO ENHANCE ENGINEERING STUDENTS LEARNING

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The Use of Differentiated Learning Activities to Enhance Engineering Students Learning

This study investigates the effectiveness of the differentiated overt learning activities (DOLA) framework[1] in an engineering context by classifying activities as *active*, *constructive* and *interactive* based on their underlying cognitive processes and their effectiveness on student learning. The claim here is that the activities designed as active are expected to engage learners more than passive instruction can; 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 all students are contributing to a substantial joint intellectual effort.

Chi[1] discusses three main advantages of this framework as: 1) the classification of overt activities helps researchers, instructors 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 inconsistent findings in different studies.

This framework differentiates and makes a claim about only overt or observable learning activities (which can be referred to as *engagement* activities in order to differentiate them from other learning activities such as reading per se). 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 on average, engaging in these overt 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 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 to those who do not contribute.

We have designed one classroom Study (i.e. Study 1) and one controlled lab study (i.e. Study 2) with engineering students at a state university in southwest of the United States. Our research questions were as follows: (1) are interactive activities related to better learning than constructive activities for engineering students? (2) Are constructive activities related to better learning than active activities for engineering students? (3) Are active activities related to better learning than passive ones for engineering students?

Study 1

Participants

The sample for the Study 1 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 seven 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. 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. Students received $5 per day for their participation.

Activities

We selected two units, atomic bonding and crystal structures, to be used for this study. 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. The final study design included three active, two constructive and three interactive activities for the two units.

Measures

Daily quiz questions for each activity were generated in order to measure students' learning and comprehension of the content covered in the activities. Student learning for each activity was measured with two-tiered questions in which the first part assessed relatively low level understanding, and the second part assessed deeper understanding that required a higher level of cognition to respond. The first question of each daily quiz was a *verbatim*-type multiple choice question, and the second question of this set was a *knowledge*-type open-ended question. The first question in second question set of each daily quiz was a *comprehension*-type multiple choice question, and the second question in the second set was a *knowledge*-type open-ended question. Overall, each daily quiz included two multiple-choice and two open-ended questions. The *verbatim*-type questions were generated from ideas and information explicitly stated in the activity, and required students to merely recall the correct responses. The *comprehension*-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. Finally, the *knowledge*-type questions required students to generate ideas beyond the information presented in the activity.

Results

Because the topics, atomic structure and interatomic bonding and the crystal structures, have different characteristics and difficulty levels, it is not meaningful to directly compare the effectiveness of activities across topics. Therefore, we compared 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.

For 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 the daily quiz questions corresponding to each activity. The results for the ANOVA indicated a significant effect of activity type, Wilks' $\Lambda = .57$, $F(1, 38) = 28.69$, $p < .01$, 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) for the atomic bonding unit. 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.

For the crystal structures unit, we initially conducted 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' $\Lambda = .79$, $F(2, 34) = 4.40$, $p < .05$, multivariate $\eta^2 = .21$. 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. 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 for total scores.

Similar to what we did for the atomic bonding unit, 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). 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' $\Lambda = .56$, $F(2, 34) = 13.53$, $p < .05$, multivariate $\eta^2 = .44$; and on the open-ended questions, Wilks' $\Lambda = .83$, $F(2, 34) = 3.60$, $p < .05$, multivariate $\eta^2 = .17$, respectively.

Furthermore, pairwise comparisons were also conducted to determine how the type of activity affected students' scores on the different question types. For the multiple-choice questions, two of the three pairwise comparisons were significant. 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, students received higher scores following the interactive activities. The overall results show: (1) students did significantly better on questions related to *interactive* activities than they did for the *active* activities; (2) students did significantly better on questions related to *constructive* activities than they did for the *active* activities; (3) no significant differences were observed between students' performances related to *constructive* and *interactive* activities in total scores, but students performed better on more difficult questions related to *interactive* activities than they did for *constructive* activities, which is also predicted by the DOLA framework.

On the other hand, there were some limitations in Study 1. First, because that study was implemented in a real classroom, it was difficult to control for confounding factors like the level of students interaction and time spent to complete tests and activities. Second, we did not record students' discussions in the *interactive* condition, so we could not evaluate the quality of dialogue and the level of interactivity. Third, there was no pure control group as a "passive" condition. Based on the limitations in Study 1, we designed Study 2 with more controlled settings and a larger sample size.

Study 2

Participants

The sample for Study 2 included 120 undergraduate engineering students in a large public university located in the southwestern United States. Seventy two of the participants were male and 48 of them were female. The mean age of the participants was 20 with a range from 18 to 23 years old. The study participants were recruited through announcements via posters and flyers across campus, and emails sent to engineering instructors and department secretaries. It was required for participants to have already completed a college level general chemistry class as a prerequisite.

Data collection was completed in one session with each individual participant in passive, active, and constructive conditions, and with dyads (pairs) in the interactive condition. Each participant was randomly assigned into one of the four conditions (interactive, constructive, active and passive). There were 24 students in each of the three conditions as passive, active and constructive; and there were 48 students (24 dyads) in the interactive condition. Each session took approximately 90 minutes to complete.

Materials

Introductory Text

We created a two page long introductory text, including definitions for the terms that were used in this study. The introductory text consisted of definitions and short descriptions for the concepts like chemical bonding, bond energy and tensile properties. We used college level general chemistry and introductory materials science textbooks for these definitions and descriptions. All participants read the introductory text to become familiar (or as a reminder) with the terminology used before taking the pretest.

Measures

We used the pretest and posttest design to measure students' prior knowledge and learning from the intervention. The pretest consisted of 15 true and false, seven multiple choice and two short answer open-ended questions for a total of 24 questions. The true and false questions were two-tiered in which the first part asked the correctness of the given statement, and the second part asked the students' explanations for their selection. The multiple choice questions had five options with one correct answer and four distractors. The open-ended questions were designed as a short answer format. The posttest consisted of the same 24 questions from the pretest along with six additional questions. Overall, the posttest consisted of 16 true and false, 11 multiple choice and three short answer open-ended questions. The formats of the posttest questions were same as the ones in the pretest.

The questions were closely aligned with the content covered in interventions, thus ensuring representative sampling of content in the assessment of student learning. Content validity was obtained by having experts from the materials science and engineering department review content. Also, the reliability calculations revealed that the Cronbach's Alpha for all items was .81 which indicates a highly reliable test.

Development of Interventions

Similar to Study 1, we used introductory materials science and engineering concepts to create our interventions for the four conditions in Study 2. We designed the *connecting atomic bonding and physical properties* interventions, which requires students to understand the relations between bonding energy, elastic modulus, melting points, and coefficient of thermal expansion concepts.

In the *passive* condition, students were asked to read a long text passage out loud. This text was different than the two pages of introductory text that all participants read before taking the pretest. The text described bonding energy, elastic modulus, melting points, and coefficient of thermal expansion concepts. The text was created by using the main introductory sections of materials science and engineering textbooks used in universities and colleges across the United States. We mainly used the William D. Callister book[3] and James Newell book[4] to create the text. Since we designed the passive condition as a pure control condition, students were not allowed to use any highlighters or pens while reading the text. In the *active* condition, students read the same text as described above. Students were given highlighters and told to highlight the most important and/or critical sentences in the text. In the *constructive* condition, each student was asked to interpret a set of graphs and figures by answering the questions in an activity sheet. Students in this condition did not read the long text that was used in *passive* and *active* conditions. The graphs and figures presented the properties of three metals in terms of elastic modulus, bond energy, thermal expansion and melting points. These graphs and figures were chosen because they corresponded to the materials in the text created for the *passive* and *active* conditions. In addition to structural differences between text in the *passive* and *active* condition versus the graphs and figures in *constructive* condition, the main difference was the inclusion of the activity sheet in the *constructive* condition. The activity sheet involved questions which made students think about and interpret the specific aspects of the information provided in the graphs and figures. In the *interactive* condition, dyads of students completed the same graph interpretation activity (as the one in the *constructive* condition) collaboratively. Finally, researchers did not provide any feedback or content-related help during any of the sessions across any condition.

Results

First, we wanted to evaluate the randomness of participants' assignment into conditions by conducting a one-way ANOVA to assess whether there was a difference between students' pretest scores across conditions. The results indicated no significant difference for students' pretest scores across conditions.

Based on the null result from pretest scores, we used students' gain scores from pretest to posttest to evaluate the relationship between experimental conditions and students gain scores. We conducted one-way ANOVA in which the within-subject factor was type of intervention (*interactive, constructive, active* and *passive*) and the dependent variable was percentages of students' gain scores from pretest to posttest. We used percentages of pretest and posttest scores instead of raw scores due to six additional questions in the posttest. The results for the ANOVA indicated a significant effect of condition, $F(3, 116) = 25.34$, $p < .00$. The strength of the relationship between the conditions that students assigned and their gain scores, as assessed by η^2, was strong, with the condition factor accounting for 40% of the variance of the dependent variable.

Follow-up tests were conducted to evaluate pairwise differences among the means of conditions. We used Holm's sequential Bonferroni method to control for Type I error at the .05 level across all six comparisons. All pairwise comparisons were significant. The students in the *interactive* condition received the highest gain scores; the students in the *constructive* condition did better than the ones in the *active* and *passive* conditions; and the students in the *active* condition performed better than the ones in the *passive* condition.

Discussion and Conclusions

The results from Study 1 provide initial evidence to support Chi's (2009) hypothesis that *constructive* activities provide greater returns in terms of student learning than *active* activities, and that *interactive* activities provide greater returns (most of the times) 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 and engineering class. We found that the highest student scores followed *interactive* activities in the atomic bonding unit, and the highest scores followed *interactive* and *constructive* activities in the crystal structures unit for total scores. However, 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 in both units.

The results for Study 2 provide strong evidence to support Chi's (2009) hypothesis. Using a controlled environment in a lab study, we compared four conditions by using introductory material science concepts. We found the highest gain scores received by students in the *interactive* condition and the lowest gain scores for students in the *passive* condition. Also, students in the *constructive* condition did better than the ones in the *active* condition. Overall, the results fit perfectly with the prediction of the DOLA framework.

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