Alternative Formative Assessments to Enhance Conceptual Knowledge Transfer in the Topic of Buoyancy: a Pilot Study

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Abstract

A pilot study was performed to investigate the effect of alternative formative assessments on conceptual knowledge transfer relating to the topic of buoyancy. The performance of a group of sophomore-level engineering students (N=52) was evaluated relative to the type of formative assessments they had been assigned. Students who performed well on formative assessments containing non-numerical type questions tended to show a deeper level of conceptual knowledge than those students who had been assigned formative assessments containing only conventional numerical calculation type questions.

Introduction

Learning is a constructive process in which new knowledge builds upon prior knowledge.^{1,2} It is for this reason that there is increased interest in inductive instructional methods like inquiry-based learning, problem-based learning, and just-in-time teaching to name a few. A common feature of these inductive methods is that questions or problems form the context for learning.³ Thus, formative assessments based on questions/problems can play a fundamentally important role in student learning.

The degree to which homework/activity questions impact student learning can be evaluated by considering them relative to Bloom's taxonomy. In order of increasing cognitive complexity, Bloom classifies the educational cognitive domains as knowledge, comprehension, application, analysis, synthesis, and evaluation.⁴ Formative assessments commonly found in engineering textbooks tend to fall under the domain of application, requiring students to apply particular solution procedures to determine numerical values. Blooms taxonomy has been further divided into four categories of knowledge for each cognitive level; factual, procedural, conceptual, and metacognitive.⁵ Thus, within the application domain, engineering education curriculum tends to emphasize procedural knowledge, rather than conceptual.

Although it is important for practicing engineers to be able to apply numerical problem solving procedures, engineers must also be able to make intuitive predictions regarding the behavior of a system, a skill which is highly dependent upon conceptual knowledge.⁶ Further, practicing engineers regularly employ the higher order cognitive domains of Blooms taxonomy by analyzing, creating (synthesizing), and evaluating systems. Therefore it is of interest to develop homework/activity questions in engineering education that highlight conceptual knowledge and reach towards the higher levels of Bloom's taxonomy.

Apart from Bloom's taxonomy, the impact of formative assessments can be considered in light of the Kolb model of learning.⁷ According to the Kolb cycle as shown in Figure 1, learning begins when a person has a concrete experience. The learning process continues when an individual reflects on that experience relative to their prior knowledge (reflective observation),

develops a conceptualization to explain the experience (abstract conceptualization), and then tests their conceptualization (active experimentation). The results observed after testing one's conceptualization represent yet another concrete experience which can be reflected upon to develop further conceptualizations to be tested and so on.

Figure 1: Kolb cycle of learning.⁷

The types of questions/problems commonly found in engineering textbooks may fail to engage learners in deep levels of reflective observation as they may fail to trigger students to think about their prior experiences, especially those concrete experiences from outside the classroom. If learners fail to make connections to their prior experiences (reflective observation) they will fail to develop abstract conceptualizations that reconcile new knowledge with prior knowledge. Without such conceptualizations, learners are unable to test their ideas (active experimentation) and identify potential misconceptions or other gaps in understanding. This can lead to erroneous understandings and limit students' abilities to transfer knowledge beyond the classroom.

This paper presents the findings of an investigation into the impact of formative assessment questions which deemphasize calculation. The questions/problems studied here are similar to those typically found in conventional engineering textbooks, but rather than asking students to determine numerical values, these questions ask students to compare two situations without need for numerical calculation. These non-numerical problems are similar to those found in concept inventories; instruments which are designed to quickly assess student conceptual understanding.⁶ However, unlike concept inventories, these questions are employed here as formative assessments to enhance student learning, rather than summative assessments to gauge student understanding.

Anecdotal evidence has shown that when students are presented with non-numerical questions, they tend to approach them from a conceptual context rather than defaulting to calculation based solution procedures. As such, these questions appear to be more likely to trigger students' prior knowledge than numerical calculation questions. Additionally, these questions appear to target the higher cognitive domains, including analysis and evaluation. This

preliminary investigation focuses on the impact of such formative assessments on student learning.

Methods

Buoyancy has been chosen as the subject in which to investigate the impact of assessment methods on conceptual learning. This is a topic familiar to common experience and is therefore a topic for which students will likely have preconceptions which they must overcome. Additionally, buoyancy is a subject which can be understood on the basis of foundational concepts without the need for a higher level understanding of fluid mechanics.

The research subjects employed in this study are students from a sophomore-level course in engineering statics (N=52). These students are familiar with the concepts of force, pressure, and free body diagrams; topics which are prerequisite for understanding buoyancy. However, these students have not yet formally studied fluid mechanics, and as such, any preconceptions they have are not the result of any formal education in the subject.

Each of the students was asked to read a one page handout which introduces the topic of buoyancy as a way of *learning* about the subject. Immediately following this, students were asked to complete a formative assessment (Activity X) involving the topics they had just *learned*. In Activity X, students were asked to calculate the tension force in a string which holds a Styrofoam™ block under water such as that shown in Table 1. This numerical calculation problem is similar to the types of instructional assessment often employed in engineering education.

Table 1: Experimental test matrix.

	Activity X		Activity Y
	Numerical Calculation <i>Determine the tension force.</i>	Non-Numerical <i>Which string has greater tension?</i>	Conceptual Explanation <i>Why does Styrofoam rise faster?</i>
Group A		Not Assigned
Group B

Approximately half of the students in the study (N=24) were randomly selected and given a version of Activity X which included an additional non-numerical question (Group B). In this

non-numerical question students were asked to compare the tension forces on two identical StyrofoamTM blocks held under water at different depths with a string as shown in Table 1. The Activity X assessments were collected by the instructor and the students' performance recorded. These activities were then returned to the students the following class period along with an answer key for the corresponding version of the activity. In an effort to control the sources of input for student learning, no grading marks or other feedback were written on the student papers.

During the third class period, students were asked to complete a summative assessment (Activity Y) in which they considered a wooden block and a StyrofoamTM block (identical size) submerged at the same depth under water as shown in Table 1. Students were asked to explain why the StyrofoamTM block is observed to reach the surface of the water faster than the wooden block when released simultaneously. These activities were collected and student performance analyzed relative to the version of Activity X assigned.

Results and Discussion

Student performance on the numerical calculation question from Activity X was very high, with only 3 of 52 students answering this question incorrectly. These same three students also answered Activity Y incorrectly. This may suggest that procedural knowledge is prerequisite for developing an informed understanding of conceptual knowledge. However a sample size of three is clearly far too small to make meaningful conclusions.

For the remaining students who correctly answered the numerical calculation question, their performance on Activity Y is outlined in Table 2. Of the students who were assigned only the numerical calculation question on Activity X (Group A), 44% correctly answered the explanation question on Activity Y. Of the students who were assigned both the numerical calculation and non-numerical questions on Activity X (Group B), 64% correctly answered the explanation question on Activity Y. This suggests that exposure to non-numerical questions increases students' conceptual knowledge beyond what is attained through exposure to numerical calculation questions alone. However, due to the small sample size in this study, this finding is not statistically significant ($z = 1.34$).

Table 2: Student performance on Activity Y relative to Activity X.

	Group Size	Activity X Performance		Activity Y Performance	
	Number of Students	Numerical Calculation	Non-Numerical	Number Correct	Percentage Correct
Group A	27	Correct	Not Assigned	12	44%
Group B	22	Correct	Assigned	14	64%
Group C	14	Correct	Correct	10	71%

When comparing students who correctly answered the non-numerical question from Activity X (Group C) to those who were assigned only the numerical calculation question (Group A), a statistically significant trend does emerge with 71% of students in Group C

answering Activity Y correctly compared to 44% in Group A ($z = 1.64$, $p < 0.1$). Thus, conceptual knowledge may be enhanced for students who perform well when prompted with a non-numerical question, compared to students who are only assigned numerical calculation questions.

If students who demonstrate a higher level of understanding in non-numerical questions are more likely to have a better understanding of conceptual knowledge, then it is of interest to increase performance on these types of questions. It seems reasonable that increased practice with such formative assessments would lead to increased performance. Future studies will seek to investigate this hypothesis.

When interpreting the results of Activity Y, the information being attained must be carefully considered. When students correctly answer this question, they demonstrate that they can provide a clear explanation of why the StyrofoamTM block rises faster. For students who incorrectly answered this question, their answer may simply reflect an inability to provide a clear explanation, rather than a lack of conceptual understanding. If the results are interpreted in this way, it follows that increased performance on the non-numerical question leads to an increased ability to provide clear explanations within conceptual contexts. Given the ever increasing importance of written communication skills, such a conclusion would still provide incentive to increase performance on non-numerical questions.

Aside from the impact on conceptual knowledge, the results of this study reveal the difficulty of non-numerical questions. While 93% (49/52) of students correctly answered the calculation question on Activity X, only 58% (14/24) correctly answered the non-numerical question. This suggests that the current methods of instruction are not adequately preparing students with the necessary critical thinking and problem solving skills to address such questions. This is cause for concern considering that these non-numerical questions reflect the fundamental basis of the types of analysis and evaluation performed by practicing engineers.

An additional observation of this study is the degree to which new knowledge can lead to confusion or rejection of prior knowledge. When answering Activity Y, 12% (6/52) of students incorrectly answered that both of the StyrofoamTM and wooden blocks would rise to the surface in the same amount of time, despite being told that the StyrofoamTM block would rise faster in the problem statement. These students were all partially correct in their reasoning, noting that both blocks experience the same buoyancy force. However, these students failed to take into account the gravitational force on the blocks (weight). This highlights the need for instructors to help students in connecting new knowledge to prior knowledge by creating learning environments which allow students to apply the Kolb cycle. Whether employed as formative or summative assessment, questions such as this will likely provide an opportunity for conceptual learning to occur. For example, by testing one's theory that both blocks rise at the same time (active experimentation) and receiving feedback that this is incorrect (concrete experience), a student is forced to further reflect until developing an accurate conceptualization of the problem.

This study will be repeated with other groups of students to increase sample sizes and improve the generalizability of the findings. Additional studies will be performed to investigate the cognitive processes students employ when they approach non-numerical problems versus

numerical calculation problems. Further, future work will investigate whether continued practice with non-numerical problems leads to increased performance on questions of this type.

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