Evidence of Students' Content Reasoning in Relation to Measure of Reform

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Abstract. As part of a study of the science preparation of elementary school teachers, we investigated the quality of students' reasoning and explored the relationship between sophistication of reasoning and the degree to which the courses are considered inquiry oriented. First, we devised written content questions, which were open ended with the distinguishing feature of applying recently learned concepts in a new context. All the questions developed were based on a common template that required students to recognize and generalize the relevant facts or concepts and their interrelationships to suggest an applicable or plausible theory. To evaluate students' answers, we developed a rubric based on Bloom's taxonomy as revised and expanded by Anderson. Along with analyzing students' reasoning, we visited 20 universities and observed the courses in which the students were enrolled. We ranked the courses with respect to characteristics that are valued for the inquiry courses. With the large amount of collected data, we found that the likelihood of the higher cognitive processes are in favor of classes with higher measures of inquiry.

Keywords: Logistic Regression, Odds Ratio, Factual Knowledge, Procedural Knowledge, Written Content Questions, Taxonomy Table.

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INTRODUCTION

The National Study of Education in Undergraduate Science (NSEUS) is studying the effect of active engagement in undergraduate science courses taken by future teachers on their teaching of science in elementary schools [1]. One of the goals of this project is to explore the relationship between students' learning of content knowledge and the degree that science courses are geared toward interactive engagement teaching-learning strategies.

nationally distributed Twenty universities participated in our study. The courses investigated at these universities covered a variety of science disciplines. Accordingly, a direct comparison on subject matter learning was impossible. Instead, we concentrated on comparisons of reasoning skills within the content that the students had learned. Because of the size of study, we were not able to interview the students and needed to rely on written responses to exam questions. Therefore, we wrote questions designed to elicit reasoning skills and developed a rubric for comparing the reasoning patterns in the students' written responses.

ASSESSEMENT OBJECTIVES

Often emphasized in previous research is the significance of applying prior knowledge to construct knowledge in a new context. In agreement with researchers of schemata theory [2] the quality of reasoning relates to the pieces of knowledge and cognitive abilities that students bring to a new context and the way they connect and organize pieces of information. In other words, reasoning can be defined in terms of the thought processes and knowledge types that students bring to a new context. knowledge pieces are brought together, knowledge is created through mental processes such as association, classification, combination and refinement [3]. The National Science Educational Standards [4] also emphasize conceptual understanding, using various procedural skills to approach a problem and engage students in higher levels of thinking such as classifying, summarizing, inferring, comparing, explaining and applying their prior knowledge to a new context. According to the National Science Education Standards, successive statements that follow one another logically without gaps from statement to statement characterize a wellreasoned response. In another study, Russ et al. [5] emphasized the association of cause and effect, and also the underlying process that explains how the cause and effect are associated. Evaluating correctness, use of controlling variables or measuring students' conceptual knowledge may not effectively assess the students' gains due to inquiry.

Using this previous research as a foundation, we selected our objectives from Bloom's taxonomy as revised by Anderson *et al.* [6]. This taxonomy originally was developed for organizing and classifying instructional objectives. One of its main goals is to make objectives specific and clear for instructional plans and assessment design. Our objectives along the knowledge dimension can be described as *Factual Knowledge*, *Conceptual Schema* (an aspect of *Conceptual Knowledge*) and *Procedural Knowledge* and along cognitive dimension, includes *Compare, Infer and Explain* from the categories of *Understand* and *Apply*. In this paper we will focus on the cognitive processes.

RUBRIC

Based on the assessment objectives that we selected from the revised Bloom's taxonomy, we developed a scoring guide with seven traits that distinguishes the different levels of reasoning. In contrast to holistic scoring, this type of approach is called analytical-trait scoring [7] in which the assessor judges students' performance several times, each time through the lens of different criteria. Based on the description provided for each trait, we determined whether evidence for the particular trait occurred in the written answer.

Understand /Compare and Contrast

We looked for the evidence of comparing those aspects and features that were fundamental for justifying cause and effect changes or comparing variables that provided plausible evidence for why, how and what changed that caused the effect.

Understand/Infer

We assessed if the answer recognized the patterns that connected series of the events and instances and plausible connections and relations between cause and effect.

Understand/Explain

We looked for a cohesive and convergent argument that both described the situation and

predicted the outcome and was well supported by showing why and how things are happening.

Apply

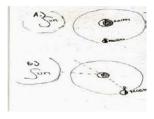
We sought evidence of the association among facts, concepts and procedures that was reconstructed in connection with the features of the question scenario to present a plausible answer.

ANALYSIS OF STUDENT RESPONSES

As an example of the type of question we used, the following question was given to an inquiry-oriented astronomy course for elementary education majors at a small Midwestern university. Fifty students completed this question on the final exam. We have chosen two typical responses that are representative of the types of reasoning that show evidence or non-evidence for each trait of our rubric.

Question: You look outside and see a first quarter moon. Suppose that an astronaut were on the moon looking at Earth. Make a sketch of the Earth as seen by the astronaut. How will the illuminated portion of the Earth appear different three days later? [8]

Response 1) The astronaut would see a 3rd quarter, waning moon. The moon will have moved slightly more in its evolution, making earth see the moon as slightly more than 1st quarter. In contrast, the earth would appear less full to the astronaut on the moon.



Response 2) The earth-illuminated portion would decrease same, it would be a waning gibbous instead of a third quarter. It would be even a waning crescent almost a full earth, depending on the rotation



Understand/Compare and Contrast: The first response compared the moon's positioning and moon's and earth's sunlit portions in the sun-earthmoon model. The second response only compared the appearance of the sunlit portions of earth that are

analogous to the moon. Although the second student's response is not as in-depth as the first one, in both cases there is evidence for the cognitive process of compare.

Understand/Infer: The first response showed an in-depth interconnection between a series of causes and effects including the changes in the location of the observer in two situations on the sun-earth-moon geometrical model that in effect causes a change in the appearance of the sunlit portions of the earth and the moon. However, the second response includes a series of disconnected concepts without any plausible connection between the described events.

Understand/Explain

The first student described his/her understanding of the situation and predicted the outcome with a series of explanations that describes why and how the predicted outcome is true. However, the second student did not provide any additional explanation to support his predicted outcome.

Apply: The first student reconstructed the previous knowledge of moon phases to predict the appearances of the earth phases from the perspective of the observer that is located on the moon, whereas the second student simply showing the previous knowledge of moon phases.

SITE VISITS

We used the Reformed Teaching Observation Protocol (RTOP) [9] as our observational instrument to determine the degree to which a science classroom is "reformed." This observational protocol uses the characteristics of reformed teaching practices based on National Science Education Standards [4]. The characteristics are organized into five categories: Lesson Design and Implementation, Propositional Pedagogical Knowledge, Procedural Knowledge, Communicative Interactions and Student/Teacher Relationships. Each category includes five items which the observer ranks on a scale of 0-4. Summing the 25 item scores results in an RTOP lesson score ranging from 0-100, which describes the degree of reformed teaching present Observations for the RTOPs, took place during site visits to each institution in the middle of the semester. The university faculty members were participants whose classes we observed. The RTOP scores for this sample ranged from 35 to 90.

STATISTICAL ANALYSIS

To explore the relationship between the quality of the students' reasoning and the measure of reform, we collected data from 904 students at the 20 universities. For every student's response to the content questions, we assigned seven binary codes. The binary codes indicated whether the response showed evidence or no evidence for each of the traits described in our rubric. Because our data are categorical and our variables are dichotomous, we cannot use normal regression to relate the quality of reasoning to the RTOP scores. Instead, the logistic regression model [10] can be used when one of the variables is binary or dichotomous.

As a first step in our analysis, we estimated the strength of relationships between evidence of cognitive processes appearing in the students' responses and the level of inquiry as measured by RTOP. To accomplish this estimation we used a simplified logistic regression analysis based on with two dichotomous variables.

A common way to create a dichotomous variable is to divide a continuous one into two groups – high and low. To obtain a dichotomous variable for the RTOP score, we used the average RTOP score for all of the classes observed as the dividing point That average (65.5) was considered the boundary between high and low RTOP scores.

First we calculated the odds that students showed evidence for each trait of rubric if they were in a class with a higher than average RTOP. (i.e. RTOP > 65.5). Then we calculated the odds for students in a class with lower than average RTOP scores. The odds are given as follows:

$$Odds = \frac{Number of (evidence)}{Number of (no evidence)}$$

Then we calculate the odds ratio as

$$Odds \ ratio = \frac{High \ RTOP \ odds}{Low \ RTOP \ odds}$$

Table 1 shows the number of students who showed evidence or no evidence for cognitive process of "Apply" for the two groups of RTOP < 65.5 and RTOP > 65.5.

Odds ratio for Apply
$$=\frac{254/195}{191/190} = 1.3$$

Table 1. Odds ratio for the "Apply" cognitive process.

Apply	RTOP < 65.5	RTOP > 65.5	Total
Evidence	191	254	445
No- Evidence	190	195	385
Total	381	449	730

The odds ratio of 1.3, implies that a student in a higher than average RTOP class is 1.3 times more likely to show evidence of using "Apply" than one in a low RTOP class. However, for the cognitive process of "Explain" the odds ratio was 1, indicating that there was an equal chance of showing cognitive process of "Explain" for both low and high RTOP courses.

Table 2 gives the odds ratios for each of the cognitive processes we investigated.

Table 2. Odds ratio for all cognitive processes under investigation.

Cognitive process	Odds ratio	
Understand /Compare	1.84	
Understand /Infer	1.42	
Understand/Explain	1	
Apply	1.3	

DISCUSSION AND FUTURE WORK

In this study, we adopted a mixed methodology using both qualitative and quantitative approaches. First, we created a protocol to develop content questions with same level of thought processes in different disciplines. Then we developed a rubric to classify students' reasoning based on the analytical scoring of the responses. The simplified version of logistic regression indicated that evidence for cognitive processes depend on RTOP scores in the favor of higher RTOP scores. Because RTOP scores for a class are a measure of the level of interactive engagement, this preliminary result indicates that students in interactive engagement classes are more likely to show evidence of cognitive processes on their written exam questions. While the simplified model and preliminary results of Table 2 provided insight into the relationship between RTOP scores and the evidence displayed on content exams, the functional form of this relationship was still needed to be described. The results of using simplified model of logistic regression were promising to use the full version of binary logistic regression. Using the full version of this statistical model, we found the nature of relationships that existed between RTOP overall scores as an independent variable and traits of our rubric as independent variables. Discussing the details of this analysis is beyond the scope of this paper and we will report that elsewhere.

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