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Argumentation and formal reasoning skillsin an argumentation-based guided inquiry course

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Abstract

The development of argumentation skills and scientific reasoning abilities is examined in an introductory inquiry-based physics class. The role of competing theories teaching strategy in fostering the acquisition of argumentation and formal reasoning skills is investigated. A repeated measures MANOVA analysis shows that argumentation skills improve during instruction which includes student exercises with competing theories strategies.

Keywords: argumentation, formal reasoning, inquiry, competing theories;

1. Introduction

Deficiencies in scientific reasoning by students in science classrooms have been the focus of much research in science education (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Kelly, Druker, & Chen, 1998; Watson, Swain, & McRobbie, 2004). Examination of student scientific reasoning revealed that students have difficulty in evaluating and constructing different alternatives to a position (Kuhn, 1993; Kuhn, Schauble, & Garcia-Mila, 1992). Argumentation has been presented as a remedy to this problem (Kuhn, 1993; Osborne, Erduran, & Simon, 2004). From this perspective, argumentation can be defined as the reasoning involved in weighing different alternative positions or theories (Driver, Newton, & Osborne, 2000).

Toulmin's argumentation pattern has been used to assess and model scientific reasoning in argumentation research (e.g., Osborne et al., 2004; Zohar & Nemet, 2002). According to this framework, the basic format of an argument consists of data, warrant, backing, and claims. Data are the facts used to support a position. The warrant is reasoning that connects the data to the claim, while the backing is a basic assumption in a domain that supports the warrant. Finally, the claim is the conclusion to be justified in an argument (Driver et al., 2000).

Studies have shown that student argumentation may be enhanced by incorporating practice in argumentation into the curriculum (Osborne et al., 2004; Zohar & Nemet, 2002). Specifically, a teaching strategy incorporating competing theories has been reported to enhance student argumentation (Acar, 2009; Osborne et al., 2004). In this strategy, alternative theories and evidence about scientific phenomena are provided to students. Students are then encouraged to construct arguments, counter-arguments and rebuttals.

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Research on student formal reasoning has predominantly examined the relation of formal reasoning to conceptual knowledge. The results of this research show that more formal reasoners hold fewer misconceptions than less formal reasoners (Lawson & Weser, 1990), that formal reasoning scores predict conceptual knowledge gain (Ates & Cataloglu, 2007; Coletta & Phillips, 2005), and that formal reasoning scores predict student achievement in college science courses (Johnson & Lawson, 1998).

Against this background, the present authors have been unable to find research in the literature examining which argumentation skills may be enhanced in argumentation-based classroom contexts that utilize a competing theories teaching strategy. In addition, no research was found which examined student formal reasoning in argumentation-based classroom contexts. The aim of this study is to address these issues. Two research questions were therefore examined in this study:

- Research Question 1: What argumentation skills develop during argumentation-based instruction that utilizes competing theories teaching strategy?
- Research Question 2: How do student formal reasoning skills change during argumentation-based instruction that utilizes a competing theories teaching strategy?

2. Context and Sample

An introductory inquiry-based physics course of 125 students comprised the initial sample for this study. Since 47 students completed all instruments used, results are reported for this sub-sample. Students met twice a week for a total of six hours per week, working in small groups consisting of three to four members. During the 10 weeks of the instructional period, students used material from Physics by Inquiry Vol. I (McDermott, 1996), doing guided experiments and exercises on the concepts of balancing, mass, volume, density, buoyancy, heat and temperature.

A group of eight instructors taught three sections of the course: one physics professor, two instructors, one graduate student, and four undergraduate students who took this course in previous years. Instructors met once a week to discuss instructional content and ways to foster student conceptual understanding and reasoning. The instructors did not lecture during the course, but rather checked student understanding and reasoning regularly by asking for explanations and providing guiding questions in small group discussions.

A competing theories teaching strategy was used to incorporate argumentation into the course curriculum. Student arguments, counter-arguments, and rebuttals were encouraged in these argumentation exercises. During the argumentation activities, students read the different points of view and discussed this controversy in small groups. In written argumentation exercises, students read the controversy and provided their arguments, counter-arguments, and rebuttals on an answer sheet.

3. Instruments

3.1. Argumentation Test

Two argumentation tests regarding balancing and buoyancy concepts were developed using the competing theories strategy. Each test was administered as a pre- and post-test. Two hypothetical students were presented as supporting alternative explanations of balancing concepts, and, in the second variant, of buoyancy concepts. Evidence relevant to this controversy was also provided to students. The evidence was selected so that some of the evidence could be used in one hypothetical student explanation and some could be used in the other explanation. Hypothetical student explanations regarding balancing were as follows (Acar, 2009; p. 136):

Student A: Masses should be equal on both sides of the balance. If the object is symmetric, then the fulcrum is at the center which makes the two sides equal and balanced. If the object is asymmetric, then the fulcrum gets closer to the more massive part making both sides of the balance have equal masses.

Student B: Balancing depends on the distance of the sides from the fulcrum and the masses on each side. If the mass of one side is bigger than the other side then that side should have less distance from the fulcrum compared to the other side.

Evidence provided regarding this disagreement were: ’a tightrope walker balances on a rope’, ’a symmetric ruler balances on a person’s finger’, ‘a baseball bat balances on a person’s finger’, and ‘A huge cup is placed at the left end of the seesaw. Three people who have equal masses balance this cup. The first person is at the right end of the seesaw’. For the buoyancy concept, hypothetical student explanations were as follows (Acar, 2009, p. 136):

Student A: The mass of the objects affects whether they sink or float. Thus, heavier objects will sink whereas lighter objects will float in a given liquid.

Student B: Both mass and the volume of the object affects sinking and floating in a given liquid. Thus, if the quantity of the mass (g) is bigger than that of the volume (cm^3) of the object, it will probably sink whereas if the quantity of the mass is smaller compared to that of the volume of the object, it will probably float.

Student argumentation tests were coded according to Toulmin’s argumentation pattern. For these analyses, both the structure and quality of the arguments were considered (Sandoval & Millwood, 2005). After an initial review of student responses, a working baseline rubric was constructed and then this rubric was revised to account for all cases encountered in the second review. Final rubrics can be seen in Tables 1, 2, and 3. A physics graduate student re-coded a randomly selected 20% of the argumentation tests to establish the inter-rater reliability. Inter-rater reliability scores for the balancing argumentation test were 0.78 for evidence scores and 0.75 for justification scores. For the buoyancy argumentation test, the inter-rater reliability scores were 0.77 for evidence scores and 0.59 for justification scores. In addition, internal consistency from Cronbach’s alpha was computed as 0.67 (n = 98) for the balancing argumentation pretest, 0.63 (n = 66) for the balancing argumentation posttest, 0.77 (n = 99) for the buoyancy argumentation pretest, and 0.69 (n = 68) for the buoyancy argumentation posttest.

Table 1: Evidence scores for student arguments and counter-arguments.

Score	Description
0	No evidence or wrong evidence
1	Citation of or reference for 1 correct piece of evidence
2	Citation or reference for 2 correct pieces of evidence

Table 2: Evidence scores for student rebuttals.

Score	Description
0	No evidence or wrong evidence
1	Citation of or reference for 1 correct piece of outside evidence i.e., evidence not provided for the argumentation tests
2	Citation or reference for 1 correct piece of evidence

Table 3: Justification scores for student arguments, counter-arguments, and rebuttals.

Score	Description
0.5	No or wrong justification
1.0	Vague justification, irrelevant justification [a]
1.5	A general justification for 3 or more observations which fits scientifically for some of the observations but not all of them
2.0	A general justification for 2 or more observations which fits scientifically for all of them
2.5	A justification that refers to an observation but is scientifically incomplete or has some scientifically correct part and some scientifically incorrect part.
3.0	A justification that refers to an observation and scientifically correct

[a] In addition to vague or irrelevant justifications, a score of 1 was also given for student rebuttals to justifications that had generalizability concerns for the hypothetical students’ arguments.

3.2. Formal Scientific Reasoning Test

To examine the change of student formal reasoning skills, the revised version of the Classroom Test of Scientific Reasoning was employed as pre and posttest (Lawson, 1978; Lawson, 2000). This test consisted of 12 two-tier multiple choice items assessing reasoning skills such as probabilistic, combinatorial, hypothetical, and correlational reasoning. Each two-tier question consists of one content and one reasoning question. Student responses were coded 1 if they answered both content and reasoning questions correctly and coded 0 if they answered incorrectly content or/and reasoning questions. To examine internal consistency, Cronbach's alpha was computed to be 0.70 (n = 121) for pretest and 0.68 (n = 118) for posttest administration.

4. Results

Descriptive statistics for balancing and buoyancy argumentation scores are given in Table 4. Multivariate Analyses of Variance (MANOVA) for repeated measures was performed on student balancing argumentation scores to examine the change of argumentation scores from pretest to posttest. Time (pre-post) was the repeated factor and student argumentation scores, i.e., argument, counter-argument, and rebuttal evidence scores together with argument, counter-argument, and rebuttal justification scores, were the dependent variables in this analysis. The results show that overall student argumentation scores changed significantly from pretest to posttest ($F(6,41) = 5.01$, $p < 0.005$). Follow-up Analyses of Variance (ANOVA) showed that argument evidence, argument justification, and counter-argument evidence scores did not change significantly from pretest to the posttest ($F(1,46) = 1.89$, $p > 0.05$; $F(1,46) = .80$, $p > 0.05$; $F(1,46) = .24$, $p > 0.05$ respectively). On the other hand, counter-argument justification, rebuttal evidence, and rebuttal justification scores increased significantly from pretest to posttest ($F(1,46) = 10.16$, $p < 0.005$; $F(1,46) = 12.94$, $p < 0.005$; $F(1,46) = 22.08$, $p < 0.005$ respectively).

Table 4: Descriptive statistics of balancing and buoyancy pretest and posttest argumentation scores

	Balancing Pretest		Balancing Posttest		Buoyancy Pretest		Buoyancy Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Argument Evidence	1.11	.81	1.32	.89	1.28	.90	1.57	.68
Argument Justification	3.10	1.52	3.17	1.62	2.88	1.63	3.76	1.63
Counter-Argument Evidence	1.41	.64	1.48	.74	1.13	.71	1.50	.68
Counter-Argument Justification	3.02	1.29	3.89	1.58	2.99	1.34	3.95	1.42
Rebuttal Evidence	.74	.90	1.34	.94	1.06	.97	1.36	.90
Rebuttal Justification	1.06	.64	1.77	.85	1.68	.82	2.13	.72

n = 47

Another MANOVA for repeated measures was performed on student buoyancy argumentation scores. Time was the repeated factor and argumentation scores were the dependent variables in this analysis. The result showed that overall student argumentation scores changed significantly from pretest to posttest ($F(6,41) = 3.74$, $p < 0.01$). Follow-up ANOVA results showed that argument justification, counter-argument evidence, counter-argument justification, and rebuttal justification scores increased significantly from pretest to the posttest ($F(1,46) = 7.19$, $p < 0.05$; $F(1,46) = 9.75$, $p < 0.005$; $F(1,46) = 14.29$, $p < 0.005$; $F(1,46) = 9.22$, $p < 0.005$, respectively). However argument evidence and rebuttal evidence scores did not change significantly ($F(1,46) = 3.56$, $p > 0.05$; $F(1,46) = 3.10$, $p > 0.05$, respectively).

To examine the change of formal reasoning scores from the pretest to the posttest, a t-test analysis was performed. It was found that posttest formal reasoning scores ($M = 8.26$, $SD = 2.18$) were significantly higher than pretest formal reasoning scores ($M = 7.02$, $SD = 2.35$; $t = 4.05$, $p < 0.005$).

5. Discussion

The purpose of this study was to examine what kind of argumentation skills develop during an argumentation-based inquiry course and to examine the change of formal reasoning scores. For argumentation skills, it was found that counter-argument and rebuttal skills developed for both balancing and buoyancy concepts. However argument score gains developed only for the buoyancy concept but not for the balancing concept. From these results, it may be concluded that counter-argument and rebuttal skills may develop during an argumentation-based inquiry course which utilizes a competing theories teaching strategy. To strengthen these findings, a quasi-experimental research design utilizing a control group would be useful, although generally difficult to implement.

Given the previous research findings that students have trouble arguing for a different alternative position (Kuhn et al., 1992), the present results are encouraging since this difficulty may be overcome with the use of competing theories teaching strategy. Examination of student formal reasoning showed that these skills improved during the instruction. In contrast, Schen (2007) found that formal reasoning scores do not develop during a traditional introductory college biology course in which argumentation skills were not taught. Thus the findings of the current study suggest these reasoning skills may be improved in a college course to which argumentation instruction is incorporated into the course curriculum.

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