Design of Argumentation Techniques for Learning Engineering Statics

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This manuscript reports the progress of a project investigating collective argumentation as a strategy to help students understand the various concepts taught in statics and to develop learning modules that incorporate this learning strategy. The intent is to reduce the number students who repeat statics, thereby enhancing the efficiency of time and resources dedicated to the course that is critical at the University of Georgia where the engineering undergraduate student body has grown from 400 students in 2012 to approximately 2000 students. Indirect impacts include affecting how students approach material taught in upper division engineering courses that require statics as a prerequisite.

A course in engineering statics provides the vital knowledge needed by students enrolled in most engineering disciplines, requires students to begin "thinking like an engineer" and is a foundation course for seven of the eight UGA's engineering curricula. Data gathered between 2000 and 2013 indicate that 20-30% students who took Engineering Statics (ENGR 2120) at this University did not make high enough of a grade to progress further through the curriculum. These students either repeated the course or transferred to another major. Similar situations exist around the world. For example, records from Malaysian universities indicate 27% of students enrolled in statics were course repeaters (Haron et al. 2012). At the University of Georgia (UGA), repeating statics commonly delays progression toward graduation by one year. Assuming our past passing rate in statics remains the same, a minimum of two ENGR 2120 course sections are needed just for repeaters, current section size for this course is 72 students. A support system addressing this single academic issue could improve the retention rate for the College of Engineering and reduce the time and resources dedicated to this one course.

Completion of an introductory physics course in Newtonian mechanics and an integral calculus course are common prerequisites for statics. A common belief is students good in physics and mathematics can quickly master the principles taught in a statics course. This belief often leads to instruction and textbooks that are insufficient for success in statics. Statics and introductory physics courses are different. First, the physics course commonly focuses on a single force acting between two bodies, provides the direction of the involved forces and limits translations to single body movement. Statics involves multiple and distributed forces across multiple bodies, force directions must be calculated, and rotation plus translation is involved. On top of this, statics instructors often assume students are so well founded in math that little needs to be done before throwing the student into a mathematical operation describing a complicated statics concept. From 2000 to 2015, 60% of UGA students who made a D or F in statics also made a B or A in calculus I and a B or A in physics I. Thirty percent of these same students earned a B or A in calculus II. Therefore, more than a well-founded background in math is needed before success in statics is certain.

So why do students who are so successful in mathematics and physics struggle in statics? Researchers at Carnegie Mellon University suggest that developing an incorrect free-body diagram is a leading cause of low performance in statics (Steif and Hansen 2006). Free-body diagrams identify the particular system of forces that need to be analyzed, and if incorrect, the student will solve a "bogus" problem. One study suggests that wrong free-body diagrams result from the practice of representing forces and moments as mathematic vectors (Brose and Kautz 2011). As such, students may be unaware of how "powerful" a force might be since it is simply a “line” on a drawing. They also perceived forces and moments as interchangeable since both were vectors. Possible causes of this include textbooks and lectures that represent moments as vectors traveling in a circle about a point. One solution allows the student to experience forces and moment through a hands-on experience where a physics example is used to explain a mathematical manipulation (Brose and Kautz, 2011). While no single learning approach appears to be used by students, a significant number just worked more and more problems until the student develops a perception of a mathematical “pattern” being associated with a particular type of problem (Venters, McNair and Pareti 2014). Often, the instructor encourages this approach as the best method to learn statics. However, merely working more problems is not learning the concepts of statics although it appears to help with passing the course. Steif and Dantzler (2005) suggest early detection of student misconceptions is key to helping students learn statics, and Venters et al. (2014) indicate that writing-to-learn strategy helps identify and overcome these misconceptions. The self-explanation approaches have shown to help weaker students understand the fundamental concepts of statics (Litzinger et al. 2010).

The principles of argumentation, an effective approach for promoting student deep-level understanding of content, provides the foundation of the investigation outlined in this manuscript (Nussbaum, 2008). A form of discourse found in multiple fields of education primarily due to its relationship with critical and higher order thinking and argumentation supports

- articulating the reason for approaching a problem in a particular way,
- justifying the approach using data and/or information to support the reasoning, and
- providing the principles that establish the justification.

Influenced by Toulmin (2003), the framework of argumentation (Figure 1) is constructed around three core members commonly called the claim, data, warrant with supporting members commonly known as backing and rebuttals. This framework provides a process for breaking down how a student approaches a problem and analyzing the student’s understanding (or misunderstanding) if the concept. Table 1 provides an example of how argumentation is used to help elementary school students understand mathematical and science concepts often misunderstood. While the content within the claim, data, warrant and other framework members is discipline-dependent, the construction of the argument is field- invariant. When using argumentation in a classroom environment, the instructor plays an important role by helping the student understand theories and principles, but the instructor is not the authority to explaining why a principle makes sense for solving a problem. Table 2 provides examples of the appropriate questions and actions that teachers can use to develop the student’s cognitive skills via argumentation. Through the lens of engineering practice, an argumentation-based framework (Table 1) is used to support the rational decisions that design teams make when analyzing, deliberating and compromising on the solution to an engineering problem (Jin and Geslin, 2009, 2010). Research indicates this framework helps the engineer identify misconceptions about the problem that is to be solved and spends more time exploring alternative

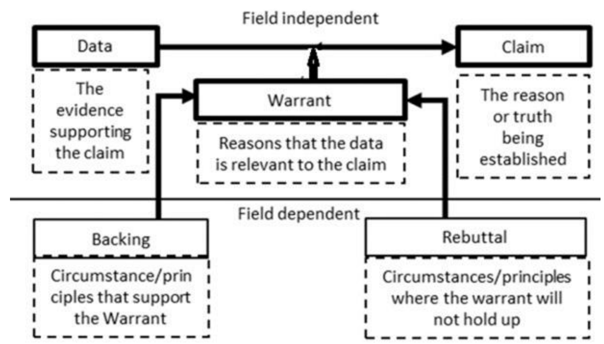


Figure 1. The general structure of Toulmin’s framework that provides a logical process for analyzing how a student constructs an argument and for determining how the students understands (or misunderstands) a principle referred to as the claim.

solutions, similar impacts that collective argumentation had on students in the classroom environment.

The research questions were "How does collective argumentation improve (or decrease) student academic performance in Statics" and "What is student reaction to the application of argumentative learning in an engineering science classroom environment." This investigation began in the 2016 spring semester and is continuing at the time of this manuscript. The following paragraphs outline the results of the 2016 spring and fall semesters.

Table 1. Examples how argumentation is used to help young students (elementary grades) understand concepts in math and science.

Members of the argumentation framework	Mathematics Example	Science Example
Claims: Statements or principles whose validity is being established	The slope of the function is 4	The further the object is from the Sun, the longer it takes to orbit
Data: Statements provided as support for the claims	Table of values on board	Table of the distance planets are from the Sun and their speed
Warrants: Statements that connect data with claims	y-values change by 4 when the x-values change by 1	Distance divided by speed equals travel time
Rebuttals: Statements describing conditions under which the warrant is not valid	Unless you calculated incorrectly	Unless orbit speeds are much faster for a planet further out
Qualifiers: Statements describing the certainty with which a claim is made	Definitely, … Probably, …	

Table 2. Examples of the type of teacher support used to develop the cognitive skills of elementary school students studying mathematics.

Teacher action	Activity to engage the student in argumentation
Requesting a factual answer	What is the sum of the exterior angles of a polygon?
Requesting a method	How did you figure that out?
Requesting an idea	Looking at this table, what do you conclude?
Promoting the exploration of an idea	You might have to try something else

Table 3. Examples how argumentation is used to help young students (elementary grades) understand concepts in math and science. Design-argumentation is a critical part of the engineering.

	Engineering Design Example
Claims	Household kitchen wastewater will provide water for the average family garden
Data	Graph showing water need vs. family size; Graph of rainfall amount
Warrants	Cumulative table of rainfall during weeks the plants grow.
Rebuttals	Graph of rainfall in a different region (desert)

Participants and course design

In the 2016 spring semester, a total of 61 students enrolled in the statics course taught by the PI of this investigation with 30 students enrolled in one class section and 31 students (1 graduate student from kinesiology) enrolled in another class section. A total of 30 lecture sessions and a total of 15 problem-solving sessions that took place, giving a total of 45-course sessions held during the semester. Both groups of students attended lecture sessions (75 minutes long) held each Tuesday and Thursday and problem-solving sessions (50 minutes long) held each Wednesday. Students self-selected which section to attend, when she/he registered for the course. In the 2016 fall semester, a total of 76 students enrolled in the course with 38 students in one of two lecture session (75 minutes long) held each Tuesday and Thursday. The 38 students were divided into groups of 19 students who attended problem-solving sessions (50 minutes long) held every Friday throughout the day. The PI taught the lecture sessions, and a post-doctoral student taught the problem-solving session.

During the 2016 spring semester, two undergraduate TAs provided support to the PI during problem-solving sessions. During the 2016 fall semester, TAs provided support during the lecture sessions. The duties of the TA's were to monitor how students engaged classroom activities and to provide support if a student did not understand what she/he was to do. Traditional drop-by tutoring services were provided to all students enrolled in statics. Of the students participating in this study, only 12 of the 2016 spring semester students and only 14 of the 2016 fall semester students attended these sessions, and no student attended these sessions on a weekly (or regular) basis.

The treatment group consisted of students enrolled in a course section where collective argumentation was the primary mode of presenting course content. The students were given a word problem that was associated with the topics for that day's lecture and asked to write answers to the following: What is the principle that you would use to solve the problem (the claim)? What is the mathematical and/or scientific rationale that demonstrates that your choice of principle/concept is valid (the warrant)? What information do you need? Next, the student was asked to discuss her/his answers with a partner and to determine "What principle did your partner choose and what was the mathematical and/or scientific rational you and your partner used (the qualifier)?" "Which of your two answers is correct?". TAs would provide assistance as requested and would observe the claim and warrant students would develop. These observations were shared with the instructor (the PI). Next, the instructor would engage the class in a discussion where an individual student was asked to express what claim did her/his group develop and what warrant was used. The student's answer guided the instructor as the lecture proceeded. Commonly two problems were worked during the class session.

The controls consisted of students enrolled in a course section where the instructor provide a traditional lecture. After a 15-30 minute lecture, the students were asked to work a problem associated with the lecture topic; typically the students would identify how to work the problem and outline the equations and data need to solve the problem. Students were allowed to work in groups, and TAs were available to provide assistance. The instructor interrupted the students only after a few minutes and worked the problem on the board, periodically answering questions.

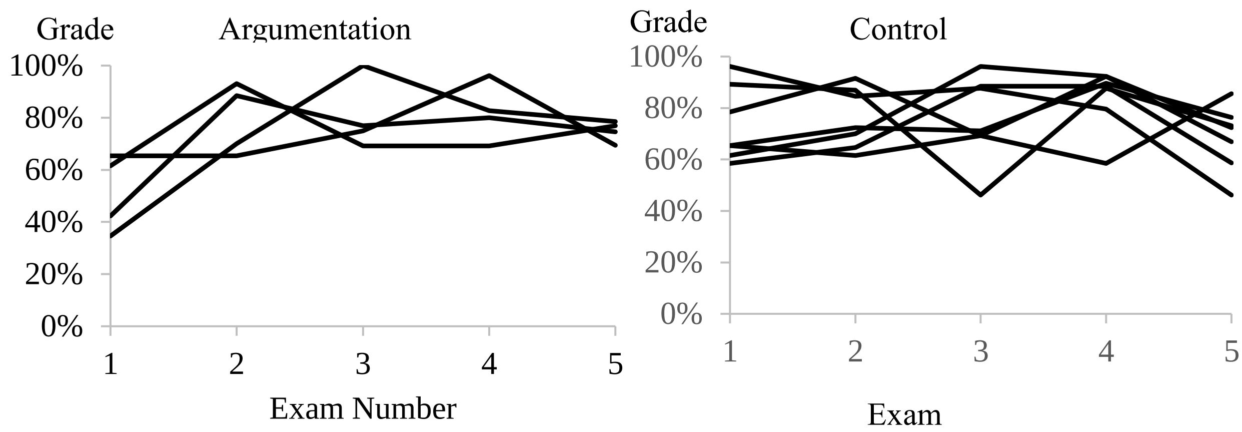
Attendance at the lecture and problem-solving session was encouraged using a grade reduction scheme. Students were allowed to miss three sessions (lecture + problem-solving sessions) without a final grade penalty. Data obtained from students who missed more than three classes or who withdrew from the course were removed from the study. During the first week of the semester, The Motivated Strategies for Learning Questionnaire (Pintrich, Smith, Garcia, & McKeachie, 1993) was used to determine if students in both treatment groups had similar beliefs and desires to do well in the course. As five-point Likert scale survey, questions assess why a student chose her/his field of study and how well the student anticipated doing in the course. During or close to the 43rd class meeting, the students completed an online survey that allowed them to assess the effectiveness of the treatments that were administered during the problem-solving sessions. The motivation survey and the course evaluation survey were analyzed using a nonparametric Kruskal-Wallis statistical procedure. A significant difference was determined at 90% ($p<0.10$). While researchers disagree how Likert scale data should be analyzed, one study (De Winter and Dodou,2010) concludes that parametric t-test procedures and nonparametric procedures have similar power.

Five exams were used to measure changes in each student's academic performance in the course as the semester progressed. Grades from these exams were used to assess changes in individual student performance over the course of the semester. A final exam was administered seven days after the last class meeting, but this grade was not used to assess the treatment since some students exempted the final exam. Statistical analysis of all quantitative data was conducted using the software SPSS. The impact of the treatment on these grades was measured by measuring the rate at which a student's exam score changed during the semester was quantified using linear regression analysis. An ANOVA analysis was used to assess the impact the treatment had on the rate at which the students' exam scores changed as the semester progressed. First, the grades for all students who provided consent to participate in the study were analyzed. A second analysis was conducted by separating the data into subgroups based on students' final course grade (e.g. C, B A) and then separated by treatment. That is, students who earned a final course grade of C and who were in the traditional treatment were compared to students who received a final course grade of C and who were in the argumentation treatment. The t-test was used to assess the distribution of the rates that grades changed during the semester.

Results and Discussion

The motivation survey provided evidence that the student population in the control group and students in the argumentation treatment group had similar learning beliefs and similar level of confidence in their ability to engage the topics taught in this statics course. One study (Shaharoun et al., 2012) provides evidence that motivation and learning belief play a significant role in determining student performance when engaged in complex topics. As anticipated, motivation survey questions indicated differences between students who earned a final course grade of A and students who received a final course grade of C. In the first week of the semester, 90% of the students who received a grade of A responded positively to the questions "I'm certain I can understand the ideas taught in the course" and "I am sure I can do an excellent job on the problems and tasks assigned for this class" while only 17% who received a final course grade of C responded positively to these questions. These differences were not significantly different between the control groups and the argumentation treatment groups.

Figure 2. The change in the grade a student earned on each exam was used to assess treatment effects. The right figure illustrates the performance of 7 students who were in the traditional treatment group and earned a final course grade of C. The left figure illustrates the performance of 5 students who were in the argumentation treatment group and earned a final course grade of C. Each line represents the performance of an individual student. The data shown is for students enrolled in the 2016 spring semester.



Changes in individual student performance on the exams were quantified by determining the rate at which the exam grades changed during the semester (Figure 2). When examining this rate between the two groups students regardless of the final course grade an individual student earns, mixed findings were obtained. During the 2016 spring semester, the grades for individual students in the argumentation group increased by 2% from the grade received on the previous exam; that is the student's grade increased at an average rate of 2%. For students in the control group, the grade earned on an exam was virtually the same as the grade received on the previous exam; that is the average rate of increase from the previous exam was 0%. These rates were significantly different ($p<0.10$). During the 2016 fall semester, no significant difference was found.

Subdividing the control groups and the argumentation treatment groups by final course grade reveals some effects due to the treatments. Figure 2 illustrates changes in grades for students who were enrolled in the 2016 spring semester section of statics. These students also earned a final course grade of C. In the argumentation group, many of these students earned less than 70% of the possible points (that is a grade of 70) on the first exam and these same students earned a significantly higher grade by the 3rd exam. Examining the figure for the control group, the grades that these students earned on the first, second, and third exam were very similar. That is, the lines illustrating grades for the argumentation group has a positive slope while the lines that represent the grades for students in the control group are relatively flat.

For the argumentation group, data in Table 4 shows that each exam grade, for students who earned a final course grade of C, increased by an average of 6% from the previous exam. That is the grade for exam #2 was 6% higher than the score on exam #1 and the grade for exam #3 was 6% higher than the score on exam #2. For the control group of students who earned a final grade

Table 4. Student performance was assessed by comparing an exam score against score earned on the previous exam. The difference in the two scores was expressed as a percentage, and then the average percentage for all five exams was calculated. For students who were in the argumentation group and earned a final grade of A, exam scores increased on an average of 2.6% compared to the previous exam, that is the score on exam 2 was 2.6% more than the score on exam 1, the score on exam 3 was 2.6% more than the score on exam 3 and so on. Students in each treatment group were divided by the final course grade earned. The data show is for students enrolled in the 2016 spring semester. The * indicates significant differences (p<.10) between treatments.

	% change in exam score compare to the score on the exam just prior		
Treatment	A*	B	C*
Control	0.7%	<0.1%	0.9%
Argumentation	2.6%	0.2%	6.0%

	Number of students in each final grade group		
Treatment	A	B	C
Control	7	6	5
Argumentation	5	8	5

of C, exam grades did not increase in a similar manner. That is, the grade for exam #2 was less than 1% higher than the score for exam #1, etc. (Table 4). While the data in this table indicates a different in student performance, based on grades, determining if this increase was due to other factors beside the argumentation treatment has not been accomplished at the time of this publication.

For the 2016 fall semester portion of this investigation, there were not a significant difference in exam grades for the argumentation group compared to the control group. These results do not collaborate the results outlined in the above paragraph. Therefore, the effects of argumentation, if any, are not entirely understood using these preliminary findings. The process to introduce argumentation was done each semester differently; this difference was due to administrative decisions regarding teaching assignments. In the 2016 spring semester, argumentation was introduced to students during a problem-solving session. In the 2016 fall semester, argumentation was introduced to students during the regular lecture session. Since the experiment has not been repeated twice using the same conditions further investigation is needed.

The end-of-the-semester survey provided qualitative information regarding how students liked or disliked collective argumentation as a learning practice. For the treatment group, discussions revolved around the questions What is the principle that you would use to solve the problem (the claim)? What is the mathematical and/or scientific rationale that demonstrates that your choice of principle/concept is valid (the warrant)? What information do you need?

Table 5 shows survey results for students enrolled in the 2016 spring semester. This information indicates in-class discussions increased students' understanding of concepts regardless of treatment while more students in the argumentation group believed in-class discussions with other students. Table 6 shows survey results for students enrolled in the 2016 fall semester and this information indicates the argumentation treatment had not impact on the students' perception of this learning technique. Again, these differences may be a result of how students were introduced to argumentation; that is the spring class was introduced to argumentation in a problem-solving session and the fall class was introduced to argumentation during the regular lecture period. Further investigation is needed.

Table 5. A survey at the end of the 2016 spring semester provided information if students believed that collective argumentation was useful to help them learn concepts taught in statics.

n=13 Treatment	Discussing concepts with other students during class increased my understanding		Discussing concepts with other students outside of class increased my understanding	
	Treatment	Control	Treatment	Control
Strongly Agree	19%	19%	7%	13%
Agree	56%	56%	27%	31%
Neither agree or disagree	19%	13%	27%	25%
Disagree	6%	6%	40%	25%
Strongly Disagree	0%	6%	0%	6%
	In class discussions with other students		In class discussions between students and the instructor	
	Treatment	Control	Treatment	Control
Did not help	0%	0%	0%	6%
Somewhat helped	13%	13%	0%	6%
Neither	19%	50%	0%	13%
Helped	31%	38%	63%	56%
Was very Helpful	31%	0%	38%	19%

Table 6. A survey at the end of the 2016 fall semester provided information if students believed that collective argumentation was useful to help them learn concepts taught in statics.

n=13 Treatment n=16 Control	Discussing concepts with other students during class increased my understanding		Discussing concepts with other students outside of class increased my understanding	
	Treatment	Control	Treatment	Control
Strongly Agree	31%	6%	31%	31%
Agree	62%	38%	69%	31%
Somewhat Agree	0%	44%	0%	31%
Somewhat Disagree	0%	13%	0%	6%
Disagree	8%	0%	0%	0%
Strongly Disagree	0%	0%	0%	0%
	In class discussions with other		In class discussions between students and the instructor	
	Treatment	Control	Treatment	Control
Did not help	0%	13%	0%	13%
Somewhat helped	8%	25%	8%	38%
Helped	46%	56%	46%	38%
Was very Helpful	8%	6%	46%	13%

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