The Effect of Argument-Based Naïve Model Development upon Student Content Knowledge and Perception of Science: Middle School Science Classroom

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Abstract: Since the release of the 2012 Framework for K-12 Science Education, educational institutions have been tasked to increase scientific literacy through the implementation of more robust science standards. The Framework identifies three key dimensions of science education: Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. The Scientific and Engineering Practices are composed of a variety of broad science-oriented skills such as engineering, mathematics, and argumentation. Research has clearly indicated the efficacy of engineering in fostering science education. However, the effectiveness of argumentation has not been fully explored, particularly in middle-level classrooms. In the spring semester of 2019, 151 7th grade science students participated in two treatment and three control science curricular units. In treatment units, students were presented a unit-specific phenomenon and provided a limited time frame to develop naïve explanatory models (those lacking scientific data). Classes then engaged in student-led argument sessions to debate and further develop their proposed initial models. Pre and post-assessment results indicated greater content knowledge growth occurred in Honors courses following treatment units while mid-low level classes showed little difference regardless of unit type. Despite generally positive student responses collected through randomly selected interviews however, overall interest in science was not significantly impacted by participation in treatment sessions.

Introduction:

Since the introduction of the Framework for K-12 Science and Engineering in 2012, science education has experienced a flurry of activity in an attempt to shift science standards nationally into a more rigorous and data-driven standing (Bulgren, Ellis, and Marquis, 2014). The desire to move from traditional instructional methodology to a more extensive and comprehensive science education is due to the Framework's assertion that previous science standards were insufficient in their ability to develop scientifically literate students. These standards, according to the Framework development team, were lacking greater coherence, resulting in a science education that was scattered, and unintentionally instructed students at a level that was often a "mile long and an inch deep" (NRC, 2012). Two central goals were selected during the development of the Framework for K-12 Science and Engineering Education: (1) all students should be "educat[ed] in science and engineering" and (2) "future scientists, engineers, technologists, and technicians" should be provided a "foundational knowledge" from which to base their future science education (NRC, 2012).

The Framework for K-12 Science Education was developed as a set of three distinct dimensions: Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas (Bybee, 2014; Figure 1). The dimensions are designed to work as a cohesive unit through which students develop a comprehensive understanding of science through realistic experiences modified for the classroom (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). The Scientific and Engineering Practices, as a dimension, is comprised of tasks that are thought to define science (modeling, data interpretation, engineering, argumentation, etc.). Crosscutting concepts are processes that bridge scientific disciplines and include the identification of patterns, cause and effect, and the use of scale and proportion. Finally, Disciplinary Core Ideas are what is typically considered in a scientific curriculum: subject-specific content. This includes disciplines such as biology, chemistry, and the physical sciences (NRC, 2012).

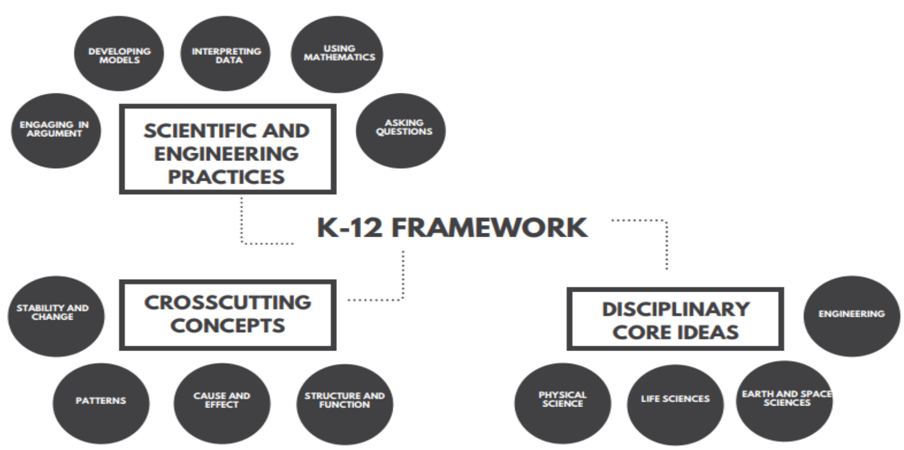


Figure 1: Three dimension of the K-12 Framework for Science Education

(Adapted from NRC, 2012)

Instrumental in the development of the three dimensions of the Framework was the conclusion that students do not arrive in the science classroom lacking prior experiences in scientific investigation. Rather, most students have spent a good portion of their childhood unwittingly performing science of their own sort, asking questions and generating their own hypotheses as they navigate the world. Unfortunately, many of these experiments are inherently flawed in their conclusions, and the resulting inaccuracies (misconceptions) often become deeply ingrained into worldview and accepted as fact (Babai & Amsterdamer 2008; Tanner & Allen 2005). Complicating correction even further, many childhood misconceptions provide surface-level explanations of phenomena that appear to work in extremely specific scenarios. Of course, when placed under the scrutiny of true investigation, these explanations crumble as their applicability to broader questions is often quite weak. However, when students are confronted with new information that appears to contradict their original beliefs, they often attempt to incorporate the data into the original, misconceived model, rather than replacing it with a more accurate explanation. Therefore, misconceptions frequently remain, even following intensive instructional intervention (Babai & Amsterdamer 2008; Tawde, Boccio, & Kolack 2017). Addressing and correcting misconceptions then, is of utmost concern to science educators.

When addressing common misconceptions in the science classroom, traditional practice relies upon the capacity of scientific data to overwhelm initial beliefs, thus resulting in the ultimate adoption of a new explanation (Chinn & Brewer 1993). Khourey - Bowers 2011 further describes this process as a growth of “dissatisfaction” in which students become increasingly uncomfortable with their original beliefs as new data is introduced, ultimately resulting in an adoption of a more scientifically accurate model. However, the tendency of data incorporation into initial models muddies the overall simplicity of this technique. Lee 2015 suggests that an imperative step in understanding scientific models is not only the analysis of accepted theory, but also in the creation and testing of one's own models. Engaging in model development that mirrors the scientific processes in conjunction with analysis of scientifically accepted models is an imperative component of science education (Campbell and Oh 2015).

In developing models, argument is thought to be a critical component of the scientific process. Through argumentation, individuals utilize higher-order thinking in order to understand and provide empirical evidence, reach conclusions from a set of data, and weigh the validity of counterarguments (Bulgren, Ellis, & Marquis, 2014; Sampson & Gleim, 2009). In the classroom, argumentation most often takes the form of a written response due to writing’s effectiveness in increasing student understanding and scientific literacy (Cetin & Eymur, 2017). However, written argumentation requires significant turnover time, as in this format, the instructor must independently examine each student or group of students’ responses to provide feedback. This strategy also severely limits student-student interaction that may be particularly beneficial in developing argument and explaining results. Mercer, Dawes, Wegerif, & Sams, 2004 argue that in tightly controlled environments, peer to peer conversation may be an especially effective and imperative component of scientific investigation, encouraging impactful argument development and understanding of scientific concepts. Structure, however, is identified as the key to encouraging successful classroom discourse, as uncontrolled classroom “discussions” can easily devolve into talk that is “uncooperative, off-task, inequitable, and ultimately unproductive”.

There are multiple examples of structurally robust student-argumentation classroom models readily available (Cavognetto 2011; Chen & Steenhoek 2013; Llewellyn & Adams 2013; Sampson & Gleim, 2009; Sampson & Grooms 2010, Osborne 2009). Most strategies recommend presenting a specific phenomenon-based question, providing students some background knowledge upon which to construct an argument, offering opportunities for students to test their models, and concluding with some form of peer-reviewed presentation of results. There are, however, slight differences in the argument-development process. Cavognetto 2011, when describing "Immersive Strategies" recommends the use of argument development prompts that guide students in the development of key components of a well-developed argument. Chen & Steenhoek 2013, incorporate the use of a "Negotiation Cycle" in which students participate in a variety of investigations, group presentations, revisions, and writing, ultimately culminating in the identification of a brand-new research question.

Despite the variety of available classroom argument instructional techniques, there is little research identifying whether these strategies are particularly effective in decreasing student misconceptions and simultaneously increasing student content knowledge. Bulgren, Ellis, & Marquis 2014 found that integrating AEI (Argumentation and Evaluation Intervention) into middle-early high school science classrooms increased student knowledge of and ability to interpret scientific arguments. However, no data was gathered regarding specific content-knowledge gains. Sadler 2006 similarly explored the effectiveness of argument-integration into pre-service teacher methods courses also finding generalized improvements in student knowledge of argument. Finally, Walker, Sampson, Grooms, Anderson, & Zimmerman 2012 applied ADI (Argument-Driven Inquiry) in post-secondary general chemistry courses, reporting increases in both student content knowledge and overall attitude towards science. However, the applicability of this model has not been explored in the middle school classroom.

Although the Framework for K-12 Science Education emphasizes the importance of integrating scientific argumentation, listing it as one of the key Scientific and Engineering Practices, little work has been completed to support its effectiveness in increasing student content knowledge and perception of science. In this project, we attempt to identify the effectiveness of integrating classroom argumentation into middle school science classrooms beginning with naïve student models. Simultaneously, we attempt to measure the effect of such strategies upon self-reported student perceptions of science as a subject of study.

Methods

Recruitment

During the 2019 spring semester, 151 research participants were recruited from a team of 163 7th grade students. Following IRB approval, students returned signed parental-permission forms indicating willingness to participate in the project. Prior to the project, potential participants were informed that regardless of participation, underpinning curriculum and student grades would not be impacted. Although non-participants completed each activity within the research, data from these students was not collected. Recruitment took place at Deer Creek Middle School within the Deer Creek School District. Deer Creek Middle School is located in north-central Oklahoma, in the city of Edmond and is comprised of households averaging a yearly income of $63,536. This value exceeds the state average of $49,742. Although the district is expanding rapidly, the current racial make-up of the district is largely homogenous with 70.9% of students identifying as Caucasian (OEQA, 2017).

Curriculum Description

Curricular units were purchased by the Deer Creek school district and were designed and organized by SEPUP (Science Education for Public Understanding Program). A branch of UC Berkeley's Lawrence Hall of Science, SEPUP develops curriculum based upon the guidelines provided by the NGSS. The curriculum integrates student investigation and real-world problem exploration to teach scientific content (Lawrence Hall of Science, 2019). With the exception of additional argumentation sessions, treatment and control subunits employed in this study followed the predesigned format provided by SEPUP curriculum team.

Two units were selected prior to beginning the study: Space and Weather/Climate. The units were further divided into five distinct subunits by natural break points in material and assigned an identifier based upon the major topic of study. The subunits selected included: The Moon's Phases, Objects in Space, Gravity, Earth's Seasons, and Local Weather. Subunits were divided into "Argumentation" and "Non-Argumentation" control and treatment categories. Treatment/control selection was randomly assigned for the first subunit (The Moon's Phases) and all following subunits were assigned a category in a 1 - 2 - 1 - 1 design determined by curricular time constraints (Figure 2).

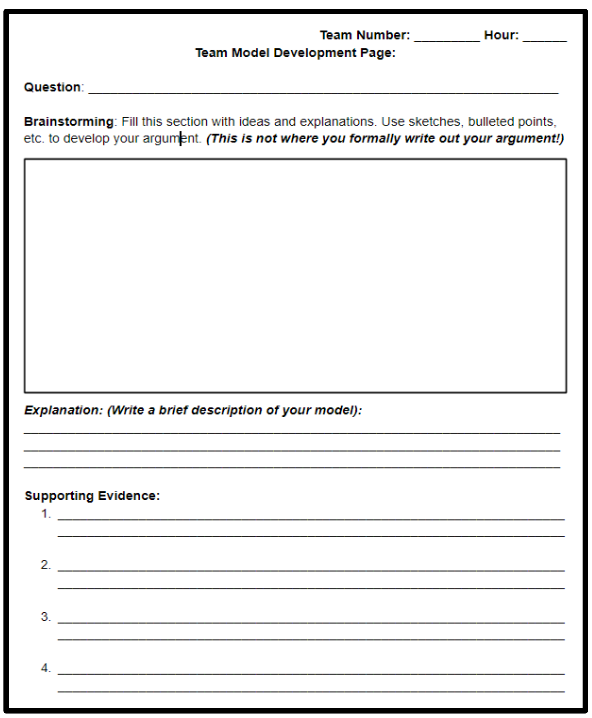
Figure 2: Curricular units organized by treatment.

Naïve Argumentation Session Design

Naïve argumentation sessions were designed following a basic pre-determined framework.

- All sessions occurred during one 50-minute class period.
- Students were not provided new instructional material prior to each session. All models would be based upon prior experiences.
- Only fifteen minutes were provided for group planning and discussion.
- Argumentation sessions were student-led.
- Participant expectations were strictly enforced.

At the start of each treatment subunit, student participants were presented with a unit-specific phenomenon to mentally explore. Phenomena were selected based upon potential student interest, relatedness to unit topics, ease of argument development, and potential for exposing misconceptions. Examples of debate topics include: "Why does the moon change shape?", and "What is gravity?". Student groups were provided a naïve-model development planning page (Figure 3) and given fifteen minutes to develop an explanation with supporting evidence. Students were encouraged to model their explanations through sketches, written responses, and graphical representations. During the planning component of the session, instructor-guided questioning was utilized in an attempt to assist groups in identifying potential weaknesses in their argument and to foster deeper thinking about the assigned phenomenon.



Team Number: ________ **Hour:** ______

Team Model Development Page:

Question: ____

Brainstorming: Fill this section with ideas and explanations. Use sketches, bulleted points, etc. to develop your argument. ***(This is not where you formally write out your argument!)***

Explanation: (Write a brief description of your model):

____

Supporting Evidence:

1. ____
2. ____
3. ____
4. ____

Figure 3: Student model-development page.

Concluding the naïve argument-development stage, students participants were reminded of the argumentation session expectations:

-Speaking is turn-based

-Sessions are student-led

-Respect for other groups' ideas is expected

Each student group was given an opportunity to present their proposed explanation for the presented phenomenon. Students were given free use of the whiteboard, classroom models, etc. to present their models. Following each presentation, classmates were encouraged to question and find fault in each proposed explanation. Discussion ensued until either a class-wide consensus was reached or debate stagnated. Initial student models were re-examined at the conclusion of each treatment unit, following a variety of data-gathering instructional activities.

Measurement Tools

Prior to investigation, formative and summative assessments were designed for each subunit. Assessments were constructed based upon the following framework:

- Eight questions in length.
- 15-25% DOK question level 1
- 55-65% DOK question level 2
- 15-25% DOK question level 3
- Accurately assesses the main learning objectives of each subunit
- Quickly and easily integrated into weekly lesson-plans

In order to regularly measure participant perception of science education, a student survey was employed alongside the formative and summative assessments. Survey design was adapted from (Summers & Abd-El-Kahlic, 2018). Survey length was limited to fifteen questions and questions attempted to measure overall interest in science, interest in future science careers, and the perceived importance of scientific knowledge.

All data was gathered and collected via ZipGrade, a classroom assessment-grading tool. Students responded to survey and assessment questions on the company-provided answer sheets and participant results were scored through the program.

Following the conclusion of the final subunit, fifteen students were randomly selected from three randomly selected classes. Representatives from both honors and standard classes were present. Students were asked to verbally respond to a list of five open-ended questions in order to gauge the general opinion regarding the argumentation sessions. Examples of polling questions included: "Do you think that argument day benefits you?", "What would you change about argument day?", and "Do you enjoy argument day? Why or why not?". Responses were recorded and stored alongside other collected data.

Study Procedure

An initial student-perception survey measurement was taken prior to all data collection. Then, following the unit schedule outlined in Figure 4, participants completed a formative assessment prior to beginning both treatment and control units. Formative assessment results were collected and recorded. Participants were not privy to formative assessment scores and discussion of assessment results was prohibited within the confines of the classroom. In treatment subunits, students participated in an argumentation session at the beginning of the subunit. These sessions occurred within one week of the start of the unit. However, there was some discrepancy in argument session timing due to uncontrollable scheduling interruptions. Control units followed the predesigned format of the SEPUP curriculum without the addition of argumentation sessions. Signaling the conclusion of each subunit, research participants once again completed the topic-specific assessment. Perception surveys were also readministered at the conclusion of each subunit. Formative, summative, and perception survey data was collected and stored physically in a secure filing cabinet and digitally on a district-monitored laptop.

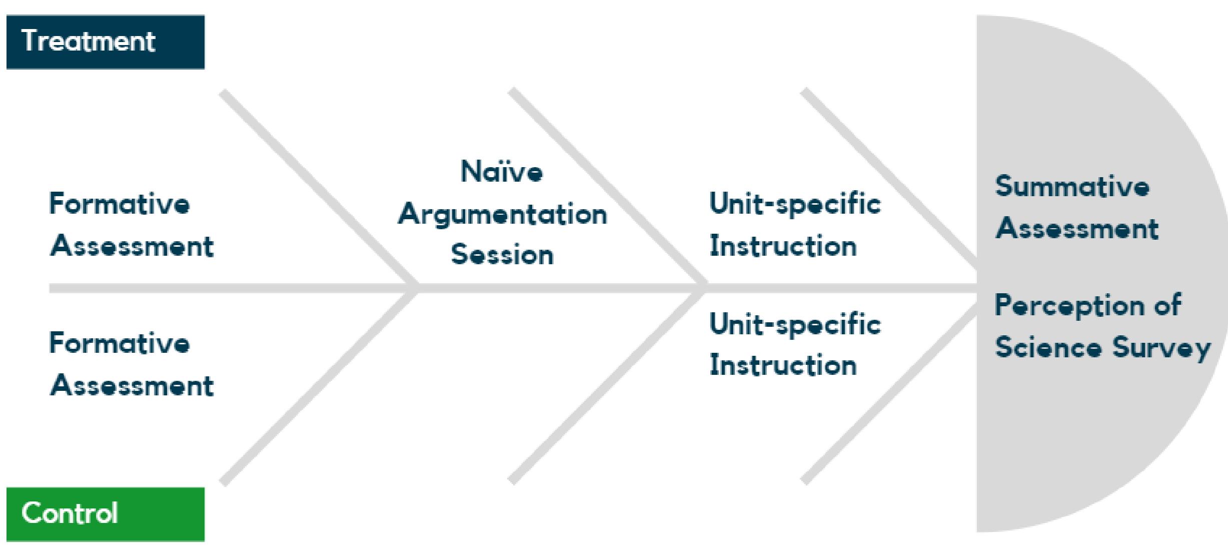
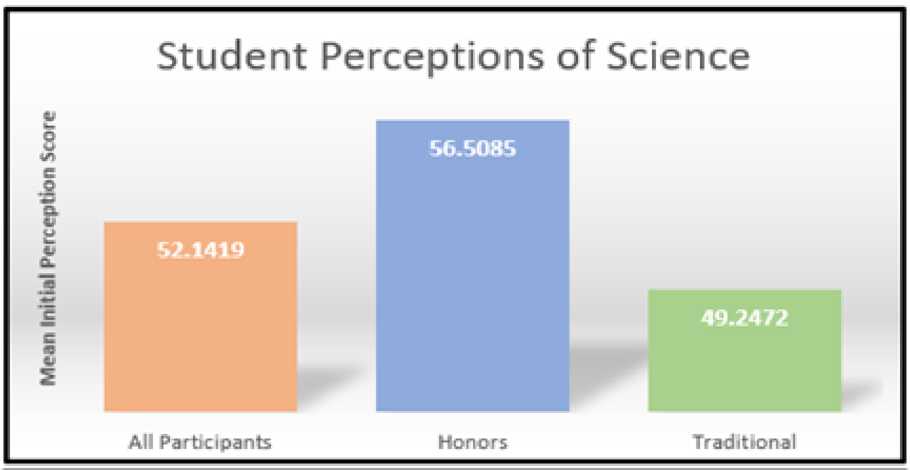


Figure 4: Study design for treatment and control curricular units.

Analysis and Results

Student perceptions of science were generally positive with a mean score of 52.142 out of a possible 75 points. Results of a Mann-Whitney U Test indicated baseline mean scores that differed significantly between honors and traditional path students ($U = 1350.5$, $p < .0001$). Honors students generally reported a higher personal interest in science than their traditional-path peers with mean scores of 56.509 and 49.247 respectively (Figure 5). Unit treatment had no significant effect upon student perception of science with mean scores revealing negligible differences between treatment and control subunits (Table 1).

Student responses in randomly selected survey groups were generally positive with most students identifying advantages to participation in naïve argumentation sessions. Advantages offered by students included identifying weaknesses in their own models, building upon their own ideas based upon ideas presented by other students, and participating in a new and challenging activity. Two students suggested that listening to other models generated confusion when new data was collected and integrated.



			Statistic	Std. Error
InitialSurvey	Mean		52.1419	.84586
	95% Confidence Interval for Mean	Lower Bound	50.4703	
		Upper Bound	53.8135	

			Statistic	Std. Error
InitialPreAP	Mean		56.5085	1.10611
	95% Confidence Interval for Mean	Lower Bound	54.2944	
		Upper Bound	58.7226	

			Statistic	Std. Error
InitialReg	Mean		49.2472	1.10185
	95% Confidence Interval for Mean	Lower Bound	47.0575	
		Upper Bound	51.4369	

Figure 5: Measurements of student perceptions of science organized by class type.

	N	Mean	Std. Deviation	Minimum	Maximum
SurveyArg	288	52.5729	11.14248	15.00	75.00
SurveyNon	429	52.4545	11.04921	15.00	75.00

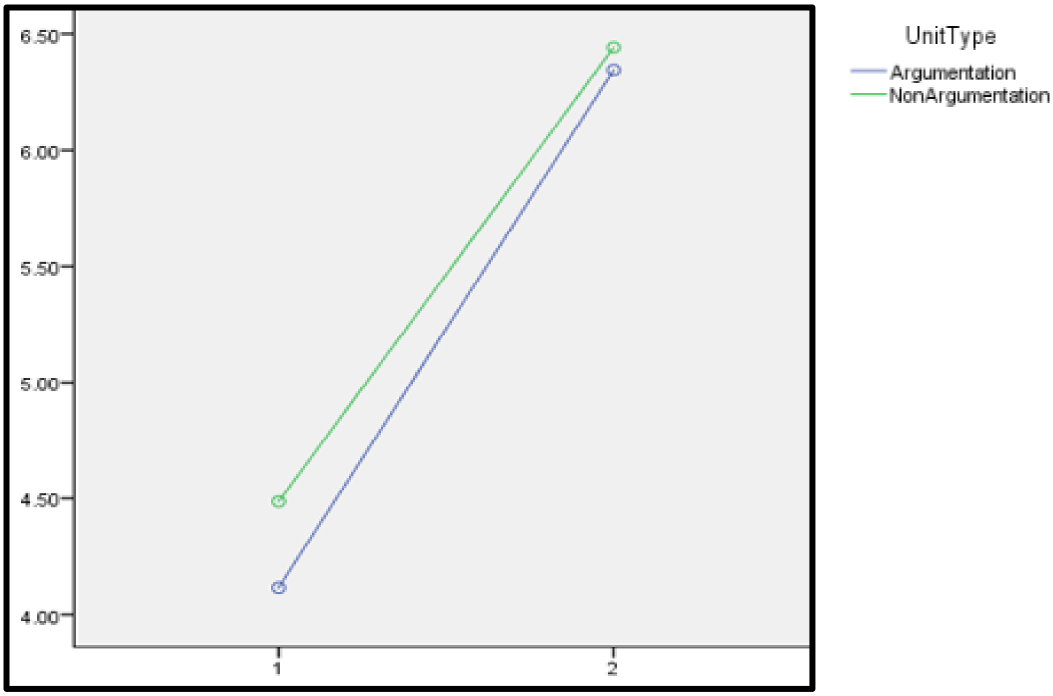
Table 1: Comparison of student perceptions of science following treatment and control units. Minimal difference in mean scores indicate little to no impact of unit type upon student perception of science.

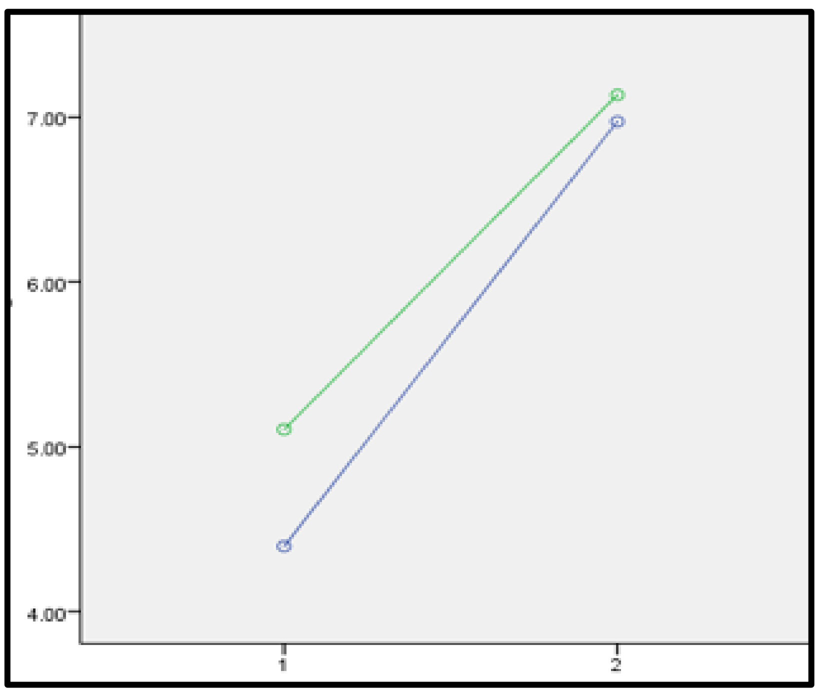
Mean pre-assessment scores differed between control and treatment subunits with naïve argumentation subunits generally presenting an overall lower score. Subunits implementing naïve argumentation sessions also produced lower post-assessment scores (Table 2). A Mixed-design ANOVA indicated no significant difference at $p<.05$ in student knowledge growth between treatment and control subunits [F (1,1) = 3.474, p = .063] (Figure 6A). Separation of honors and traditional path students, however, produced Mixed-design ANOVA results in which there was a significant difference at $p<.05$ in learning growth between treatment and control groups in honors courses [F (1,1) = 7.508, p = .007] (Figure 6B).

	TypeofUnit	Mean	Std. Deviation	N
Pretest	Argument	4.1162	1.38028	284
	Nonargument	4.4869	1.41352	421
	Total	4.3376	1.41102	705
Posttest	Argument	6.3451	1.37646	284
	Nonargument	6.4418	1.47505	421
	Total	6.4028	1.43594	705

Table 2: Comparison of pre and post-assessments for treatment and control subunits. Pre and post-assessment scores remained consistently higher for control subunits.

A.





B.

Figure 6: Graphical representation of student learning growth between time 1 (pre-assessment) and time 2 (post-assessment). Figure 6A displays average growth for both honors and traditional path students with no significant difference between treatment and control subunits. Figure 6B indicates a significant difference in growth for honors students during treatment subunits [F (1,1) = 7.508, p = .007]

Discussion

Content Knowledge Growth

Inserting a naïve argumentation activity into the middle school science curriculum generated mixed results in content knowledge growth. Contrasting somewhat the results ofWalker, Sampson, Grooms, Anderson, & Zimmerman 2012, significant differences in learning between control and treatment units were detected only in Honors level courses, suggesting that additional misconception elimination occurred in these courses and not in the non-honors courses. However, the intensity of intervention utilized in this study was significantly less than that of Walker, Sampson, Grooms, Anderson, & Zimmerman 2012 and potentially explains this gap. Though all students displayed significantly increased content knowledge between pre and post-assessments, content knowledge growth for non-honors students was essentially equal between treatment and control units. Thus, the additional intervention strategy of naïve argumentation appeared to have little to no effect upon non-honors student misconceptions despite their lower initial pre-test scores and therefore greater potential to produce significant outcomes.

Two of the four non-honors courses generated conflicting results with the overall average of the non-honors subgroup. One class of medium size (approximately twenty-six students) generated significantly positive outcomes when argumentation strategies were employed. However, unlike other non-honors and honors classes that saw nearly a 100% participation rate, six of the total twenty-six students declined participation in the study. Of these six students, the majority were generally lower-performing students with some presenting a documented disability who wished not to be included in the research. This voluntary removal almost certainly impacted the overall average scores of the participants, likely skewing the outcome. The removal of these students resulted in a class composition that more closely resembled that of an honors course than that of a more traditional non-honors class.

In addition, a relatively small class of approximately sixteen students actually reported negative results from the inclusion of argumentation into curriculum. In this classroom, growth during treatment units appears to have been hampered by naïve argumentation sessions. This result may have been due to student discomfort with verbal presentation in front of their peers due to the small class size or due to the limited discussion that occurred in this class. Discussion was difficult to initiate within this class and required significant instructor intervention as conversation regularly stalled even with little in-depth thought. Thus, it is likely that in this classroom, verbal argumentation as an instructional strategy was not effectively providing students the opportunity to develop early models.

Student Perception of Science

Participation in argument development produced no significant difference in student perception of science between treatment and control units. These results were consistent between Honors and Non-honors classes. Walker, Sampson, Grooms, Anderson, & Zimmerman 2012 (where a more complete argumentation model was employed and significant gains were observed in student perceptions) it is possible and quite likely that the implementation of a single activity into each unit was insufficient in significantly altering a student's perception of science as a subject. It is also possible that repeated questionnaire use led to survey fatigue, producing an inaccurate measurement.

Despite the concerns presented by some students that examining multiple models was generating confusion, most students responded positively when given an opportunity to express their opinion regarding argumentation sessions. Argument sessions also appeared to positively impact student engagement, generally requiring few instructor interventions to keep students on task and producing a classroom environment where students were comfortably able to share and debate ideas. Although the student perception survey revealed very minute shifts in student interest, it is entirely possible that if the survey questioned students more directly about argumentation as an activity, the results would differ substantially.

The success of verbal argumentation as an instructional tool appears to mirror average ratings that classes assigned science during the perception survey. Honors classes reported statistically higher scores on the perception of science survey than scores reported by their Non-honors peers. Conversely, classes in which treatment learning growth was greatest similarly reported high scores on the perception of science survey. These classes generally fostered debate independent of instructor intrusion. Students within these classes were typically more willing to present and discuss topics with their peers and therefore required very little oversight. It is possible that these students simply felt more comfortable expressing ideas due to a more solidly established science background. It is also possible that non-honors students found the task of developing an initial model particularly difficult and thus were less likely to present their ideas. This is not necessarily to suggest that argumentation is an ineffective means through which to instruct students with a comparatively low interest in the field of science. Instead it is likely that student engagement (generally a result of interest) is a key factor in the success or failure of verbal argumentation strategies. Greater effort is almost certainly necessary to foster engagement within Non-honors classrooms, where science was sometimes not of high interest. The phenomenon employed in this study were potentially insufficient in peaking the interest of Non-honors students resulting in an instructional strategy that did not produce measurably different outcomes.

Future Research

A primary goal of this project was to determine whether developing models through a naïve form of argument could effectively increase student content knowledge. Towards this goal, our model produced mixed results. Positive results were detected for Honors students but Non-honors students saw little to no difference in learning outcomes. Future research will need to consider whether a greater emphasis upon argumentation (a process requiring more than a single day of implementation) may produce the desired results in Non-honors classes that were not detected in this study. Further research should also consider whether argumentation is equally effective for all groups of students, including those from traditionally underrepresented groups.

The Student Perception of Science survey indicated little to no difference in treatment and control units in swaying student opinion of science. Contrasting survey results, students generally responded positively when questioned specifically about argumentation activities. Much like content knowledge gains for non-honors students, it is unlikely that a single intervention, occurring at approximately two-four week intervals, is capable of overtly altering a student's perception of science as a field of study. Therefore, future research will need to determine whether a more intensive integration of argumentation into current curriculum is truly capable of impacting a student's overall perception of science.

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