Using Laboratory Activities That Emphasize Argumentation and Argument to help High School Students Learn how to engage in Scientific Practices and Understand the Nature of Scientific Inquiry*

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Introduction

The main objective of this study was to determine if high school students' ability to participate in scientific practices and their understanding of the nature of science and scientific inquiry (which are both important aspects of science proficiency) improved when they participated in a series of laboratory activities that were designed using the Argument-Driven Inquiry (ADI) instructional model. The ADI instruction model (Sampson, Grooms, & Walker, 2011) is designed to make laboratory activities more authentic than the prescriptive lab activities that tend to be observed in high school classrooms (National Research Council, 2005). ADI lab activities are more authentic, or at least more realistic, than prescriptive lab activities because this instructional model gives students more opportunities to participate in the practices of science. These practices include designing and carrying out investigations, collecting and analyzing data, developing arguments, participating in episodes of argumentation, and communicating findings. The ADI instructional model is also designed to make laboratory activities more educative for students because students are given an opportunity to discuss and then reflect on what they know and what they have learned during the lab. In addition, students are given a great deal of feedback about how well they did and how they can improve at various stages of the model. Figure 1 describes the stages involved in the ADI model. Teachers can use this instructional model as a template or guide when designing new or modifying existing laboratory activities in order to make them more authentic and educative for students.

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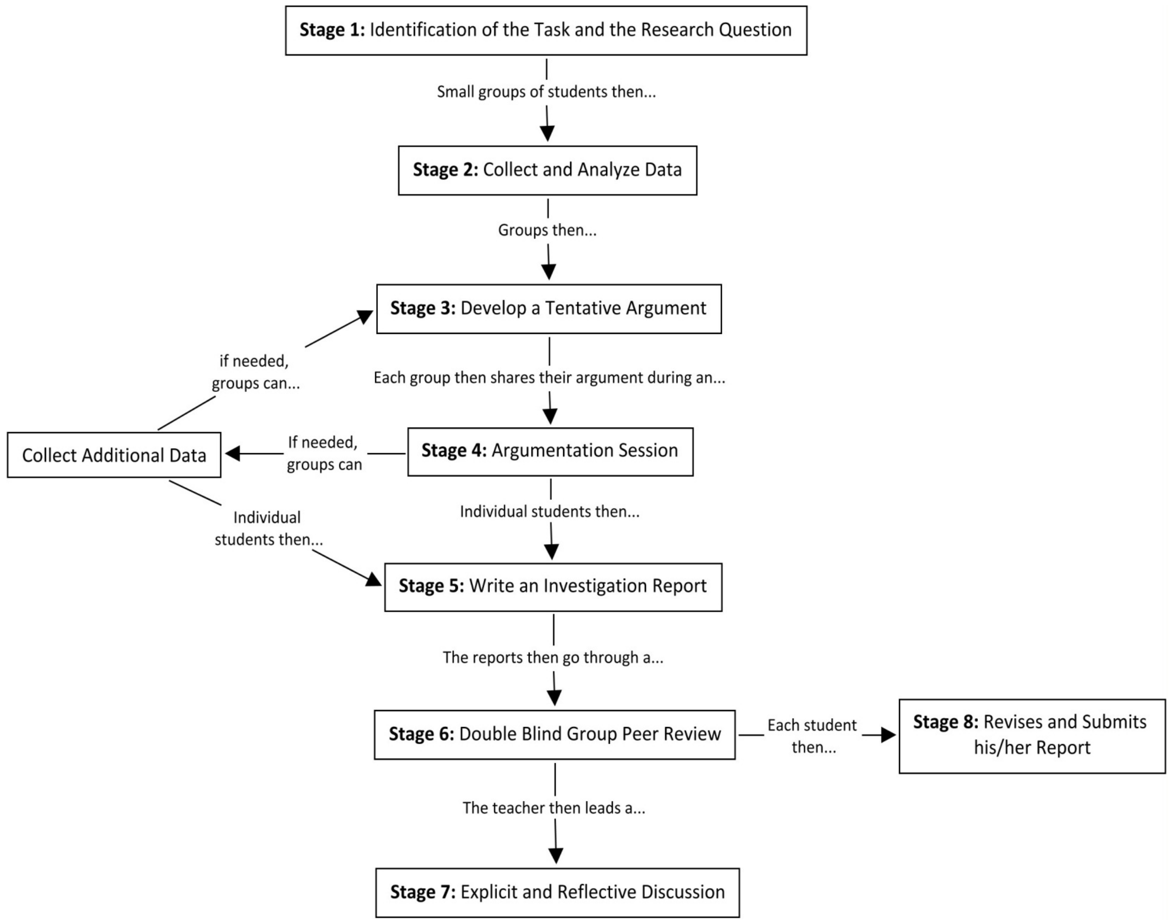

Figure 1: Stages of the Argument Driven Inquiry (ADI) instructional model

Conceptual Framework

Science proficiency, as defined by Duschl, Schweingruber, and Shouse (2007), includes a variety of knowledge and skills that individuals need to develop in order to function effectively in an increasingly complex, information-driven society. The framework of scientific proficiency positions science as "both a body of knowledge and an evidence-based, model-building enterprise that continually extends, refines, and revises knowledge" (p. 2). A person who is proficient in science can: (a) understand and use scientific explanations of the natural world; (b) understand the nature and development of scientific knowledge; (c) create and evaluate scientific explanations and arguments; and (d) productively participate in the practices and discourse of the scientific community. In order to help students develop science proficiency, the nature of classroom instruction needs to shift from traditional, prescriptive activities to those that afford students the opportunity to engage in the practices and discourse of science (Duschl, Schweingruber, & Shouse, 2007; National Research Council, 2005, 2008).

Important practices in science, as noted earlier, include such things as designing and carrying out investigations, collecting and analyzing data, crafting arguments and communicating findings orally and in writing. Unfortunately, a large body of research indicates that students struggle when given an opportunity to participate in scientific practices (Duschl et al., 2007; National Research Council, 2005, 2008). This literature suggests that most students do not learn how to participate in the practices of science because many science teachers either (a) do not incorporate laboratory-based instruction into their curriculum at all (Weiss et al, 2001) or (b) rely heavily of prescriptive lab activities that do not provide an opportunity to participate in these important practices (National Research Council, 2005; Weiss, Banilower, McMahon, & Smith, 2001). Teachers, therefore, need tools that they can use to help change the nature of traditional laboratory activities so students have more opportunities to participate in the practices of science within the context of the classroom. The opportunities to engage in the practices of science, however, also need to be educative for students so the way they participate in the these practices improves over time.

In addition to learning how to participate in the practices of science, students also need to develop an adequate understanding of the nature of science (NoS) and the nature of scientific inquiry (NoSI) in order to be considered proficient in science. Unfortunately, the available literature indicates that students often have inappropriate conceptions about NoS and NoSI. This literature also suggests that efforts to improve students' conceptions of NoS and NoSI using curriculum materials or instructional strategies that simply engage students in prescriptive laboratory activities or inquiry-based investigations have very little impact (Lederman, 1992). Abd-El-Klalick and Lederman (2000) suggest that the failure of these materials and instructional strategies to have a substantial impact on students' conceptions of NoS and NoSI is to due to the unfounded assumption that students will develop informed conceptions of NoS and NoSI simply by participating in some of the activities scientists do (such as collecting and analyzing data). Abd-El-Klalick and Lederman (2000) describe this type of approach as implicit instruction. They argue that an implicit approach to instruction is ineffective because understanding the various aspects of NOSI and being able to articulate these ideas to others requires explicit attention.

The ADI instructional model was designed, in part, to help address the shortcomings of traditional laboratory instruction, which often does not give students an opportunity to participate in the practices of science or make the nature of science and scientific inquiry explicit for students. The design of the ADI instructional model is based on a hypothesis that efforts to improve science proficiency will require the development and continued use of laboratory experiences that are more authentic and educative. We therefore predicted that the students who engaged in laboratory instruction designed using the ADI instructional model throughout a school year would demonstrate improvement in several aspects of their science proficiency. Figure 2 offers a graphical representation of this hypothesis.

Figure 2: Hypothesis describing the potential impact of implementing ADI instruction

Method

This study took place during year one of a three-year research project aimed at assessing students' improvements in science proficiency as a result of experiencing ADI-based instruction and then using this information to refine the ADI instruction model (IES Grant #: R205A100909). The project is using methods consistent with the major tenets of design-based research (Brown, 1992; The Design-Based Research Collective, 2003) to refine the ADI instructional model through several iterative cycles of design, enactment, analysis, and redesign.

Context

The context for this study was a K12 university research school. All research activities related to this study took place in the high school biology course. During the 2010-2011 school year, the school offered nine sections of biology. Two teachers taught the biology course. These teachers were introduced to the ADI instructional model through a four-week summer institute. As part of this institute, the teachers helped develop the ADI lab activities used in the course.

Participants

The initial subject pool of students enrolled in the 9 sections of the biology course consisted of 229 students. The final sample, however, includes only 118 of these students due to issues of consent and frequent absenteeism. The demographics of the students enrolled in the biology course mirrored that of the school (51% Female; 52% White, 29% Africa-American; 10% Hispanic; 11% Free and Reduced Lunch).

The Intervention

The students completed 14 unique ADI lab activities during the 2010-2011 school year. These investigations, which were designed by the researchers and the two biology teachers, focused on several major themes in biology including cell theory, evolution, and genetics.

Data Sources and Analysis

<u>*The Performance Task*</u>. This assessment was developed to understand and measure the progress in students' abilities to design an investigation that will allow them to generate an argument in response to a research question. The students must also make decisions about the most appropriate data to collect and how to analyze it. This assessment is done in groups of 3-4 students, and the group submits a final answer sheet for scoring. The answer sheet includes areas for students to describe the investigation they designed, the data they collected, and the argument they created. It also requires students to provide a justification for decisions they made during their investigation. Initial group composition was maintained as much as possible during separate administrations, and if it was not, the resulting scores were not included in the analysis.

The *Performance Task* was administered at the beginning of the year and again after the first and second semesters of instruction. The rubric for this assessment, which was developed by the research team, focuses on the overall quality of the observations made by the students, the method used, and argument they develop as well as the justifications provided for these elements. A pair of research team members scored 25% of the full set of assessments (pulled at random and blinded concerning student identity and timing of administration) in order to establish inter-rater reliability. The scoring team achieved an intra-class correlation coefficient (ICC) of 0.792 (two-way random effects, absolute agreement). Once inter-rater reliability was established, the team members scored the remainder of their assessment sets individually (these assessments were also blinded to the scorers).

<u>The SUSSI</u>. The Student Understanding of Science and Scientific Inquiry (SUSSI) instrument (Liang et al., 2006) was adapted to measure students' understanding of the development and nature of scientific information. This instrument consists of 44 Likert-scale items. We assigned a value to each response in relation to the nature of the item. Statements representing accurate ideas about science and scientific inquiry were scored on a scale from 0 (strongly disagree) to 4 (strongly agree). Statements representing inaccurate ideas about science were scored in a reverse manner. The authors of this instrument originally separated the assessment into several subscales representing major NOS concepts; however, we condensed these subscales into two groups to better align them with Aspect 2 of the science proficiency framework. This assessment was administered at the beginning and end of the academic year.

Results

Figure 2 provides a graphical representation of the mean overall score on the performance task at the beginning of the year and again after the first and second semesters of instruction. The results of a repeated measures analysis of variance (ANOVA) test on the overall score indicated a significant effect of time, Wilks's $\Lambda = .51$, $F(1, 24) = 21.90$, $p < .001$, multivariate $\eta^2 = .48$. These results suggest that this sample of students' skills improved with each semester of ADI-based laboratory instruction.

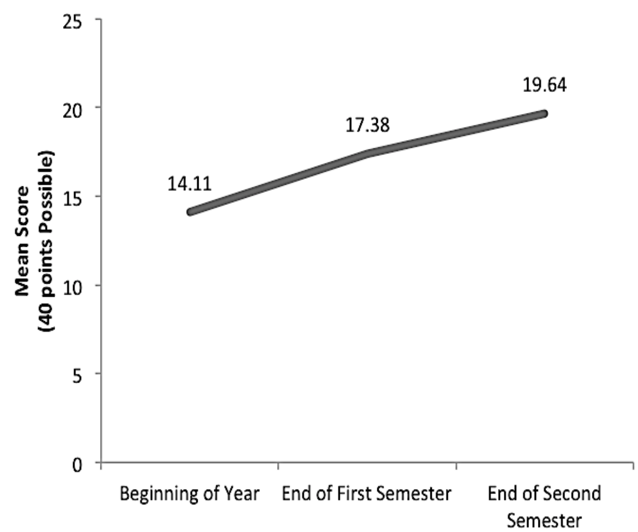

Figure 2. Changes in the overall score on the *Performance Task* over time

Figure 3 illustrates the improvement on the three different components of the task (quality of the data collected, description and justification of the method, and the quality of the argument). The results of a repeated measures ANOVA for the observation component of the task was significant, Wilks' $\Lambda = .86$, $F(1, 24) = 5.05$, $p = .03$, multivariate $\eta^2 = .11$. The observed improvement on the method, Wilks' $\Lambda = .55$, $F(1, 24) = 18.89$, $p < .23$, multivariate $\eta^2 = .48$, and argument components, Wilks' $\Lambda = .68$, $F(1, 24) = 9.89$, $p = .004$, multivariate $\eta^2 = .29$, were significant as well. Together, these results suggest that this sample of students' inquiry skills improved with each semester of ADI-based laboratory instruction.

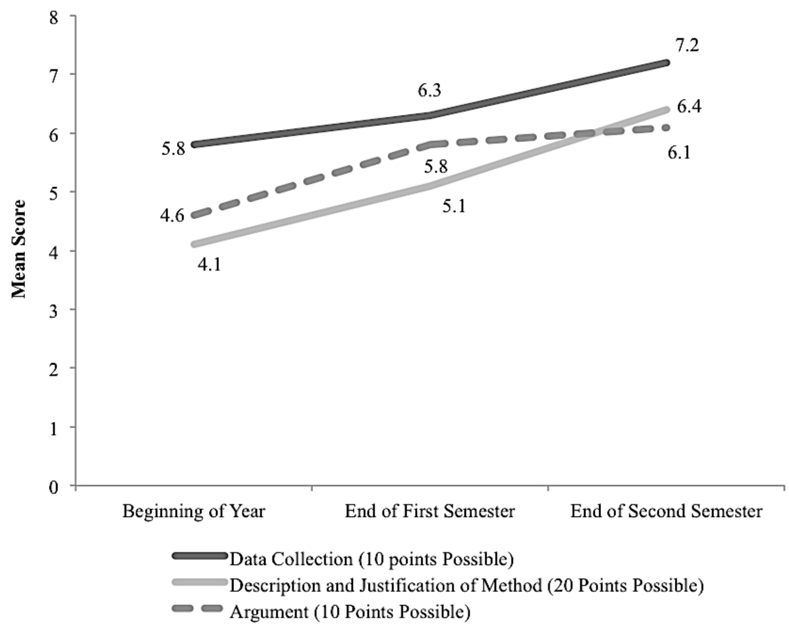

Figure 3. Changes in the score for the three main aspects of the *Performance Task* over time

Figure 4 provides a graphical representation of the change in mean SUSSI scores over time. The results of paired samples t-test indicate that the mean score on the SUSSI at the end of the year was higher than it was at the beginning of the year, $t(118) = 4.47$, $p < .001$. Although the overall change of 5.56 points on a scale of 148 is small, the effect size was moderate, $d = .48$.

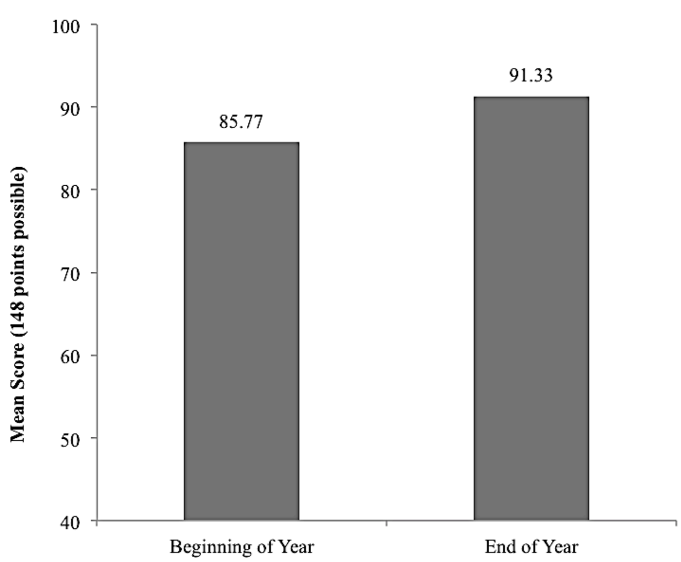

Figure 4. Mean SUSSI scores at the beginning and end of the school year

Figure 5 provides a graphical representation of the change in mean scores on the SUSSI broken down by items that target students' understanding of the nature of scientific knowledge (NoSK) and items that measure students' understanding of the development of scientific knowledge (DoSK). The results of a paired samples t-test indicate that the mean score on the items on the SUSSI that target students' understanding of the NoSK were significantly higher at the end of the year, $t(118) = 3.78$, $p < .001$, $d = .46$. The results of a paired samples t-test for the items on the SUSSI that focus on students' understanding of the DoSK also indicate that the difference in scores was significant, $t(118) = 3.64$, $p < .001$, $d = .37$. These results, when taken together, suggest that this sample of students developed a better understanding of the nature of scientific inquiry.

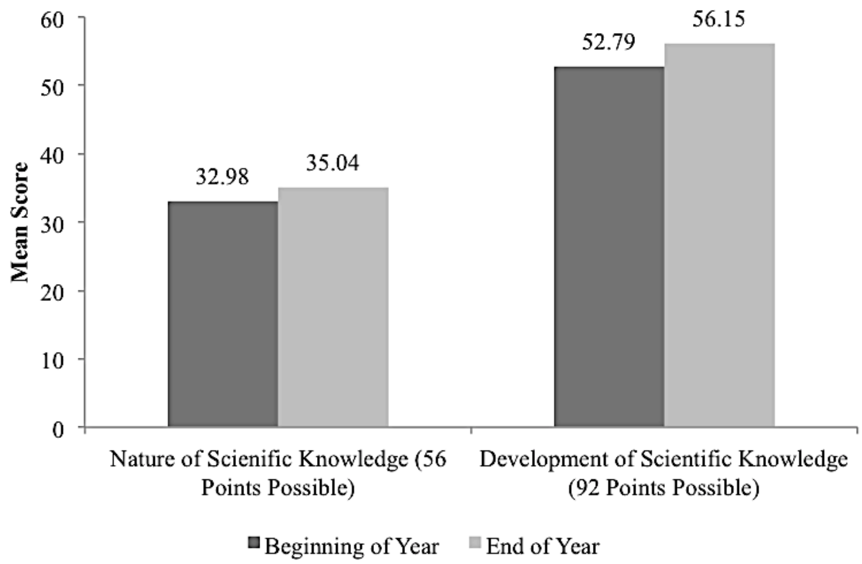

Figure 5. Mean scores on the Nature of Scientific Knowledge (NoSK) and the Development of Scientific Knowledge (DoSK) SISSI subscales at the beginning and end of the academic year

Conclusions

The results provide some evidence for the positive impact that ADI-based instruction can have on the development of inquiry skills and an understanding of the nature of scientific inquiry in the context of high school biology. Significant changes from the beginning to end of the year were noted on both assessments with moderate effect sizes. It is important to note, however, that the nature of the research design used in this study only provides support for a correlational, not causational, relationship between ADI instruction and the outcomes of interest. Yet, this does not mean that the results reported here should be dismissed outright; the results simply suggest that ADI *might* be able to provide teachers with a way to help students develop inquiry skills and a more appropriate understanding of the nature of scientific inquiry. This type of finding is important, we argue, given the substantial amount of literature which indicates that most students do not develop important inquiry skills or a nuanced understanding of the nature of scientific inquiry as a result of their high school education (NRC, 2005; 2008; 2011). In addition, the results also indicate that future research that examines the efficacy of the ADI instructional model in comparison to other approaches using an experimental or quasi-experimental design is not only warranted but also needed.

Our findings also support the validity of the hypothesis underlying this study and the overall research project because the outcomes we observed were consistent with our initial predictions. The biology students, in others words, exhibited significant improvement in their inquiry skills and their understanding of scientific inquiry when they participated in a series of lab activities that were designed to be more authentic and educative. The magnitude of growth for these two outcomes, however, was not as large as one would hope. The magnitude of growth also differed for the various components of the performance task. These observations suggests that the ADI instructional model will need to be refined in order to help students learn more. In the paragraphs that follow, we will outline our plans to address these issues.

The students in this study made the greatest gains on the investigation design aspect of the performance task but made smaller gains on the data collection and argument generation aspects of the assessment. In order to score well on the data collection aspect of the performance task, students needed to focus on multiple variables and attempt to quantify their observations. Our analysis of the data collected by the students during the performance task indicates that the students were able to collect relatively high quality data at the beginning of the intervention and therefore made only modest gains by the end of the year. In order to score well on the argument generation component of the performance task, in contrast, the students needed to be able to develop a claim that answers the research question and the claim needed to be accurate. The students also needed to be able to support their claim with evidence and provide a rationale that explains why the evidence was important. Our analysis of the arguments generated by the students at the beginning of the year indicated that students were able to provide an adequate claim in response to the research question and support it with weak evidence. Most of the claims, however, were inaccurate. The students also did not explain why they included the evidence in their arguments. At the end of the year, the students were able to provide an argument with an accurate claim and strong evidence but were still not including a rationale. This issue, however, is not surprising given the available literature, which suggests that students often do not think that it is necessary to explain the importance of their evidence as part of the arguments they create (Berland & McNeill, 2010; Berland & Reiser, 2009; McNeill & Krajcik, 2008). The teachers also commented that students often did not understand what they wanted when they asked the students for their rationale during the various stages of the model. To address this issue, we plan to change the term "rationale" in our argument framework and all instructional materials to "justification of evidence" in order to help students develop a better understanding of this important component of a scientific argument.

The small but significant growth in SUSSI scores observed during this study is not surprising in light of findings from other research that has established that developing an understanding of the nature and development of scientific knowledge, which are rather abstract concepts, is often challenging for students (Hodson, 2008; McComas, 1998). We were also not surprised by the amount of growth given the limited amount of time the teachers devoted to nature or development of scientific knowledge during the reflective and explicit discussion stage of the model (stage 7, see Figure 1). The NOS/NOSI research literature has clearly demonstrated that students do not make substantial gains in their understanding of these abstract concepts when their teachers do not engage them in an explicit and reflective discussion about the concepts during a lesson (Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-

Khalick, 2002; Schwartz, Lederman, & Crawford, 2004). In response to this observation, the teachers claimed that placing the explicit and reflective discussion stage towards the end of the model was too late for a meaningful discussion to occur. In response to this issue, this stage of activity has been purposefully moved to Stage 5 (see Figure 6), directly following the argumentation session and preceding the initial drafting of the investigation report. The project teachers felt this was a more sensible placement since they observed that these kinds of discussions more naturally emerged at this point in the model. The second year of data collection will provide insight as to the impact of this change.

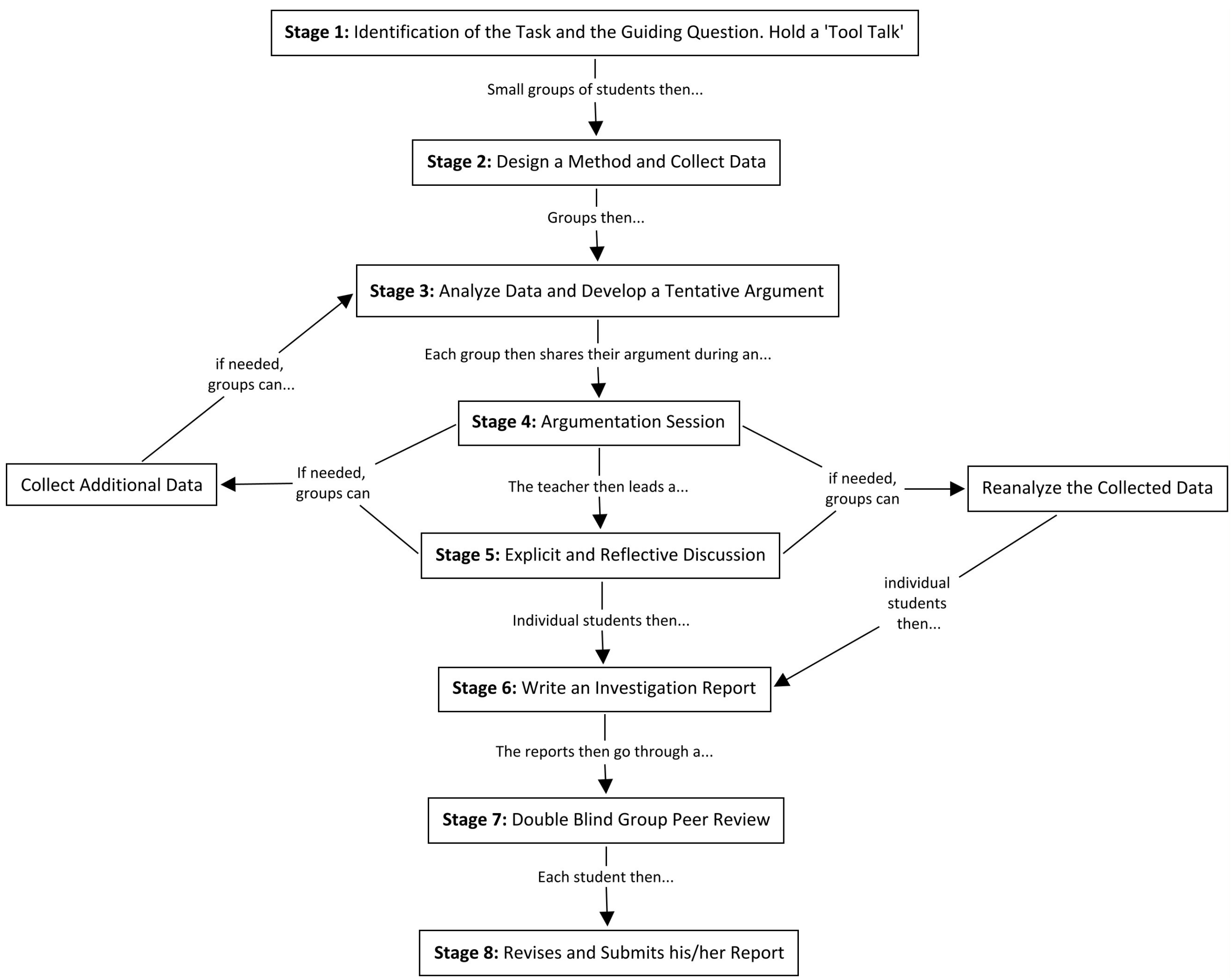

Figure 6. Current stages of the ADI instruction model

Implications

This study provides support for the potential benefits of instructional models that are being developed in order to give students more opportunities to participate in important scientific practices. In order to help students learn by participating in scientific practices, however, science educators must help students understand ‘what does and does not count’ in the context of science. In addition, our results suggest that the implementation of such models must be more extensive than one lesson, one unit, or one module. The development of complex inquiry skills and an understanding of abstract concepts, such as the nature of scientific inquiry, will require longer and more complete immersions in learning activities, including more authentic and educative classroom laboratory experiences like those that are fostered by the ADI instructional model.

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