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Analysis of Instructor Facilitation Strategies and Their Influences on Student Argumentation: A Case Study of a Process Oriented Guided Inquiry Learning Physical Chemistry Classroom

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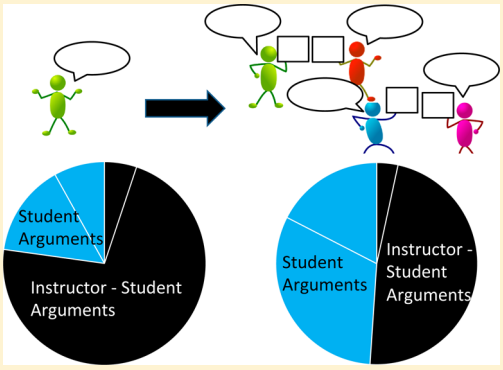
Supporting Information

ABSTRACT: Encouraging students to participate in collaborative discourse allows students to constructively engage one another, share ideas, develop joint understanding of the course content, and practice making scientific arguments. Argumentation is an important skill for students to learn, but students need to be given the opportunity in class to engage in argumentation. To investigate the importance of instructor facilitation on argumentation, two iterations of one instructor's Process Oriented Guided Inquiry Learning (POGIL) physical chemistry course were studied using the Toulmin analysis and the inquiry-oriented discursive moves frameworks. Data were collected by recording class conversations and interactions taking place in the POGIL classrooms. Initial analysis of an individual instructor's implementation of the POGIL materials provided data regarding the nature of small group and whole class interactions and the nature and quality of student-generated arguments. The instructor was then able to make modifications to the facilitation of that course for the next iteration of the course. Data were collected for this subsequent implementation, and the two sets of implementations were compared. It was found that slight changes in facilitation can lead to significant differences in the types of student interactions and the nature of students' arguments. Simultaneous reporting was useful in encouraging iterative argumentation and discussion among students, and setting expectations that students must be ready to explain how they solved the problem and justify their work helped students develop their argumentation skills.



KEYWORDS: *Upper-Division Undergraduate, Chemical Education Research, Physical Chemistry, Collaborative/Cooperative Learning, Inquiry-Based/Discovery Learning, Learning Theories, Student-Centered Learning*

FEATURE: Chemical Education Research

INTRODUCTION

There is increasing emphasis on expanding the implementation of evidence-based learning strategies that actively engage students.[1−4] Inquiry classrooms provide students the opportunity to actively engage during class to understand concepts and solve problems, to analyze data and discuss ideas in order to draw conclusions and construct new knowledge, and to learn how to work together with others.[5] In active learning environments, instructors are often not the center of the classroom but still play an important role in facilitating student learning and assisting students in constructing knowledge. This study focuses on exploring how the nature of instructor facilitation of guided inquiry activities influences student reasoning and ability to develop an understanding of thermodynamics conceptually and mathematically.

Encouraging students to participate in collaborative discourse allows students to constructively engage one another, share ideas, develop joint understanding of the course content, and practice making evidence-based claims or scientific arguments. When students engage in scientific argumentation in the classroom, they have a chance to consolidate existing knowledge and construct new knowledge.[6] Argumentation has been shown to improve conceptual engagement of students in science classrooms,[7−9] and the process of constructing explanations and evaluating evidence are core components of understanding content knowledge.[10−13] Though it is widely believed that collaborative learning classrooms help improve students' understanding of the content,[1,2] only a few studies have examined the role of instructor discourse in collaborative learning environments and how instructors can influence student behavior at the undergraduate level.[13−17] The goal of our project was to use a qualitative research approach for analyzing classroom discourse to determine how alterations in an instructor's facilitation of an inquiry-oriented physical chemistry course influenced students' construction of scientific arguments.

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BACKGROUND

Theoretical Frameworks

Social constructivism is based on the idea that learning takes place through individuals interacting and engaging with peers and their environment.[18,19] Every social environment has different tools and signs or affordances, used to assist learners in developing mental processes through social interactions. Assistance can be provided to the learner by the instructor, a peer, or the course materials. Consistent with the idea of the zone of proximal development, the goal of learning is for the learner to internalize knowledge and have something that they could originally do with assistance become something they can do unaided, thus allowing the boundaries to shift as a learner gains more knowledge.[18,19] In student-centered classrooms, students can collaboratively construct knowledge and build a culture of shared tools and meanings, ideally leading to the individual being able to internalize these meanings. In the case of thermodynamics, students use models and equations to explain chemical and physical phenomena. By working together students are able to share ideas and discuss how thermodynamic equations and concepts are connected and develop a shared understanding of the course material. Instructors support learning in this environment by giving students the opportunity to discuss concepts and encourage students to use models and equations to articulate their understanding of thermodynamic concepts.

The second theoretical framework that grounds this work is situated learning. This theory asserts that learning takes place through participation in a community of practice.[20] Each community of practice has its own traditions, beliefs, and behaviors that one must accept to become a member of the community. Students start on the periphery of a community as novices and move toward the center of the community working their way to becoming experts. Individuals become active members of the community by collaborating, interacting, and engaging with other members in the community of practice. The nature of the Process Oriented Guided Inquiry Learning (POGIL) pedagogy incorporates many of the practices of the scientific community with an emphasis on making sense of data and models to form scientific arguments.[5,21] The whole class discussions also serve as a space where the instructor can model and support transitions to more "expert-like" behavior.

Process Oriented Guided Inquiry Learning

POGIL is an inquiry-oriented instructional approach that encourages collaboration among students. The POGIL curriculum was designed based on student-centered and constructivist approaches of learning.[19,22−24] The POGIL activities are designed to lead students through a learning cycle of exploration, concept development, and application to help them construct new knowledge. These activities focus on core concepts and encourage a deep understanding of the course material, while developing process and higher-order thinking skills.[5,21]

POGIL classrooms differ from traditional classrooms in that the instructor acts as a facilitator and students take a more active role in learning new concepts. Students are encouraged to engage in discussions of questions and concepts; they then internalize these concepts and manipulate and transform those concepts to apply them in multiple contexts. There is no single correct way to implement POGIL, but there are four core characteristics that must be present for an implementation to be considered POGIL:[21,25]

1. Students are expected to work collaboratively in groups of 3 or 4.
2. The activities that students use are specifically designed for POGIL implementation and follow the learning cycle process.
3. The students work on the activity during class time with an instructor present.
4. The instructor serves predominately as a facilitator of student learning, not as a lecturer.

Within these constraints, implementation of POGIL is fairly flexible and use varies from class to class. The facilitation strategies used are important because they influence the classroom's community of practice and the instructor expectations of students. The particular implementation strategies chosen by instructors will be determined by their experiences implementing POGIL, the constraints of their learning environments, and their teaching philosophies.

The Importance of Scientific Argumentation in the Classroom

Recent science education reforms have pushed for students to engage in authentic scientific discourse in the classroom. One practice frequently used in scientific discourse is argumentation or the practice of generating, considering, and comparing arguments.[26,27] Furthermore, the facilitation of argumentative discourse has been shown to promote conceptual understanding of scientific content.[11,28] Incorporating argumentation into science classrooms is beneficial for two reasons. First, experimentation used to generate scientific knowledge is accompanied by scientific discourse that involves "assessing alternatives, weighing evidence, interpreting texts, and evaluating the potential validity of scientific claims."[9] The generation and justification of claims based on evidence is a key practice within science.[27,29] Failing to model this practice results in a positivist representation of scientific knowledge as though it is final and must simply be accepted by the student.[9,27] By facilitating argumentation, the science classroom is better situated to authentically represent science as well as prepare students to competently engage in the discursive practices of scientific inquiry.[27,30,31] Second, the use of argumentation in the classroom has also been shown to promote scientific understanding.[11,32−34] Ford and Wargo define scientific understanding as having the following three qualities: the ability to explain a phenomena with scientific knowledge, the recognition that this understanding is one of many alternative explanations, and the capacity to show how this understanding is superior to alternative explanations.[35] A key feature of argumentation is the consideration of multiple perspectives in the form of counter-arguments.[7]

RATIONALE AND RESEARCH QUESTION

Argumentation is an important skill for any member of a scientific community; it is one of the primary ways in which scientists inform others about their work and new findings. It has also been shown to play a critical role in the development of new knowledge.[7] Being able to generate a scientific argument is a skill that not only is beneficial as a chemist but also can be easily transferred to many areas of life. The classroom provides an ideal space to help students develop this skill, and it has been advocated that a key role of the science classroom should be to prepare students to enter this discourse.[36,37] To aid students in learning how to develop an argument using scientific concepts, instructors can model suitable ways to construct an argument

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Table 1. Comparative Overview of Classroom Demographics for 2009 and 2010

	instructor: Dr. Black	
parameter	2009	2010
instructor experience	9 years of implementing POGIL	10 years of implementing POGIL
setting	medium-sized, Midwestern university; thermodynamics; Spencer, Moog, and Farrell POGIL physical chemistry materials[a]	
number of participants	15 students (10 female; 5 male)	18 students (5 female; 13 male)
participant demographics	third- and fourth-year students at least 1 semester of calculus[b]	third- and fourth-year students at least 1 semester of calculus
class time	50 min a day 3 days a week 15 weeks	75 min a day 2 days a week 15 weeks
	1/3 to 1/2 class small group work, the rest whole class discussion	

[a]See ref 39. [b]One student had not taken a semester of calculus.

and provide students the opportunity to practice constructing their own scientific knowledge.[7,36] Because the instructor plays a critical role in any classroom environment, it was of particular interest to see what specific teaching strategies and techniques an instructor could use to help students generate scientific arguments.[38] Therefore, the research question that this study aims to answer is How do alterations to an instructor's facilitation of a POGIL physical chemistry classroom influence the students' construction of scientific arguments and explanations?

DATA COLLECTION AND METHODS

Participants and Classroom Setting

This study compares two iterations of a physical chemistry course, from 2009 and 2010, at a Midwestern comprehensive university. A detailed summary of both iterations is shown in Table 1. Because the participants included a mixture of third- and fourth-year chemistry majors, the background for the students varied, but in general, the participants had completed two semesters of general chemistry, two semesters of organic chemistry, other upper-division chemistry courses, and one or more calculus courses. Even though the length of each class session varied for the different iterations, the total time that the students met was consistent and identical course content was covered in each iteration. This study was IRB-approved, and participants gave informed consent.

For this study, the research team selected one group of students during each iteration to observe during the small group portion of the class. The group was essentially selected at random, but it was noted beforehand that there was significant interaction among group members. While no formal assessment was done to establish the representativeness of the small group, it was observed that student interactions were very similar in all of the groups. The membership of the group remained the same throughout the observation period. In this instructor's implementation of POGIL, the students worked through the ChemActivities from the POGIL workbook[39] in small groups of three or four students, in which individuals had been assigned roles that rotated on a weekly basis. In both iterations the roles include manager, spokesperson, recorder, and reader. Each activity began with a focus question, then continued on to the critical thinking questions (CTQs) that would prompt the students to explain trends in data, make predictions about chemical and physical processes, and define terminology and symbolism.[25,39] Students would work in their small groups on the assigned questions for a designated amount of time (typically 5−10 min), and then the instructor would bring the groups together for a whole class discussion. The instructor would present mini-lectures as needed.

For both iterations, the small group discussion facilitation remained consistent. The instructor used mini-lectures to present the background information in the activities to address differences in reading speed and ensure that all groups started answering the CTQs at the same place. The instructor chose to assign blocks of CTQs followed by whole class discussion to assist in time management and provide additional opportunities to assess and expand on student reasoning. Breaking the activity into smaller blocks allowed slower groups to catch up during whole class discussion and helped manage the time students spent on any particular question. More details about facilitation of whole class discussion are provided in the findings to provide context for the results.

Data Collection

Data for both iterations was collected during a five-week period in which concepts on work, heat, enthalpy, heat capacity, entropy, and Gibbs Energy (ChemActivities T1-T10) were addressed.[39] The data for this study comes from video recordings of both the whole class and small group discussions. The conversations were transcribed verbatim; however, due to some technical difficulties, some portions of the small group work were not audible and could not be transcribed.

Discourse Analysis

Discourse analysis is one method that can be used to analyze how students reason through and develop an understanding of concepts and mathematical equations in physical chemistry. To better understand teaching and learning, discourse analysis is useful because it takes into consideration the social aspect of learning, such as student−student, student−instructor, and student−course material interactions.[40−43] This analysis is aligned with social constructivism, which considers social resources such as language and symbolic representations to be crucial mediators to the learning process.[18] In chemistry classrooms, instructors encourage students to participate in discussions and serve as experts helping students understand the disciplinary expectations and what is considered acceptable justification.[20,43]

Discourse analysis allows researchers to identify similarities and differences among populations of students and gain insight into different instructional pedagogies. Because the classroom learning environment is complex, it is easier to focus on one area of interest. This project focused on the influence instructors have on the development of student-generated scientific arguments; therefore, two iterations of one instructor's class were analyzed, and the classroom interactions were compared.

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Analytic Frameworks

Toulmin's Model of Argumentation. Toulmin's model of argumentation, sometimes referred to as Toulmin's argument pattern (TAP), acknowledges the use of argumentation as a way to build explanations, models, and theories.[44] According to Toulmin's model of argumentation, shown in Figure 1, an

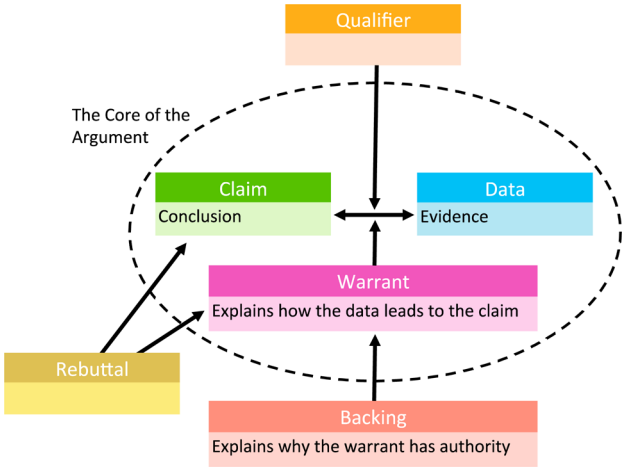

Figure 1. Toulmin's model of argumentation.

argument comprises a series of statements with each playing a different role in the structure of an argument. This process is essentially what scientists do in building arguments to connect evidence (data) to the claims they reach through the use of warrants and backings.[12,13,45] The core of an argument consists of a claim, data, and warrant. The additional three components of an argument add sophistication to the argument.

Toulmin's analysis has been primarily used in examining the processes of discussion and argumentation, particularly in classrooms that emphasize cooperative and collaborative group work.[27,30,46,47] Toulmin's model was used as an analytical framework because it provided a structured approach to coding the presence of arguments, identifying the participants in an argument, as well as their contributions to the argument. It also allows connections to be made between the type and strength of arguments and curricular materials and facilitation strategies.[47] Analysis of arguments can also provide insights into student misconceptions or difficulties in understanding chemistry concepts, which can then inform the development of curricular materials or instructional strategies.[26,27]

A limitation of Toulmin's analysis is that it can assess only the structure of an argument. This method is good for evaluating the presence as well as the strengths and weaknesses of argument construction, but it does not evaluate the correctness of the argument nor does it indicate the extent to which the content agrees with scientifically acceptable knowledge.[26] There are also significant amounts of classroom discourse that cannot be characterized (or coded) as arguments. Therefore, another analytical framework is necessary to analyze these other aspects of dialogue that are not part of argumentation. Additionally, the argument in the actual flow of conversation rarely develops in the sequential manner in which the formalized argument is presented.

Inquiry-Oriented Discursive Moves. The inquiry-oriented discursive moves (IODM) framework was used to examine the verbal statements, or discursive moves, used by the instructor to create and sustain an inquiry-oriented classroom.[13,48] IODM analysis helps document instructor practices to characterize facilitation of student-centered learning environments. This framework was developed to focus on aspects of classroom discourse not captured by Toulmin's framework. Correlating the discursive moves of the instructor to the presence and quality of student arguments can provide insights into understanding effective facilitation of active learning environments. This analysis allows for comparison of different classroom interactions and facilitation and how these factors relate to argumentation.

Discourse analysis using IODM consists of characterizing discourse as one of four distinct discursive moves: revoicing, questioning, telling, and managing (shown in Figure 2). Each of these discursive moves can be broken down further into four categories that provide a finer-grained analysis used to describe teacher inquiry.

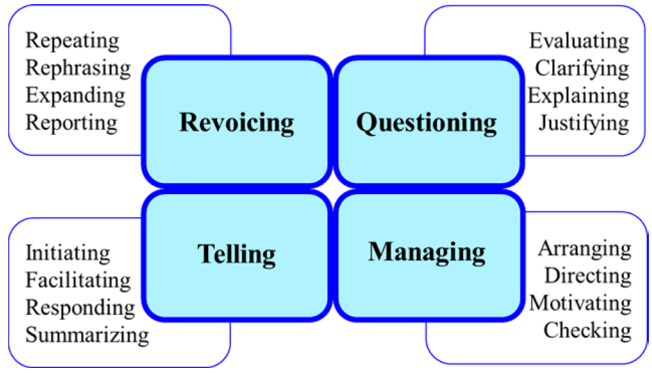

Figure 2. Categories coded by the inquiry-oriented discursive moves framework.

A *revoicing* discursive move is when an utterance is said again by another speaker. The four categories of *revoicing* are (i) *repeating*, (ii) *rephrasing*, (iii) *expanding*, and (iv) *reporting*. *Revoicing* moves highlight specific ideas and move the discussion forward, empower student thinking, and help students understand what are considered reasonable explanations.[48,49] *Questioning* discursive moves are explicit questions directed to students. The four categories—(i) *evaluating*, (ii) *clarifying*, (iii) *explaining*, and (iv) *justifying*—help reveal a student's understanding of the material. *Questioning* moves are important tools for instructors because they allow instructors to determine whether students are coming to the correct conclusions, and they can be used to encourage students to justify and explain how they arrived at their conclusions. Getting students to explain their thought process is significant because it helps instructors better understand the connections students are making and helps ensure conclusions are based on sound reasoning.[48] *Telling* discursive moves are characterized by information being stated or procedures defined and can be divided into four categories: (i) *initiating*, (ii) *facilitating*, (iii) *responding*, and (iv) *summarizing*. *Telling* moves are used to further discussion, direct student attention to a new task or idea, provide insight, or guide student argumentation. Lecturing is primarily composed of the components of *telling*. Many studies of inquiry-oriented classrooms tend to underemphasize this type of discourse, but *telling* moves are important techniques for moving an inquiry classroom forward and assisting students when needed.[48] *Managing* discursive moves focus on moving the class forward but do not contain content-

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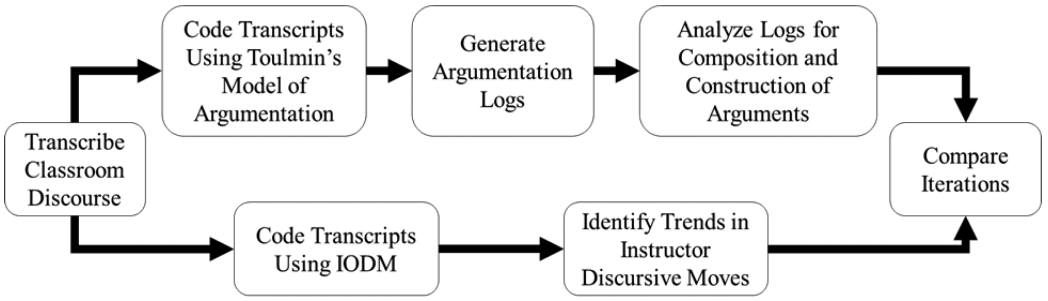

Figure 3. Summarization of the data analysis process.

Table 2. Summary of Argument Types Used To Characterize the Nature of the Arguments

type of argument	description	where argumentation occurs
initial argument	This is the first argument presented during discussion of a question.	small group work; whole class discussion
rebuttal argument	This argument must challenge a previous argument and can be constructed by multiple groups.	small group work; whole class discussion
alternate argument	This argument is constructed during small group work and presented during whole class discussion of a question. It can either agree or disagree with the initial argument.	whole class discussion
consensus argument	This argument presents the agreed upon correct response to a question in the case of disagreement between previous arguments; it can be constructed by multiple individuals or groups.	small group work; whole class discussion

related information. The four categories of managing are (i) *arranging*, (ii) *directing*, (iii) *motivating*, and (iv) *checking*. Classroom management at times may seem a trivial part of an instructor's repertoire of discursive moves, but they help keep an inquiry classroom together as a unit and ensure the students are keeping pace with the material.[48] A more detailed description about each code is provided in the Supporting Information.

Data Analysis

A two-pronged analysis, as shown in Figure 3, was used to analyze the discourse in this study. The first approach used an extension of the process described by Rasmussen and Stephan[50] for using Toulmin's model of argumentation to document and analyze students' mathematical progresses.[12,13,45] The second approach used the inquiry-oriented discursive moves framework developed by Rasmussen et al.[48] to identify the various facilitation strategies employed by instructors to elicit discourse from students and frame the classroom discourse.

Coding Using Toulmin's Model of Argumentation. The first step of the analysis was to code the transcripts using Toulmin's argumentation scheme. The researchers identified components of arguments present in classroom discourse by focusing on the nature and purpose of the utterances. Details of this process have been described elsewhere.[45] In this classroom setting, the data components were often not verbalized by the students but were implied based on the information given to the students in the ChemActivities. Because this study wanted to examine how the instructor impacted students' abilities to generate arguments, some partial arguments that consisted of only claims and data were identified to document how often justifications were provided for given claims.

To better capture the difference in argumentation for the two semesters, additional codes were developed to characterize the nature of the arguments, as shown in Table 2. Initial arguments were the first arguments expressed in response to a question. Rebuttal arguments occur in response to an argument and challenge some component of an argument. Alternate arguments were arguments that were generated during small group work but presented to the class during whole class discussion. They were considered alternate if they were not articulated by the first group to present their response to a particular question. Note that alternate arguments occur only in whole class discussion. Consensus arguments were generated during discussion to reconcile rebuttals to arguments or variations in alternate arguments.

These sequences of arguments resulted in iterative arguments, in which multiple arguments were voiced to answer one question, as shown in Figure 4. More than one argument could

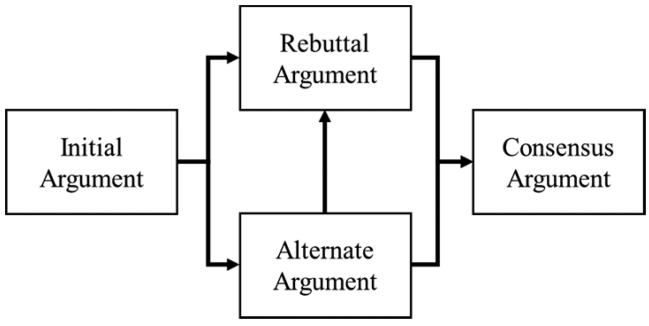

Figure 4. Structure of how different argument types appear during classroom discourse.

be coded as an initial argument for a question if the second argument follows a break in argumentation during which discussion of content with the instructor occurs where information is being generated or shared that is not in the form of an argument. After this discussion, a separate initial argument was then generated when the instructor prompted students to respond to the same question or expand upon some aspect of the question. This second initial argument is different from an iterative argument because it is not in response to the initial argument or presented simultaneously.

Generation of Argumentation Logs. After the transcripts were coded using Toulmin's model, argumentation logs were generated for each class period. The argumentation logs presented each argument in a consistent manner (claim/data/

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warrant/backing), even though arguments rarely developed in this sequential manner in the actual flow of conversation. Additionally, to condense data when isolating arguments, dialogue was paraphrased if it could retain the same sense of function of a particular statement in an argument. Direct quotes were identified by using italic text. Each argument was tagged with the ChemActivity and relevant question number that was the focus of discussion.

Analysis of Argumentation Logs. Once the individual arguments were identified, the logs were analyzed to look at completeness and who contributed to each argument. For completeness, we identified the different components used to construct the argument (claim, data, warrant, etc.) as well as any iterative arguments. For contributions to the argument, we determined who voiced each component of the argument.

Coding Using Inquiry-Oriented Discursive Moves. After the arguments were coded and analyzed, we returned to the transcripts and recoded them using the IODM framework to identify the discursive moves the instructor used to frame class discussions and elicit classroom discourse.[13] When analyzing a transcript to code the different discursive moves, the units of analysis are identifiable utterances, each serving a different function, instead of the entire passage of an instructor talking. This was done because there was often more than one discursive move present in a specific interaction.

Analysis of the Instructor's Discursive Moves. By analyzing the discursive moves of the instructor, one can identify patterns of how the instructor interacts with students. Differences and similarities for instructor interaction between the two iterations were analyzed to see how this influenced student behaviors.

Comparison of 2009 and 2010 Data Sets. For the purposes of this study, only the whole class discussion portions of the courses were compared, because the alterations in facilitation primarily affected this portion of the classroom interactions. By using both the Toulmin and IODM frameworks, one can investigate how the instructor's interaction with the students to elicit student discourse was reflected in the ways in which students generated arguments.

Reliability

For the analysis of the transcripts using Toulmin's model, a portion of the transcripts was coded collaboratively by the research team to establish consistent use of our coding scheme. After the initial collaborative coding, the remaining transcripts were coded independently by at least two team members. The team would then discuss all identified arguments until a consensus was reached. These agreed-upon consensus arguments were then used to develop the argumentation logs that were used for further analysis.

For the analysis using the IODM framework, the 2010 data set was coded collaboratively by the research team to establish a consistent use of the coding scheme. One team member coded all of the 2009 transcripts, while a second team member coded approximately 25%. The percentage agreement between the two raters was 80%, and all discrepancies between the raters were reconciled through discussion. In addition, members of the team met with the original developers of the IODM framework to ensure the framework was being interpreted and applied correctly.

FINDINGS

A comparison of arguments generated in whole class discussion in 2009 and 2010 revealed an increase in argumentation for every type, as shown in Table 3. Further analysis was conducted to determine if the alternations in facilitation could explain these differences.

Table 3. Comparison of the Number of Each Type of Argument Found in Whole Class Discussion by Year

argument types	2009, *N*	2010, *N*
initial arguments	125	190
alternate arguments	4	21
rebuttal arguments	3	12
consensus arguments	6	14
total arguments	138	237

Structure of Arguments in Whole Class Discussions

One of the trends identified was a difference in the structure of the arguments generated during the whole class discussions. Figure 5 illustrates the flow of the arguments constructed in 2009 and 2010 for the same CTQ during the whole class discussion. Here, the instructor is represented in black and each individual student is represented with a different color to indicate who contributed which component to the argument. Note that italic text indicates a direct quotation from the transcript.

In 2009, the instructor asked a spokesperson from one group to present their group's solution. When there was general confusion or disagreements between groups, the instructor attempted to get students to engage one another and critique other groups' arguments. However, the students would infrequently speak up if they had different answers. Therefore, the instructor typically would aid the students in reaching the correct solution. In these situations, the instructor contributed several components to an argument because students were struggling to explain a concept or they did not want to volunteer their opinions. This resulted in the whole class discussions clearly being directed by the instructor. In this example, student 1 provides an argument stating that Ne and N_2 will have different temperatures because N_2 is larger and requires more energy to move. The instructor challenges the student and pushes the student to think about why the temperatures for Ne and N_2 will be different. This first argument is followed by two additional arguments, predominately voiced by the instructor, further expanding upon why Ne will have the higher final temperature.

The instructor was particularly frustrated with the evidence that students would not contribute the fact that they had different solutions or arguments than the presenting group. This was in contrast to the small group discussions in which students were more likely to provide opposing points of view and expand on each other's arguments. The instructor was also surprised by the extent to which she contributed to arguments in whole class discussion because students did not fully articulate their reasoning. In response to these observations, the instructor made a number of changes to facilitation during the 2010 implementation. First, each group was given a 2 ft × 3 ft white board on which students could write their answers to enable simultaneous reporting. The instructor had become aware of this strategy used in Modeling Physics,[51] which allows everyone to see how each group answered the questions. This

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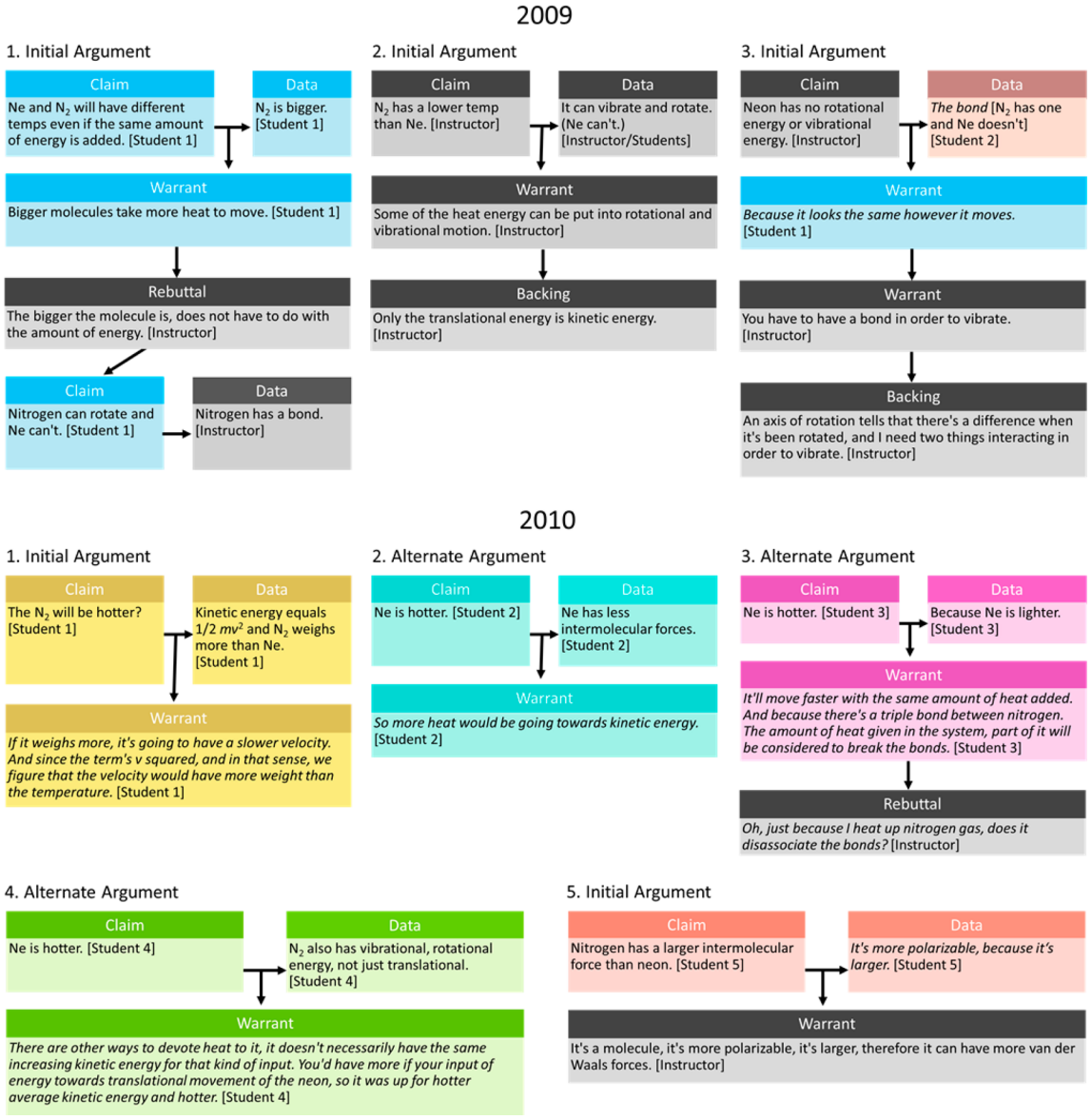

Figure 5. Differences in the structure of the conversations taking place in whole class discussion in 2009 and 2010. The number indicates the order in which the argument was presented; color indicates different speakers (with the instructor in black). Italic text in the figure designates direct quotes. Class discussion centered on this critical thinking question: *Consider 1 mol samples of Ne and N_2 at the same temperature. Equal amounts of heat are added to each sample under otherwise ideal conditions. Predict whether the final temperature of the two samples will be the same or different. If different, which will have the higher final temperature? Explain clearly.* [CTQ 2 from Activity T4; see ref 39].

was done to prevent students from not sharing when they had different responses and to provide more opportunities for students to compare their answers to the questions. Second, the instructor was more conscious about trying to encourage students to explain and justify their answers. It was hoped that being more intentional in requesting students to provide reasoning would result in more complete student arguments.

In 2010 we see a different type of dialogue taking place, one that is more directed by the students. When there is disagreement or confusion between groups, the students are the ones leading the discussion instead of the instructor. In this iteration, the instructor had every group hold up their white boards for the other members of the class to see simultaneously; therefore, each group had to be prepared to defend and explain their answers. When a disagreement occurred, the instructor could more easily prompt the students to defend the answers written on their boards because the instructor could see who agreed and disagreed with the presented answer. This resulted in several students explaining their group's answer to a given problem. In this example the instructor prompted the spokesperson from the first group to explain why they believed N_2 would be hotter than Ne. However, this answer differed from what others students had written on their white boards. Therefore, the instructor called on the other groups sequentially to explain the reasoning behind their claims that Ne is hotter than N_2. Here, the instructor contributed to the argument only when there was a need to correct a misconception or incorrect information. After a satisfactory answer was provided by student 4, the conversation continued to further expand on the reason why N_2 would be at a lower temperature then Ne.

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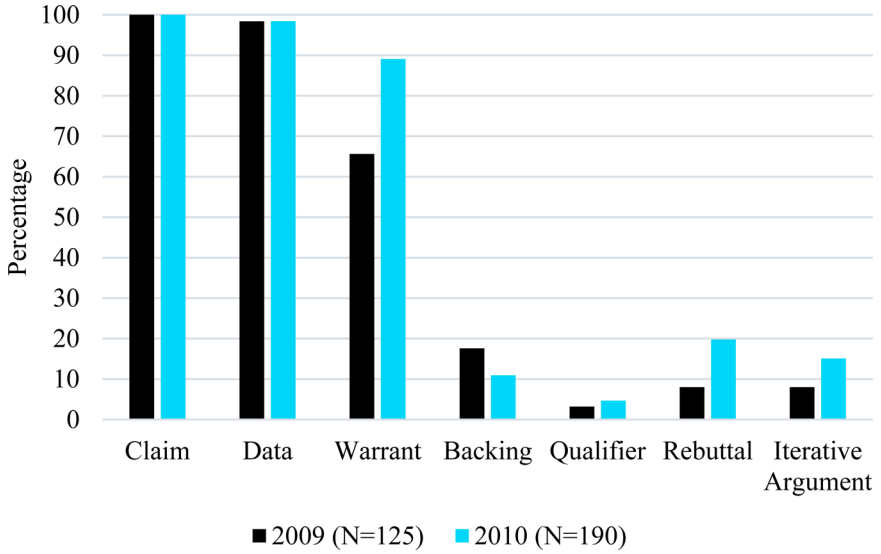

Figure 6. Comparison of the components for the initial arguments generated during whole class discussion in 2009 and 2010.

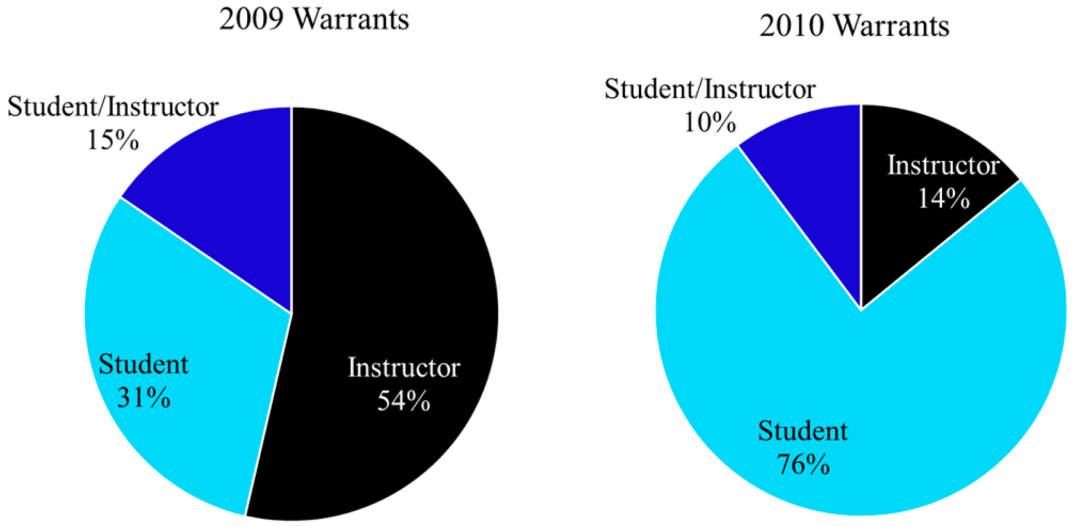

Figure 7. Comparison of who voiced the warrants of the initial arguments generated during whole class discussion in 2009 (N = 125) and 2010 (N = 190).

Construction of Arguments

In addition to the increase in the number of arguments, another difference between the two iterations was the completeness of the arguments, shown in Figure 6. According to Toulmin, in order to be recognized as a complete argument, a claim, data, and a warrant must be identified.[44] However, students do not always construct complete arguments; they regularly make claims without any support or provide claims and data without any explanation as to how their data supports their claim. As discussed in the data analysis section, some partial arguments that consisted of only claims and data were identified to document how often justifications were provided for given claims. In general, most claims were backed up by some form of data, except for a few instances in which a rebuttal directly followed the claim. Claims without any evidence of the reasoning used to generate them that were not immediately challenged by another were not included in this analysis because these statements do not indicate that students were actually trying to construct an argument. When the 2009 and 2010 data sets were compared, the most notable difference was in 2010 in which there was a 43% increase in the number of arguments that were supported by a warrant.

With the increase in arguments being supported by warrants, the research team investigated who was actually voicing the different components of the arguments, particularly the warrants, as seen in Figure 7. Ideally, in a student-centered classroom the students should be the ones supporting and justifying their claims during whole class discussion. It should be noted, however, that for both iterations there were several instances in which the claim or data was provided in the POGIL materials and therefore not voiced. In 2009, 54% of the warrants voiced were attributed to the instructor and 31% were attributed to the students. With the 2010 iteration, the reverse is seen: only 14% of the warrants were contributed by the instructor and 76% of warrants were attributed to the students. Both iterations also contained a small portion of warrants that were constructed from information provided by both a student and the instructor; these are what are referred to as student/instructor warrants. This increase in warrants shows that the students were providing more justifications for their claims.

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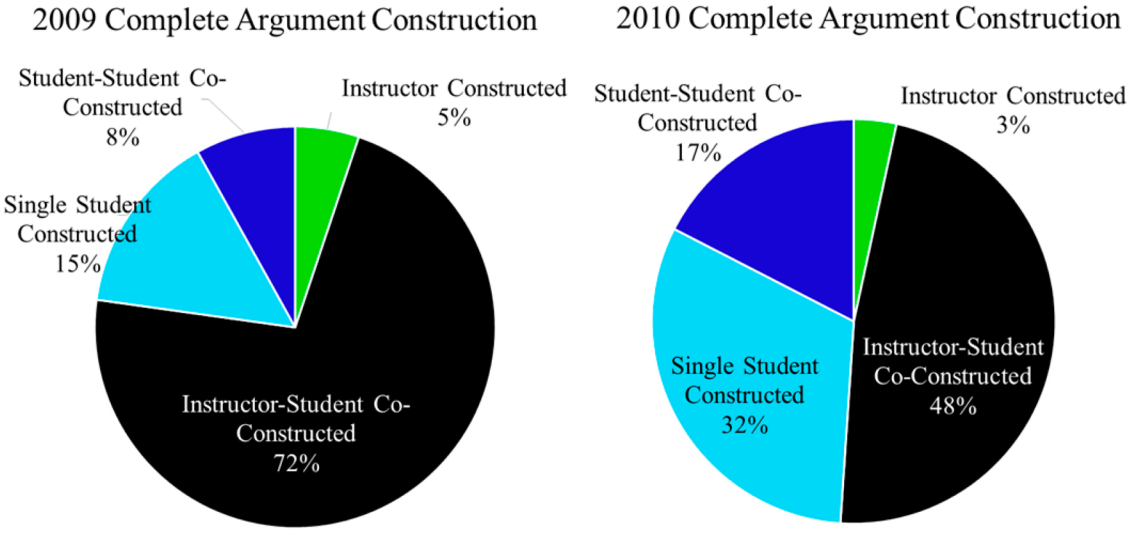

Figure 8. Comparison of who constructed a complete argument in whole class discussion.

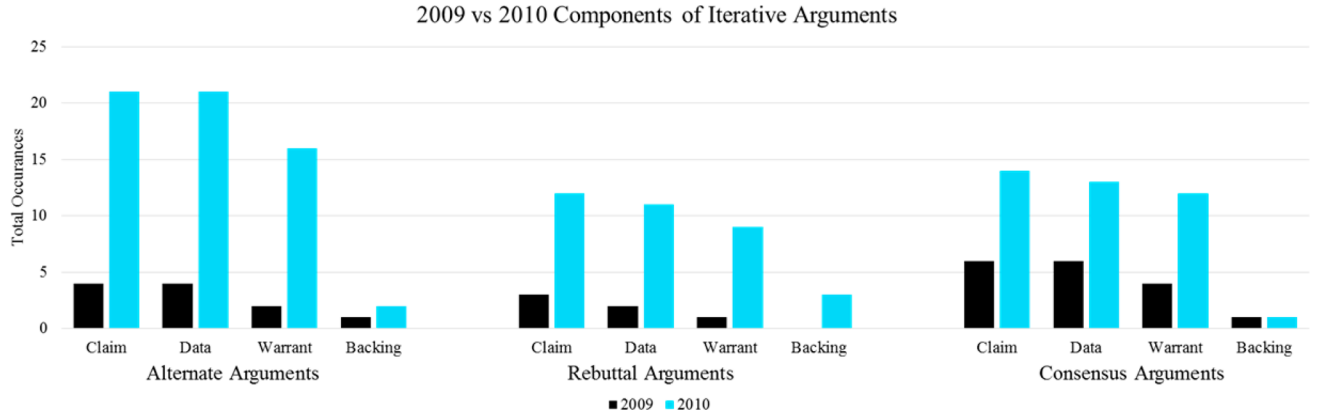

Figure 9. Comparison of the iterative arguments generated during whole class discussion in 2009 and 2010.

Once it was identified that the students were contributing more warrants to arguments, the researchers explored whether students most often constructed arguments individually, with the assistance of their peers, or with the assistance of the instructor, as shown in Figure 8. The instructor was counted as assisting in the construction of an argument if they contributed any component of the argument. It was found that in 2009, 72% of the arguments were co-constructed between students and the instructor and ∼20% were presented by individual students or co-constructed with the assistance of their peers. In 2010, there was an increase in the number of student-generated arguments, with 32% of the arguments constructed by individual students and 17% co-constructed by multiple students during the whole class discussion. It should be noted that in whole class discussion the arguments presented by a single student were usually the agreed-upon argument that was developed by the group during the small group work portion of the class. This increase in student-generated arguments resulted in a decrease of the percentage of arguments in which the instructor took part. This shows that in the second iteration of the class the students were more likely to generate scientific arguments without input from the instructor.

In addition to the increase in warrants and student-constructed arguments, there was also a 55% increase in the number of discussions that resulted in iterative arguments or instances in which multiple arguments were generated in response to one CTQ. It was found that there was an increase in each of the types of arguments—alternate, rebuttal, and consensus—shown in Figure 9. (See Table 2 for descriptions of the types of arguments.) While many alternate arguments existed in 2009, as evident from the analysis of small group discussion, students rarely shared these arguments with the rest of the class.[12,45] The increase in these iterative discussions is attributed to the use of the white boards; because every group had to show their answer to the rest of the class, the instructor could more easily identify when there were disagreements among the groups of students. Once the disagreement was identified, the students were then expected to explain and defend their answers to their peers. When analyzing the iterative arguments to identify who constructed the arguments, it was found that the alternate arguments were predominately constructed by the students with the instructor providing the backing.

Derivation Questions

In the analysis of the 2009 classroom discourse, it was noted that students did not often discuss their reasoning when answering questions that required them to derive equations or provide expressions. In the few arguments that were generated, students struggled to clearly articulate their reasoning and

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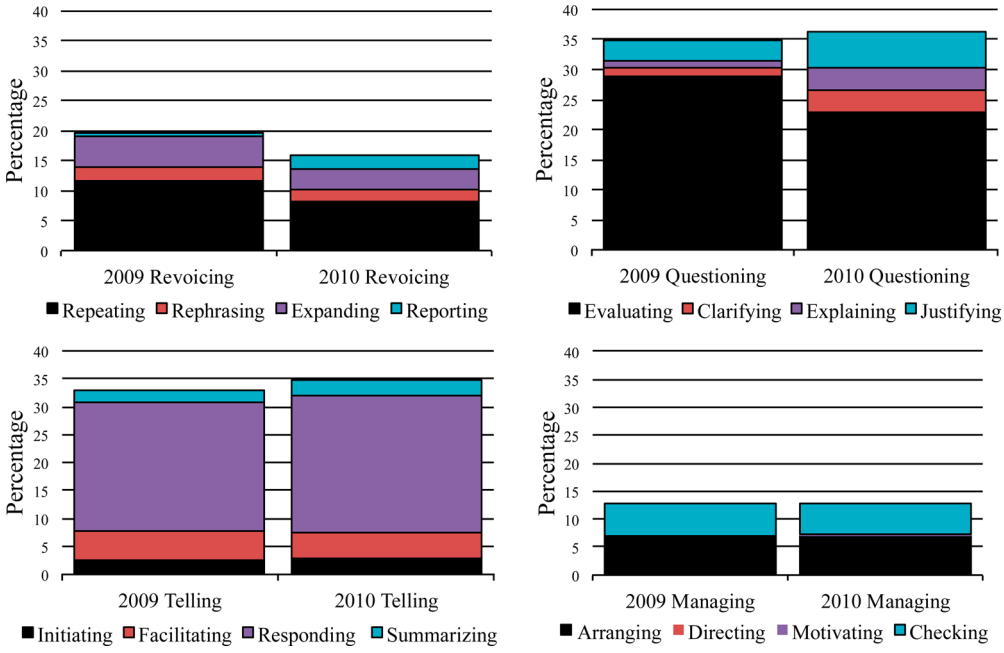

Figure 10. Detailed comparison of each of the inquiry-oriented discursive moves employed by the instructor in 2009 and 2010 to elicit student discourse and sustain an inquiry-oriented classroom. Each graph represents a different discursive move illustrating the percentage that each subcategory was used by the instructor.

generally just described the mathematical manipulations or process being used.

In an attempt to engage students in more meaningful discussion of questions deriving mathematical models, the instructor decided to assign questions that emphasized deriving relationships as homework, which the groups would then present to their classmates. The intention was that students would spend less class time trying to remember how to do the mathematical operations and would spend more time focusing on the form and function of the derived relationships. If successful, this would result in more argumentation for these questions. The instructor was also more conscious of asking students to verbalize equations in terms of the concepts being represented rather than reading out the symbols.

Of the 40 questions that were assigned as homework, one-third of the questions resulted in arguments in both 2009 and 2010, one-third resulted in arguments being generated in 2010 but not 2009, and one-third resulted in argumentation in neither year. While there was an increase in argumentation, the focus of the arguments generated by the 2010 students was still very much at the procedural level, similar to that of the 2009 arguments. In both years many of the arguments involved the instructor assisting in providing different pieces of information to construct the arguments. This shows that students were still struggling to generate arguments about the mathematical processes used to arrive at thermodynamic equations. There was very little evidence that students understood why deriving different equations is useful in explaining thermodynamic concepts. However, the quality of the warrants provided by students did improve as they used more scientifically acceptable language for the variables and relationships in the equations. These results suggest that additional changes are needed to encourage students to engage in more meaning-making regarding the mathematical relationships that are key to understanding thermodynamics.

Role of the Instructor in the Classroom

In the previous sections, it was shown that the students were more active participants in class discussion and provided more warrants for their arguments in 2010 than in 2009. The research team wanted to identify how the instructor's interactions with the students might influence student participation in class discussion. All of the instructor's discursive moves during whole class discussion were coded using the IODM framework to analyze how the instructor was supporting student discourse. Overall, it was found that the instructor spent the majority of her time using *questioning* and *telling* moves, as shown in Figure 10. In both 2009 and 2010 the instructor predominately asked *evaluating* questions to elicit specific answers from the students. However, in 2010, the instructor asked more *clarifying*, *explaining*, and *justifying* types of questions to encourage students to use thermodynamic concepts to explain the reasoning behind their claims.

In contrast to lecture-type classrooms in which the instructor spends the majority of their time *initiating* or *summarizing* information, the instructor was mainly using *responding* moves to answer students' questions and acknowledge student answers. In addition to *questioning* and *telling* moves, *revoicing* moves were used to emphasize student responses to questions. In 2010, there was an increase in the frequency of *reporting* moves; this is attributed to the use of the white boards. When there were differences in student answers, the instructor would report the solutions that different groups had written on their white boards and then ask students to defend their solution. This detailed analysis shows that overall the instructor interacted with her students in a similar fashion during both iterations of the physical chemistry course but increased the percentage of *justifying*, *explaining*, and *clarifying* questions to prompt students to support their claims.

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LIMITATIONS

In this study, classrooms were observed at one institution facilitated by a single instructor who was very experienced using the POGIL format in her physical chemistry classroom. The findings reported here represent a case study of an instructor's facilitation style and how it influenced student argumentation in the classroom. It is not to be taken as a generalization for how all instructors affect student behavior. More work is needed to see how instructors with various levels of experience, different facilitation styles, and classroom settings can influence how students generate scientific arguments in the classroom.

Furthermore, because this study examined only student discourse and not written work, we were not able to assess how this alteration to instructor facilitation influenced how students construct arguments independently on items such as homework or exams.

In this study we looked at the role of the instructor discourse on student argumentation; however, instructors are not the only influence on student learning. The course materials also play a role in students' ability to construct knowledge at the various levels of chemistry. Therefore, work must be done to see what influence the course materials and the instructor have on students' argumentation and understanding of thermodynamics.

CONCLUSIONS AND IMPLICATIONS

This study investigated the whole class discussion portions of two iterations of a physical chemistry class to investigate how the instructor's instructional decisions influenced students' generation of scientific arguments. According to our findings, though the instructor's discourse differed little between the two iterations of the course, the facilitation of the whole class discussion and expectations for the students did vary. This resulted in an increase in the number of initial arguments, an increase in the number of warrants being generated overall, and more iterative arguments being generated. This indicates that there is an increase in the students taking ownership for their ideas. However, students still struggle to articulate and reason with mathematical expressions. The increase in students providing warrants to justify their claims, their likelihood of generating a complete argument without the assistance of the instructor, and the students contributing more to the discussion indicate that students are able to internalize and make meaning from the content they are discussing. This is thought to be influenced by two main factors. First, students use whiteboards to share their groups' solutions with the class, allowing the instructor to more easily see student solutions and prompt for justification, and second, the instructor more explicitly set forth the expectation that students must be able to defend and explain the reasoning behind their answers. Modeling Instruction,[51] Learning Physics,[52,53] and Argument Driven Inquiry[10,54,55] include the use of whiteboards in the classroom and laboratory to help the instructor assess student argumentation and understanding of the content. Argument Driven Inquiry has shown that whiteboards help to promote and support the growth of student argumentation. The results of our analysis also support previous findings that using open-ended questions and scaffolding encourage discussion between students and promotes student argumentation.[13,14,56−58]

Implications for Teaching

This research shows that even slight alterations to how a class is managed can lead to significant changes in student behaviors in a classroom. The addition of whiteboards for students to write their answers on during small group work to be shared with the rest of the class is a simple addition that can be used in a variety of active-learning classrooms. This not only allows the instructor to monitor group progress but also gives students the opportunity to more easily show their peers their approach to solving a problem if there was confusion. In addition, simultaneous reporting was useful in encouraging iterative argumentation and discussion among students. The questions assigned as homework helped students to be better able to explain the mathematical processes required to derive thermodynamic equations. However, students still focused on procedural aspects and had to rely on the instructor for assistance in explaining the derivations as they struggled to make meaning of the equations or ignored this aspect. The expectations of the instructor also can greatly influence the types of student responses during discussion. An instructor can use *questioning* moves such as *justifying* and *explaining* to encourage the students to explain and justify their answers. Setting forth the expectation that students not only share their answer with the class but also be ready to explain how they solved the problem and justify their work creates a learning environment that helps students develop their argumentation skills. This can be further encouraged by having instructors model good scientific practice themselves by providing the reasoning behind the claims they present in class. With prompting from instructors, students are able to gain the necessary skills needed to become members of the scientific community.

Implications for Research

This research also illustrates the robustness and the utility of the inquiry-oriented discursive moves framework. This framework, originally developed in mathematics education, was successfully implemented in chemistry classroom settings and served as a way to characterize how the instructor engaged students in classroom discourse and helped sustain an active learning environment. In addition, this work complements previous analyses that showed how IODM further complements Toulmin's model of argumentation to identify patterns in instructor discursive moves used to elicit arguments from students.[13]

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00993.

Inquiry-oriented, discursive moves coding definitions (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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