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# THE ROLE OF TEACHER GUIDANCE AND FAILURE DURING INQUIRY BASED LABS IN THE PHYSICS CLASSROOM

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**ABSTRACT**

Recent national and state standards have called for more inquiry and authentic activities within the science classroom. The definition of inquiry activities is somewhat ambiguous and even more ambiguous is how these inquiry activities are created in the science classroom. Current research examines these inquiry activities and various aspects that impact the activities. This study continues this line of research by examining the role of teacher guidance in influencing the discourse patterns of the students. Additionally, the potential benefits of failure during a lab were examined.

In order to examine teacher guidance (both the structure of the lesson and the support given by the teacher) and the role of failure, videos of both a traditional lab and an inquiry-based lab were analyzed. Both an honors section and an academic section were used for each type of lab. These videos were analyzed using a program known as *Studio Code.* The actions of the teacher were coded into procedural, conceptual and communicative support. The actions of the students were coded into procedural, conceptual and communicative actions. Each student action was given a label to indicate if it occurred before or after teacher support. In this way, the effect of the teachers support as well as the structure could be observed and described.

The study provided three main results. The first is that the structure of the lab must align with the support given during the lab for the teacher to have an effect on the discourse patterns of the students. For example, if the structure has a procedural focus, but the support given is primarily conceptual, there will be little change in the discourse of the

students. The second finding was that open support, meaning support where the teacher did not finish the interaction with a final evaluation, served to foster student-to-student discourse. Closed support (which included a final evaluation), on the other hand did not encourage discourse; it often gave the students tunnel vision and hindered the discourse. The last result was that under the correct conditions, a failure could be productive in the science classroom. In the context of this study, temporary failures lead to better discourse amongst the students.

These results contribute to a theory of learning in that they further emphasize the need for teachers to be reflective about their practices. In this case, teachers must consider their learning goals and ensure that the structure of the lesson compliments the support given during the lesson. Teacher also must consider the potential benefits of fading out the support structure to allow for a failure. This may seem counterintuitive, but under the correct conditions these failures allow for learning opportunities. Further research needs to be done to examine the conditions under which a failure can be productive as well as the means by which the teacher can fade the support structure to allow for these failures.

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Current trends in science education call for more inquiry and authenticity in the science classroom (Chinn and Hmelo, 2002). This call for authenticity and inquiry activities where students are engaged in scientific discourse stems from the social cognitive view of learning (Bluemenfeld, 1997). Current research in science education examines the concepts of authenticity and inquiry. The research centers on the question of how this student-to-student scientific discourse can be created and fostered in the science classroom.

The call for more inquiry and authenticity has lead to the creation of and research on inquiry activity structures such as problem-based, discovery and practicum labs. Past studies have examined the role of the activity structure on student discourse and found that inquiry structures are beneficial in promoting this discourse (Krystyniak & Heikkinen, 2007; Berg et al., 2003; Hofestein et al., 2004). Related to the structure is the role of the teacher in supporting the discourse. Studies have investigated the effect of the well established I-R-E pattern describe by Mehan (1979) along with variations of this pattern described by Mortimer & Scott (2003) and Wells (1993). The findings have shown that open, dialogically focused support also fosters discourse (Augiar et al., 2009; Chinn, 2006).

Recently, research has begun to examine the possible benefits of fading teacher structure and support and to allow the students to fail. Productive failure, as describe by Kapur (2008), provides a new direction of research that examines how failure can have positive learning outcomes. The Kapur study provided support for possible benefits of students failing to complete ill-structured tasks, however there is a need for further research to examine the failure.

This study examines how the teacher provides guidance for the students through activity structure and the support given during an activity. The focus will be on the effect of structure and support on the discourse of the students. The study will also look for possible benefits of failure during student discourse to provide additional support for the theory of productive failure.

**THEORETICAL FRAMEWORK**

Bluemenfeld (1997) indicates that, in the context of social constructivist theory, learning is "cognitive processes that are engaged by the students as they learn" (p. 824) while knowledge is "contextualized and cannot easily be separated from the situation in which it develops" (p. 831); social constructivist notions of learning focus on the importance of discourse, community and context. The ideas of discourse and community as critical to learning come primarily from the work of Vygotsky whose theories rely heavily on the importance of social interactions to learning. Students are viewed as a part of a discourse community; they are introduced into the knowledge and "language of the community by more competent others" (Blumenfeld, 1997, p. 832). Vygotsky theorized that students have a level of competence in a subject without assistance and a higher level of competence in a subject with the assistance of a more capable peer. This difference in abilities is called the Zone of Proximal Development (ZPD). According to Vygotsky, it is the role of the teacher to provide instruction within this zone, which will increase the student's ability (both assisted and unassisted) in a technique known as scaffolding.

In addition to discourse and community, context is another essential feature of the social constructivist view. Since learning and knowledge are contextualized, classroom tasks should be authentic, which is to say that they should parallel the work of scientists. Recently there has been a lot of research into authentic tasks and how they are used in the science classroom (e.g. Chinn & Hmelo, 2002). These tasks extend beyond the classroom and have real world applications. Along with these authentic tasks, the use of alternative assessments is also encouraged. This stems from the fact that standardized tests “promote fragmented and decontextualized knowledge, the use of alternative assessments is encouraged” (Blumenfeld, 1997, p. 834), but alternative assessments allow students to apply and represent their knowledge without taking it out of context.

This study will focus on three specific ideas within social constructivism as well as one idea that complements parts of the social constructivist approach. Bereiter’s (1994) Progressive Discourse will be used as a model for effective discourse. Practicum labs, developed through the American Association of Physics Teachers will provide an example of an authentic task as well as an alternative assessment (Amann et al., 2005). Mortimer and Scott’s ideas of authoritative and dialogic discourse will be used to examine the role of the teacher and analyze interactions between student and teacher (2006). The complementing piece is the idea of productive failure, which was first characterized by Kapur (2008).

***Progressive Discourse***

Progressive discourse outlines a way in which science (and science education) can walk the line between viewing science as purely objective (positivist) and viewing science as the socially constructed and subjective opinions of scientists (postmodern view). The central idea of progressive discourse is to view science as having a commitment to progress: a belief that “today’s knowledge is better than yesterday’s” (Bereiter, 1994, p. 4). Thus it is not a rigid objective truth nor is it the opinions of an influential set of people, but an evolving commitment to improving understanding of the natural world.

Bereiter describes four importance pieces, or commitments, of progressive discourse (Bereiter, 1994). The first is a commitment to *mutual understanding*. Mutual understanding means that all parties involved, in this case the classroom community, eventually work towards an understanding that is agreed upon by everyone. It is important to note that this does not mean compromising, but rather engaging in discourse until there is agreement upon one idea that is satisfactory to all. The second commitment is to *empirical testability*. In this commitment, ideas must be presented so that evidence can be used to support or refute them. This commitment is central to science as a whole, since it is what separates science from other fields where opinions and thought experiments can have validity without testability. The validity of theories in science is determined by experimentation and other methods of comparing ideas to the natural world, such as observation. Any theory that cannot be tested in some way cannot be considered scientific. These first two commitments outline the discourse piece of progressive discourse. For effective discourse, scientists (or science students) should aim to eventually agree upon one idea or theory and the ideas should be developed in a way that makes them able to be tested empirically.

The third and fourth commitments are to *expansion* and *openness*, which is essentially a commitment to the progressive piece of progressive discourse. The expansion commitment strives to expand the number and scope of ideas that are considered valid. This is a commitment to progress in a quantitative sense: having more valid theories regarding a phenomenon is evidence of a deeper understanding of that phenomenon. The qualitative concept of progress (having theories that are considered more valid than before) is fulfilled by the openness commitment. Since theories are generally built upon other theories, falsifying one theory in turn falsifies any theory that relies on the initial theory. The openness commitment requires that any theory be "subject to criticism" (p. 7). While theories can never be truly proven (Popper, 1972), the repeated, unsuccessful attempts at falsification of theories can make them more valid. The qualitative and quantitative elements of progress are satisfied by the commitments to openness and expansion respectively.

Progressive discourse outlines a method for which science can achieve progress, however it can easily be considered a model for science classrooms. "The fact that classroom discourse is unlikely to come up with ideas that advance the larger discourse in no way disqualifies it" (Bereiter, 1994, p. 9). The discourse can still be progressive in the sense of it developing greater understanding of science amongst the students. For the purposes of this study, elements of progressive discourse will be identified in the classroom and viewed as an ideal way of using discourse to further student's understanding of science.

***Practicum Labs***

The importance of context is a large piece of social constructivist approaches to learning. Since learning is situated and cannot easily be transferred, it is important for classroom activities to be authentic. The practicum lab is an example of an authentic activity structure. It was originally developed by Jon Barber and Hank Ryan of Bethel University (Amann et al., 2005). In this type of lab, the students are presented with a problem to solve, but are given only limited direction on how to solve the problem or the measurements needed to solve it. The students are not assigned set groups, but rather work as a whole class and can organize themselves however they choose to arrive at one final, whole class solution.

The practicum lab has a few important features that make it authentic as well as a useful learning experience. The first is the lack of set groups or a procedure. Unlike many of the so called "cook book" labs, the practicum requires the students to divide up the work, determine the important measurements, make the appropriate calculations and present a solution. Another layer of authenticity is the fact that "nature, rather than the authority of the teacher, grades the students" (Amann et al., 2005). While there is a part of the grade that depends on the explanation of the students, the ultimate test of whether or not they solved the problem is determined by nature not the teacher. In real life context, there is not an authoritative figure to determine the success of a solution or theory; it is empirical testing that determines this. The last key feature is the difficulty level. Ideally, a practicum is difficult, but solvable. It should present a unique problem which the students will struggle to solve by will eventually solve together. The lab should be within the ZPD of most if not all students, especially because the students can often act as more knowledgeable others for their peers.

### *Role of the Teacher*

The social constructivist view focuses primarily on the concept of students learning through social interactions with each other (Blumenfeld, 1997). The role of the teacher is somewhat less defined. The teacher should support this learning through scaffolding, but the means through which this accomplished can be vague. Mortimer and Scott (2003) defined and categorized the interactions between students and teachers in discourse communities in their analytical framework. In their framework, the interactions between the student and teacher are grouped into four different communicative approaches.

There are two dimensions to the communicative approach as defined by Mortimer and Scott (2003). The first is the *Interactive-Noninteracitve* dimension, which measures how much the teacher is engaging the students. More interactive means the teacher is soliciting student ideas whereas noninteractive means the teacher is the primary person offering ideas and the students assume a more passive role. The second dimension is the *authoritative-dialogic discourse* dimension. The dialogic end of the spectrum means the teacher is open to listening to and exploring multiple ideas. This is also sometimes called *reflective discourse* (Van Zee & Minstrell, 1997). The authoritative side is where the teacher has one idea in mind and pushes the conversation towards that idea. Together, these two dimensions create four possible communicative approaches: interactive/authoritative, interactive/dialogic, non-interactive/authoritative and non-interactive/dialogic.

Mortimer and Scott (2003) also examine the patterns of interaction between the student and the teacher. All of these patterns, by definition, must fall into the interactive dimension of the communicative approach, however they could be either authoritative or dialogic. Mortimer and Scott discuss the well-established I-R-E (Initiate-Respond-Evaluate) pattern described by Mehan (1979), which they claim is authoritative.

Whenever the teacher makes the evaluative move in the pattern the teacher (as a figure of authority on the subject) is rejecting any alternate ideas that the students may have. They go on to describe possible extensions of the pattern where the cycle continues with the teacher prompting (instead of evaluating) and the students responding (I-R-P-R-P). They claim that this cycle can end in either an open or closed manner. In the closed case the teacher makes a final evaluation (I-R-P-R-E), but the open pattern the teacher does not (I-R-P-R-P-R-). The closed pattern still falls into the authoritative dimension, because the evaluation still rejects any alternate views. The open pattern is considered dialogic because the final move by the teacher is a prompt rather than an evaluation. The prompt does not eliminate other ideas like the evaluation. Instead, these ideas can continue to be a part of the discussion amongst the students, thus it is dialogic. This important distinction between open and closed support will be used to categorize interactions between the student and the teacher in this study. The student discourse following the two different supports will be examined focusing on how the teacher creates the potential for productive failure using either open or closed support.

***Productive Failure***

Kapur's (2008) suggests the basis of productive failure is that there is educational value is allowing students to fail at performing ill-structured tasks. This concept opposes the idea of traditional scaffolding. Kapur argues against the idea "that structure helps learners accomplish what they might not otherwise be able to in the absence of structure" (p. 382), which is the essence of scaffolding. Kapur hypothesized that by removing the structure and allowing students to fail, there would be the potential for learning.

Kapur examined groups of students solving a physics problem set within a computer supported collaborative learning (CSCL) environment. Some groups were given a "complex and ill-structured" problem and the other groups were given a "well-structured" problem. In this case, the *ill-structured* problem means that:

- Possessed many problem parameters with some unknown, or known only with some degree of confidence
- Possessed problem parameters that interacted with each other in interesting ways such that the effect of each could not be examined in isolation
- Possessed multiple solutions and solution paths
- Possessed multiple criteria for evaluating solutions, and required learners to make assumptions, judgments, and express personal opinions or beliefs (p. 387)

The *well-structured* problem is more typical of what is seen in high school physics textbooks where the exact numbers are given in a concise problem scenario that contains little to no miscellaneous information.

The study produced two interesting results: the first is that the ill-structured groups focused more on problem analysis, problem critique and criteria development (items that were coded for based on discussions within the CSCL environment), but the well-structured group focused more on solution development and solution evaluation. The first result suggests that ill-structured problems force students to analyze and spend more time conceptualizing the problem. The second result was that although the well-structured group outperformed the ill-structured group on their respective tasks during the CSCL activity, the ill-structured group outperformed the well-structured group on an ill-structured post-test *and* a well-structured post-test. The students who were given an ill-structured problem "failed" at performing their task initially, but later outperformed their peers who were given a well-structured task and "succeeded" initially. The second result supports Kapur's hypothesis that "[t]he process [of exploring, struggling and even failing at solving ill-structured problems] may well be less efficient in the shorter term, but it may also allow for learning that is potentially more flexible and adaptive in the longer term."

As Kapur suggests, the concept of productive failure needs to be examined in other contexts, as there is little research on the topic outside of his study. The practicum lab, it could be argued, is an example of an ill-structured problem as it has some of the characteristics of an ill-structured problem outlined above. There are multiple problem parameters and they are only known to some degree of confidence since many of the parameters are measurements made by the students. There are multiple solution pathways (even though there is ultimately only one solution or range of solutions) and the students are required to make assumptions. The role of failure in these labs will be examined, as in the Kapur study; however, the evaluation of whether or not the failure was productive will not be a post-test. The productivity, learning and failure will be examined in terms of the observed discourse patterns in the classroom.

### *Previous Research*

Research related to the idea of discourse patterns in the classroom can be divided into three categories. The first examines the teaching style, beliefs and actions of the teacher and links them to the observed discourse patterns in the classroom. The second category studies the interactions between the student and the teacher and links it to the discourse patterns. The last looks at discourse patterns and relates them to the activity structures in the classroom.

Eshach (2009) identified different conceptual flow structures of a physics class and linked them to teaching style using Mortimer and Scott's (2003) framework. The three structures that were identified were an accumulation around budding foci pattern, a zig-zag pattern and a concept tower pattern. The budding foci pattern describes situations where the class discusses one idea in depth, then transitions to another idea. Eshach found that this type of pattern corresponds to minimal interference by the teacher. The zig-zag pattern describes a situation where the discussion oscillates between two or more ideas, instead of discussing one idea in depth before moving to a new idea. This pattern also corresponds to minimal interference by the teachers. The main difference that Eshach notes is that the budding foci pattern requires the teacher to actively foster the ideas more than the zig-zag pattern. In both cases the teacher's communicative style would be considered dialogic and interactive using the Mortimer and Scott (2003) framework, because multiple student ideas are able to develop. The final pattern is the conceptual tower. In this pattern the ideas build upon one another, eventually leading to some final conclusion. The teacher must guide this type of discussion, because only ideas that build upon previous ideas are brought into the discussion. Any alternative ideas are not discussed. This pattern corresponds to an authoritative interactive communicative style because only one idea is pursued.

McNeill and Pimentel (2009) examined three different teachers using the same curriculum and looked for a correlation between who dominated the classroom talk (student or teacher) and the other classroom characteristics (argument structure, types of evidence used, type of interactions and teacher questions). The study found that in classrooms that were dominated by student talk, there were more dialogic interactions (as opposed to authoritative or teacher-directed), more open questions asked by the teacher and more focus on evidence. McNeill and Pimentel summarize the implications of their findings:

> This study suggests that open-ended questions may play a key role in supporting students in argumentation in terms of both providing evidence and reasoning for students' claims and encouraging dialogic interactions between students. (p. 23)

Thus they connected the observed discourse with specific discourse actions by the teacher.

The second category of research, linking student-teacher interactions to discourse patterns, is similar to the first area (linking teaching styles and philosophies with discourse patterns) in that they both examine how the teacher influences the class. The key difference is that the effect of interactions on the discourse examines the effect of the teacher on a smaller scale as opposed to the broader effect of teacher philosophies and styles. Much of this work centers around the triadic I-R-E (Initiation-Response-Evaluation) model described first by Mehan (1979) and various deviations from this model such as the I-R-P-R-P model described by Scott and Mortimer (2006), where P stands for prompt. This model is sometimes rewritten replacing prompt with F for feedback (Wells, 1993).

Chin (2006) looked at teacher questioning of students, specifically how teachers use questioning as feedback in interactions with students. When examining the F move in the triadic cycle, Chin found that students are more actively engaged when the feedback "was not just evaluative, but also supportive in that it embedded a further question that provoked deeper thinking beyond simple recall (p. 1334)." This suggests that the teacher can create a dialogic communicative approach in the classroom by using further questioning instead of simple evaluation when responding to student ideas.

Aguiar, Mortimer and Scott (2009) examined a similar concept: how teachers respond to student questions. They identified a "tension" between responding to student ideas with an authoritative approach and with a dialogic approach. The teacher can chose to either "get through the lesson using an authoritative approach [or] to look at science as involving argument and explanation, using the dialogic approach (p. 16)." They recognize that the approach that the teacher uses has an impact on the nature of the lesson, but also recognize the importance of the student in this process. Without the students' involvement the lesson would not be possible, thus there is a cyclical relationship between the student and the teacher where both parties determine the extent to which a lesson is authoritative or dialogic.

The third area of research regarding discourse patterns involves the structure of the lesson and how that impacts the discourse patterns. Research shows that the "inquiry based" lesson structures have positive impacts on students' attitudes and learning. Krystyniak and Heikkinen (2007) found that during inquiry based lessons the students "relied less on their instructors for assistance (p. 1181)." When they did ask for assistance, it was regarding conceptual tasks rather than procedural as was the case during non-inquiry lessons. The study suggests that the inquiry lessons encourage the students to rely more on each other and the lesson transforms the teacher's role from "deliverer of information to facilitator (p. 1181)." Berg et al. (2003) found that the inquiry structure contributes to a higher frequency of "reflective questions" asked by the students as well as a deeper reflection about what was learned. The study also saw a more positive attitude towards the lesson and a belief that more was learned during the inquiry based lessons when compared to more traditional lessons. Hofestein et al. (2004) had similar results, finding that inquiry based lessons improved the quality of the questions asked by students and that the students who participated in the inquiry lessons believed that it was an effective way to learn science.

### *Purpose of the Study*

Research has shown the importance of creating authenticity in the classroom where students are engaged in scientific discourse with each other. The effect of the structure and teacher interactions has been shown to have an impact on these discourse patterns. This study has two purposes related the role of structure and support in influencing classroom discourse. The first purpose is to simultaneously examine the role of structure and support to see how they compliment each other and influence student discourse. The role of these types of guidance examined by looking at the immediate impact on the student discourse after various types of teacher guidance are given. The second purpose of the study is to examine the effect on student discourse when structure and support is faded to allow the students to experience a failure. This purpose will serve to provide evidence for or against the idea of productive failure in a more naturalistic setting than Kapur's laboratory-based study. The research questions corresponding to these goals are:

- What is the effect of lesson structure and teacher support on the discourse patterns of the students?
- What are the implications of productive failure in regards to the discourse patterns of the students?

## DESIGN AND PROCEDURE

### *Context*

The data collection for this study took place at a small (400 students), rural high school in central Pennsylvania. The teacher, Ms. Lee, teaches three sections of physics and two sections of environmental science. She has over 10 years of experience teaching high school physics, however, she previously received a bachelors and masters degree in nuclear engineering. Two of her three physics classes were included in the data collection. The first class is an honors class of approximately 15 students. The class is part of the College in High School program run through the University of Pittsburgh, so the students receive 4 credits of college-level introductory mechanics by passing the course. The other class was a middle level, academic class comprised of approximately 25 students.

Data collection took place over 3 class periods in each class. The first period was a *traditional lab*. In this case, a *traditional lab* is defined as a lab where students are given a set procedure, place in fixed, small groups and asked to complete a task. The second lab spanned 2 periods and was considered to be a *practicum lab.* In this context, a *practicum lab* is defined as one where the students are presented with a problem to solve, which requires a variety of measurements, calculations and application of physics knowledge, but they are not given a procedure. The entire class is asked to work together and they must agree upon one final solution, which is then presented to the teacher and tested (Amann et al., 2005). A more detailed description of what took place in each lab is found in the vignettes section.

### ***Data Collection and Analysis***

The data collection and analysis follows the procedure of integrating qualitative and quantitative data as outlined by Chi (1997). In both the honors and academic class, the video focused on two groups during the traditional lab. Each group was videotaped and the audio was recorded separately with a voice recorder for clarity. In the practicum labs for both classes, there were 2 cameras and 3 voice recorders. The nature of the practicum lab made it more difficult to capture all of the audio, since groups often formed and separated multiple times during the lab (there were no fixed groups and the class was working as one). In order to deal with this problem the voice recorders often had to be moved to follow the development of the lab. Once the videotaping was completed, the audio tracks were overlaid on top of one or both of the videos, so that each track could be analyzed separately. In addition to the video, the teacher and 3 students from each class were interviewed after the *practicum lab.* The student interviews focused on how the practicum lab differed from other labs that the students had done. The teacher interview focused on her goal for the practicum and assessment of how well the practicum accomplished her goals.

Once the video was collected, it was analyzed using a program known as *StudioCode.* The framework for analysis was developed within the context of the Invisible College for Inquiry Science Studies (ICISS). ICISS is a collaborative group of practitioner-researchers engaged in the study on inquiry science teaching. The framework developed as a modification of and synthesis between work on classroom discourse by Bereiter (1994) and Mortimer & Scott (2003).

The video was chunked into *phases* and *sequences* based on the model of chunking described by Kelly & Chen (1999). Phases were any sections of the lesson that focused on a common theme or task. These phase chunkings are a slightly smaller grain size that those used by Kelly & Chen, since they actually break up parts of the lab activity. Examples of phases would be measuring the velocity of the ball, designing a plan to solve the practicum problem or figuring out what pattern to walk to match a certain graph in the traditional lab. *Sequences* are sections of a phase that have the same focus, but are competing ideas or small but necessary tangents from the focus of the phase. An example of sequences would be the students devise one plan to solve the practicum, but decided that the plan won't work and they devise a new plan.

After the video was chunked, it was then coded. Anything relevant that the students did or said was coded as one of 3 actions (procedural, conceptual or communicative), which are described in table 1 located at the end of the section. In addition to the student's actions being coded, the teacher's actions were also coded. One of the roles of the teacher in the classroom is to scaffold by providing verbal support; thus the teacher's actions were all coded as a type of support, with the exception of the neutral interaction, which did not give support. Table 2 displays the coding scheme for the teacher's support.

In addition to each of these codes, each student action was also labeled to show how the teacher support was influences the students' actions. Each code was given one of two labels:

**Before support** - This label describes any actions where the teacher is not interacting with the students, nor has the teacher had previous interactions within the particular phase/sequence

**After Support** – This represents any action performed by the student within the phase/sequence that occurred after some sort of support by the teacher. In addition to this label, each of these actions was also given a label to represent the type of support that preceded it:

- **After Procedural Support**
- **After Conceptual Support**
- **After Communicative Support**
- **After Neutral Support**

There are two important things to note about the labels. The first is that since one of the goals of the research was to look at the immediate effect that teacher support had, these labels "reset" themselves whenever a new phase or sequence began. In other words, each phase or sequence was viewed individually when determining whether the action occurred before or after teacher support. The second is that in addition to the after support label, an additional label was put on each code to indicate what type of support it followed (procedural, conceptual, communicative or neutral).

The teacher supports were labeled as either open or closed as described by Mortimer and Scott (2006). The open label represents interactions where the discussion was left open and did not include a final evaluation by the teacher thus it is dialogic. This would be the I-R-P-R-P pattern. The closed support does include the final evaluation making it authoritative (I-R-E pattern).

Once all of the video was coded, the data was analyzed within *StudioCode.* The percentages of time spent doing each type of action were broken down and compared by class and type of lab. Additionally, within each specific class and type of lab, the percentages were compared between actions done before support and after each type of support to see what changes took place.  The type of support given by the teacher was also analyzed for the number of times each support was given depending on the class and type of lab.  The full data tables containing this quantitative analysis can be found in the appendix.  Throughout the analysis, parts of these charts will be used in addition to dialogue taken from interviews and class to support the claims.

**Table 1 – Description of Actions**

| Actions | Examples |
|---|---|
| **Procedural Action** – The student does or talks about doing something that is a necessary for the completion of the lab, but *does not* require the student to generate a novel idea (in the scope of the lab) or apply a physics concept. This includes gathering information, executing a plan (seen in practicum lab), making a measurement or performing a calculation. | **Bani**: Hey, is [the motion detector] going to pick this up? Make sure it doesn't pick anything else up.<br>---------------------------------------------------<br>**Brittany**: Is the ramp set up to the same height as last time? Like…<br>**Becky**: Yea, cause its…yea |
| **Conceptual Action** - The student does or talks about doing something necessary for the completion of the lab that *does* require the student to generate a novel idea (in the scope of the lab) or apply a physics concept. This includes generating a hypothesis, analyzing an existing idea, creating a solution method or applying a physics concept. | **Chaz:** We need to find the area [under the curve]<br>**Larry:** Let's graph it then.<br>**Chaz**: We need to find the area [under the curve] cause we can get meters.<br>---------------------------------------------------<br>**Bani**: We could find this.<br>**Becky**: Does that help us with anything?<br>**Bani**: Yea, cause that tells us where you start.<br>**Becky**: We don't know how fast it goes |
| **Communicative Action** – The student communicates any idea that has previously been discovered, through a procedural or conceptual action, to another student. | **Becky**: What did you do? *[After both students have different methods that lead to the same solution]*<br>**Jack**: We did it real easy<br>**Becky**: So did we.<br>**Jack**: We figured out how much time…<br>---------------------------------------------------<br>**Jessica**: These two numbers right here, they were found using the [motion detector]<br>**Christine**: What does this number represent? Oh, that's the 2.5 mark.<br>**Patty**: That's the slope of the ball and this is the slope of the car. |

**Table 2 – Description of Supports**

| Supports | Examples |
| --- | --- |
| **Procedural Support** – Teacher says something that gives the students a hint or guidance for a procedural task. This includes suggesting a better lab technique or methodology, or clarifying the directions. | **Ms. Lee**: I didn't give you [batteries] that were running out, but I'd think about it every time I turn that car on.<br>---------------------------------------------------<br>**Ms. Lee**: *[During testing]* Folks, now you gotta think logistics. When does the person start the car? |
| **Conceptual Support** – Teacher says something that gives the students a hint for a conceptual task. This includes pointing out an import physics concept, asking a question that leads to identification of an error in reasoning, or in some cases making connections between physics concepts for the students. | **Ms. Lee**: How important is it to have it at 45 degrees?<br>**Anthony**: It makes it easier to calculate.<br>**Ms. Lee**: Ok, you going to have to calculate something with the angle?<br>---------------------------------------------------<br>**Ms. Lee**: And that gives you…<br>**Patrick**: 2.84<br>**Ms. Lee**: Which has a unit of…<br>**Patrick**: Meters per second, oh no, meters<br>**Ms. Lee**: See if it makes sense to someone else, your units work. |
| **Communicative Support** – Teacher says something to support communicative action, such as encouraging students to share an idea or ask another student about his or her idea. | **Ms. Lee**: Ladies, people have been trying to explain this to Jerome, but they keep getting distracted or walk away from him, alright. Look at how clear Brandy has it written out. |
| **Neutral Interaction** – Teacher requests information from students, but does not support any of the actions. This includes asking students what value they measured or how they calculated something. It is important to note that this differs from the teacher knowing the students did something incorrectly and trying to point it out by asking them to elaborate. In this case the teacher does not know what or how the students have done, thus it does not give support, but is still an interaction. | **Ms. Lee**: So what am I looking at? What is this number? |

## VIGNETTES

The major themes of this study are the role of structure, teacher support and productive failure. It is important to have an understanding of what occurred in each lab to better understand how those three effect the discourse patterns. The following vignettes detail the major action of each lab, with an emphasis on the support and structure of the teacher as well as the effect of a failure in the practicum lab.

### *The Traditional Lab*

In this study, the traditional lab focuses on the concept of motion and its graphical representation in one dimension. The students were given a sonic motion detector and either a position vs. time graph or a velocity vs. time graph on the computer. The students then had to walk the correct pattern (moving backwards and forwards) in front of the motion detector to match the graph that they were given. At this point in the school year, the students had already been introduced to the idea of position, velocity and acceleration. They also had reviewed the meaning of slope and area under the curve, with a focus on the resulting units for each, depending on the type of graph. The purpose of the lab was to be an introduction to motion graphs and to help students make the connection between the slope on a position vs. time graph with velocity.

### *The Traditional Lab in the Academic Class*

In the academic class, the video focuses on 2 groups: a group of 4 females (Nadia, Samantha, Georgia and Stacy) and a group of 4 males (Abe, Jeremy, Evan and Mike). Ms. Lee sets up the lab by giving the students a brief introduction to how to use the motion detector equipment. She states that "we will be using this a lot this year, so it's important that everyone know how to hook it up." She continues her introduction emphasizing that while they don't have a formal write-up for the lab they should "make notes of how they move while they make the graph." She also states, "this is all about trying to connect your motion to what's on the screen."

In both of the groups that were videotaped, the students spent a significant amount of time simply setting up the equipment. The group of males spends over 13 minutes simply reading the directions given, which instruct the students on how to set-up and then test the motion detector to make sure its working properly. The group of females also spends approximately 13 minutes setting up the equipment and figuring out what to do. The girls end up running into 2 major problems that slow them down. When they test their motion detector by walking back and forth, the girls think that this is their first graph and they begin to analyze it like they are supposed to do for the actual graphs (discuss when they were stopped, speeding up, slowing down, ect.). When Ms. Lee sees this, she comes over to correct them stating, "They're good by the way, but have you made that graph…you want to match the graph that's on there." After this correction, the students try again, but are confused about what the graph represents. The students believe that the graph shows left to right motion, instead of forward and backward motion. This misconception is exemplified in the conversation below:

> **Nadia:** So we're going to tell you when to change… *[talking to Georgia who is about to walk]*
> **Samantha:** Yea, so walk slow.
> **Nadia:** …change directions.
> **Samantha:** Yea, try to walk slow.
> **Georgia**: I'm going to change directions?

**Nadia:** Yea, like you're going to turn your body.
**Georgia:** Like right or left?
**Nadia:** Just walk and we'll tell you.

The students realize that this doesn't quite work, but still struggle to figure out the graph until the cameraman jumps in and tells them that the graph is measuring how far they are away from the detector.

Once both of these groups has everything set up and they understand the idea, they walk out a series of 3 or 4 graphs. While the students are doing this, the teacher can be seen going from group to group and giving them what she calls "the spiel." Here the teacher approaches a group and walks them through a derivation of sorts that connects the slope on a position versus time graph to velocity. A sample of this is shown below from her discussion with the group of girls:

**Ms. Lee**: Alright, what's the slope of that thing? Does it have a big slope, a little slope or not slope? *[Gathers whole group around her]*
**Samantha:** No slope.
**Ms. Lee:** No slope, alright. So, what's the unit on the y?
**Samantha**: Position.
**Ms. Lee**: Yea, what's the unit? That's what it is, what…
**Samantha**: Meters
**Ms. Lee:** Meters, how about on the x?
**Samantha**: Seconds.
**Ms. Lee:** Seconds…What's the units on slope for this one? Look at this guy *[Starts to write m/s on paper]*
**Stacy**: Meters per…
**Ms. Lee**: Meters per second, what is that? If I said you're going at 5 m/s is that a velocity? An acceleration?
**Samantha**: It's a velocity.
**Ms. Lee**: It's a velocity. So your slope is your velocity. So you said, no slope, no velocity. So try and think about that.

The teacher also emphasizes "to have everybody try it, because you are going to get like 80 percent of the ideas by walking this graph." The students do continue to walk out these graphs repetitively, even after they have already figured out the correct pattern. With the group of boys it turns into somewhat of a competition. When Evan walks off one of the graphs, Jeremy says, "You lose, look, loser. Mine was better." Later on, Abe proclaims, "Mine was the best."

***The Traditional Lab in the Honors Class***

In the honors class, one video focuses on a group of 2 males (Anthony and Lou) and a group of 1 male with 2 females (Jack, Becky and Emily). Ms. Lee starts the lesson in a similar manner to the academic class, but there are a few small differences. She seems to have done some sort of graphing review that can be seen on the board but is not seen in the video. She has the "3 things" (as she calls it) that you can do to a graph (read it, take the slope, find the area under the curve) written on the board along with how to find the units (not specific to position vs. time graphs), but she does not explicitly link velocity and slope. When she is talking about how the motion detector works, she explicitly mentions that it measured forward and backward motion. She states, "it will map out your motion when you move, not when you go this way [motions with her hand to show side to side motion], but as you go away and towards it."

The students, similar to the academic class, take a significant amount of time to simply set up the lab. Anthony and Lou are faster than the others, but still spend 6 minutes setting up. Jack, Becky and Emily take over 11 minutes to set up. The one group of Jack, Becky and Emily, gets into a very interesting conversation as they finish up their first graph. They manage to link slope to velocity without the intervention of the teacher:

**Jack:** I think what happens here is if you take bigger or smaller steps *[talking about the slanted sections of the graph]*
**Becky:** Its your, its your speed.
**Emily:** Yea, it depends on how fast you're going.

**…**

**Jack**: Sean *[member of adjacent group]*, is that what you found out? Like the slope changes with how big your steps would be.
**Sean**: Uh, no…The lines going to be steeper for, um, the fast you go the lines going to be steeper. If it's a positive slope you're moving...
**Jack:** Positive slope is away and…
**Sean**: Negative slope is towards and the steeper the line the faster you're going.

This type of conversation was only observed once in this group of students and was not observed at all in the academic class. Additionally, Jack seems to be the instigator of this conversation and the two girls do not seems as interested. While Jack is engaged with Sean, Becky and Emily continue to read and follow the directions of the lab.

Later on the teacher intervenes to have the conversation about slope, similar to the academic class. Even with the honors class, the teacher drives much of the conversation:

**Ms. Lee**: Let me give you the spiel. Alright, connected to what we did with the unit bingo, what unit's on the Y?
**Becky**: Oh, meters.
**Ms. Lee**: And on the X?
**Becky**: Seconds.
**Ms. Lee**: So if you slope it?
**Emily**: Um, meters per second.
**Ms. Lee**: Which is what? I have 5 m/s, what am I telling you?
**Emily**: How many meters you move in a second.
**Ms. Lee**: Which is also called your…
**Emily**: Velocity
**Ms. Lee**: Yea, your velocity or your speed. So however the slope goes, so does your velocity.

This conversation is no different than the conversation seen in the academic class. The students in the honors class might produce the answers a little bit quicker, but the questions are still very simple, definition questions and the teacher makes most of the conceptual connections. It is evident from the introduction to the lab and the conversation that she has with all the groups about slope the key idea in this lab is the relationship between slope and velocity.

The group completes 2 graphs, both of which are position versus time graphs with constant velocity segments (except for the transitions, but ideally those are instantaneous). The next graph they open up has acceleration (and thus changing velocity). The teacher once again comes over to make the connection between the graph and the concept of speeding up or slowing down:

> **Ms. Lee**: Talk to me about this, cause this one's a little different.
> **Becky**: It slows down.
> **Ms. Lee**: How do you know it slows down by looking at it?
> **Becky**: Because it curves this way.
> **Jack**: Slope goes back up towards you.
> **Ms. Lee**: Yea, it gets flatter, it gets towards zero.
> **Becky**: Yea, its longer
> **Ms. Lee**: Cause if the slope is zero you're stopped, right? So this is getting closer to zero.
> **Jack**: I think about it like sledding. I mean, you're pushing yourself and then you go really, really, really fast and then you slow down.
> **Ms. Lee**: That would work.
> **Jack**: And it's the same thing with walking, you got to go really, really fast then slow down.

Here, its interesting to note that the teacher opened up this conversation with a very open ended question, and it leads to Jack coming up with an analogy for the appearance of speeding up or slowing down on a graph. This group completes one more graph and then the period is over.

The other group of students, Anthony and Lou, had a very similar experience to the first group. They walked off a number of graphs successfully and received a very similar slope discussion. In contrast to the other group, Anthony and Lou spend a lot of time working of the first graph. After walking it 7 or 8 times the students were close enough to the specified pattern to move on to the next graph. They might have stopped 10 cm short or long of where they should be, but by any reasonable measure they successfully walked the graph. These 2 students are not satisfied, however, and they continue to refine:

> **Anthony**: It was ok, I think, well you were standing here earlier, I think that its going…I think it could be fast or something's up.
> **Lou**: I need to be back a little bit.
> **Anthony**: Maybe back a little bit like here.
> **Lou**: So with my toes on the line.
> **Anthony**: Yea, because it's measuring you above, it's measuring you closer than 1 meter. So we'll try that and then back to there. Well, not with your heels there, maybe a little closer than your heels on 3, but around there.

Eventually the cameraman jumps in to state, "I think the idea is just to see if you can match the graph closely…" But the students continue to walk the graph. They finally move on to the next graph after the teacher has the slope conversation with them and tells them to move on to the next graph.

### *The Practicum Lab*

In the practicum lab, students are given a motorized car, a basketball and a ramp. The students are told that the ball needs to roll down the ramp and then 2.5 meters on the floor before colliding with the car, which is moving perpendicularly to the ball at constant velocity. The students are allowed to set the angle of the ramp to be whatever they choose. The task for the students is to find the distance away to place the car so that it collides with the ball after the ball has traveled 2.5 meters on the floor. In the academic class, the students start the car when the ball hits the floor (thus it has constant velocity), but in the honors class the car must start when the ball is released (meaning that they have to deal with the acceleration of the ball down the ramp). The students are allowed to use any equipment present in the room (including motion detectors), but they cannot use a stopwatch or any form of clock. The practicum is meant to be a summative lab for motion graphs and it takes place approximately 2 weeks after the traditional lab. The goals of the practicum lab are to foster communication and to let the students fail at first, but then eventually succeed. In both classes these goals are evident.

### *The Practicum Lab in the Academic Class*

The practicum starts with a brief introduction to the idea of the practicum and some explanation of this specific practicum. Written on the board are 2 important elements of the practicum: "Decide on one solution" and "one person presents solution." In addition to writing these things on the board she elaborates to emphasize the important parts of the practicum and the scientific nature of the practicum:

> "Now if this was NASA, NASA doesn't just guess and check. 'We'll let's build a billion dollar satellite and see if it works. Alright, you do calculations first, you predict. That's what this is about. As a class, you're going to decide when to release the car. That's what it really is, when to release the car so that it hits the basketball. The deal is, ok, at the end of it you all have to come to one conclusion. So if we have competing answers, you have to argue it out and decide as a class. This is a class grade, alright, you have to decide *as a class* how to do it. I will call one person to present it at the front and you know I'm probably going to pick the person I think isn't doing anything. So, even if you don't know how to do it, it is your responsibility to go up to someone and say, 'I don't get it, why did you do that? How did you do that?' so that you understand how you got the solution. Then, once somebody tells me the solution, then we'll try it."

The focus here is on the fact that this is a scientific endeavor and that the students must communicate to arrive at one answer that everyone agrees on and understands. This communication and agreement is a common theme of her guidance throughout the lab.

As Ms. Lee wraps up her introduction she suggests, "Car people maybe want to be up her, basketball people maybe want to be back there." The students take her advice and split the class in half with one half working on the car and the other half working on the ball. At the start, both groups are a little unsure how to figure out this problem without a stopwatch. Some of the students, that weren't paying attention before, suggest that they use a stopwatch. Others suggest that they just count out the time verbally, but the ball group quickly figures out to use the motion detectors with the help of Ms. Lee's suggestion:

> **Ms. Lee**: You have $7,000 worth of technology
> **Kevin**: You telling me to use the motion graph, huh?
> **Ms**. **Lee**: I'm not telling you to do anything. All I know is that you have $7,000 worth of calculators in this room.

The students are very quick to pick up on the teacher's hint. The car group, possibly seeing the ball group set up the motion sensor follows suit and sets it up to take velocity measurements.

Starting with this idea, Kevin assumes a leadership role for the ball group especially, but also for the whole class. In the car group, this is also true, with 2 students Stefan and Nick, assuming leadership roles although their roles are not as dominant. This has an effect on the other students. In the ball group especially, Kevin is leading a group of 3 or 4 students who are trying to figure out the velocity of the ball, while the others in the group sit in the back of the room disengaged. This causes the teacher to react and do something that becomes a common theme throughout the lab:

> **Ms. Lee**: Folks, I want to remind you that I'm going to pick someone to present, so all of you have to…
> **Larry**: I'm the roller, I roll
> **Ms. Lee**: It doesn't matter; everyone needs to write down a solution and know what's going on.

The teacher is constantly trying to get more of the students involved in the actual procedure, however most of them are content to let others figure it out and then have the solution explained to them.

After approximately 10 minutes, which included some technical difficulties, the students arrive at a speed for both the car and the ball using the motion detectors. Once this happens, Kevin goes over to the car group to find out the velocity of the car. This is a critical point, because Kevin's dominant leadership begins to affect the other group. Additionally, this is where the students begin to mix up units. This problem is not resolved for a while and it eventually leads to a failure:

> **Kevin**: Your car travels about 1.211 *[This is the slope of the position versus time graph]*, that's how long it takes to get to 2.5.
> **Christine**: Kevin, this number, what does that say?
> **Kevin**: That's how long it takes from the ball to get from the bottom of the ramp to 2.5 meters and your car takes 1.211 meters per second to get to 2.5.

Notice the casual substitution of velocity for time to get to 2.5 meters. This crucial mistake plagues the students for the rest of the first day of the lab. The other students follow Kevin and begin use this incorrect substitution:

> **Kevin**: That was their slope and it takes 1.211 meters per second to get to 2.5
> **Christine**: Wait, so it takes 2.11 *[incorrectly stating number]* meters per second to get to 2.5.

**Abe**: So you set your car that far away from the 2.5 meters.
**Kevin**: That's how long, 1.211 is how many meters it travels per second *[correctly using the slope]*, so you take 1.211 time 2.5.

In the end, Kevin correctly uses the slope, but later evidence shows that he does not actually understand the concept. His misuse of the slope becomes commonplace for the entire class until it is eventually shown to be incorrect.

At this point, Kevin leaves the car group and returns to the ball group to explain to them what needs to be done. Some of the students in the car group are satisfied with Kevin's explanation, but there are a few girls who want to actually understand the solution and they are frustrated by Kevin's authoritative position and lack of explanation:

**Ms. Lee**: Have you gotten information from them that you need?
**Jessica**: No, [Kevin] talked to the stupid people in our group who [don't] know how to do anything
**Christine**: Any they're like playing with the thing and not doing their work.
**Ms**. **Lee**: Ok, then somebody can go over too them and ask them a number.

At this time, Kevin has completely taken over the problem solving and the rest of the class is simply following. Most are satisfied to let Kevin find the answer, but a few (as demonstrated in the dialogue above) want more of an explanation. While Kevin is with the ball group, there is an interesting shift of leadership in the car group. Initially, Stefan and Nick took a leadership role when they were obtaining a motion graph for the car. Now, that they have all the numbers, Stefan and Nick have become more passive while Jessica and Christine take a leadership role. While Kevin seems to have ignored the differences in velocity (he simply multiplied the cars velocity by 2.5 meters), the two girls realize this problem, even though they are not sure how to reconcile it. Jessica states, "This took longer to get to 2.5 than this one did, so you have to let the ball go first." The times she is referring to are actually the velocities, but she still realizes that they need to start at distances or times and is on her way to finding a solution. She later continues, "We have to somehow get the numbers to equal so the car will have to be back further than it is, because the cars faster." Jessica is also mixing up speed and time here it seems, however the important point is that she is coming up with an alternate solution and thinking through the problem.

Christine and Jessica continue to reason through their solution, and even produce a few numbers, but Kevin stops them when he decides to announce the answer to the class. Kevin is convinced that he has the right answer and everyone should just blindly accept the answer he obtained. This is evident when he makes his announcement to the class:

> **Kevin**: Alright, everybody's got to look and me and listen, so we all know. You set the car at 3.22126 meters. When the ball hits the floor at the bottom of the ramp you start the car and they should meet at 2.5 meters.
> **Christine**: How'd you find the 3…
> **Kevin**: Because we're smart.

This answer seems to be accepted by almost the whole class, however some of the students (mainly Christine and Jessica) want a more detailed explanation still. Kevin clearly doesn't want to explain his process, but is eventually forced by the teacher to do explain it:

> **Andrea**: Hey Kevin, wait, how'd you figure that out?
> **Kevin**: It was a long process.
> **Ms**. **Lee**: Everyone needs to know, Kevin, because your grade depends on whomever I pick.

The students and the teacher continue to ask Kevin to explain the answer, but he keeps just stating the basic numbers without providing any reasoning. His frustration continues to grow and he keeps falling back on his "it's a long process excuse." Finally he gives an explanation, but it is not very clear:

> "You got to find out the slope of the ball and find the slope of the car. You go to find out how many meters per second the car travels, how many meters per second the ball travels. Then you go to split the meters up, set it at 2.5. How long would it take the car to travel 2.5 meters? How long would it take the ball to travel from where it's starting to 2.5 meters and then you need to find you time."

There are obviously flaws in both the explanation and the logic, but the other students accept this solution. After trying to explain the solution to the other students, Kevin engages in a conversation with the teacher about how difficult it is to explain the solution. Whether or not the teacher recognized the flaw in thinking before, she does once Kevin explains his solution. The teacher examines Kevin's idea of multiplying the speed of the car by 2.5 meters to point out this potential flaw. She writes the arithmetic out on the board with the correct units and engages them in a conversation about the units:

> **Ms. Lee**: Look at the units.
> **Kevin**: Times 2.5 you get 2.6 seconds.
> **Ms**. **Lee**: Do you?
> **Christine**: Its meters per second…meters squared per second.
> **Ms**. **Lee**: And what's that?
> **Christine**: Its nothing.

After realizing that the solution is incorrect, multiple small groups of students form and they try and devise a new solution.

After exposing this mistake the teacher gives the students a piece of advice which they rely heavily on during the end of day one and on into day 2 of the lab. The teacher states, "The units tell you whether you did the math right." At the end of day, by using this concept, the students are able to uncover a very important piece of the puzzle: In order to find the time it takes for something to travel a certain distance, the distance must be divided by the speed:

> **Ms. Lee**: So what'd you figure out?
> **Andrea**: 4.84 meters.
> **Ms**. **Lee**: Ok, and what did you do to these 2 numbers?
> **Andrea**: Divided them
> **Ms**. **Lee**: Which number is on top?
> **Andrea**: We divided them, um, 25 was on top.
> **Ms**. **Lee**: This number or the meters per second on top?
> **Andrea**: 25 is on…2.5 is on top.
> **Ms**. **Lee**: So we've got meters divided by meters per second, and we flip it right *[referring to flipping the fraction and then multiplying instead of dividing].* So, how…what do I do? Right? *[writing this information on the board].* Does that equal seconds?
> **Students**: Yea.
> **Ms**. **Lee**: There you go, units don't lie. I don't know whether your numbers are right, but at least now you have a unit of seconds

Day 2 begins with the teacher providing a quick recap of the units problem, once again emphasizing the fact that the units must work. Kevin then provides a brief recap of the numbers that they found yesterday. Here he is clearer about what the numbers are, however he still refers to velocity as "the slope of the car" or "the slope of the ball." Ms. Lee calls to attention this fact saying, "I would put units after that, cause the 'slope of the car,' I don't know if that's a velocity, or a meters or a meters per second squared number."

Once the introduction and recap is finished, the student's break off into 4 different groups to begin to try and figure out the problem. The students are actively engaged in the discussions about and analysis of the solution. Interestingly, much of the analysis focuses on what the students/teacher figured out at the end of the first day: the units must work out correctly. Their focus on unit analysis is shown in the conversations that they have about the solution:

> **Jessica**: For the first one, 2.5 divided by the 1.065 *[which is the velocity]* and you'll get seconds, because meters divided by…
> **Kevin**: Yea, that's how long it takes to go 2.5
> **Jessica**: These cancel out and you'll be left with seconds, so it'd be 2.347.
> …
> **Jessica**: Ok, then you find seconds *[continuing her earlier thought]*. Then you have to try to get meters out of this. So you take the 2.34 seconds times the meters per second to get rid of the seconds, so you'd be left with meters.

This was one of the groups that eventually solved the problem, but another group (almost simultaneously) came up with the same solution. The students were not close enough to the microphone for the audio to be heard, but it is important that there are multiple students and groups involved.

Even the groups that did not eventually arrive at an answer were using unit analysis and trying to develop a solution. Their logic isn't very clear, but they are engaged in discourse:

> **Jon**: It'd be easy enough if we just took that number divided by that number. Wait, don't we have to eliminate the meters, just to get seconds? And then you could eliminate the seconds and just get meters.
> **Abe**: Yea.
> **Jon**: Wouldn't that be it?
> **Larry**: We got to graph…*[one of their solutions involved finding the area under the curve]*
> **Jon**: Wouldn't that be right?
> **Abe**: What are we finding the area of?
> **Stefan:** That should just get us seconds, right? If it's dividing…

The students continue to reason through possible solutions. The conversations shows that in addition to the two groups who eventually arrived at a solution, there were other groups actively engaged in finding a solution.

Once it is announced that two solutions are identical, the students begin a chain of explaining the solution to everyone. Amongst the groups that did not come up with the correct solution, there is evidence of effort to understand the solution. In this conversation, the students are looking at the work done by one of the students who was in the group that figured out the solution:

> **Abe**: Why do we have to multiply that?
> **Chaz**: Cause this was meters per second and that was seconds.
> **Abe**: Doesn't any units eliminate?
> **Larry**: Yea, meters per second and seconds, the seconds eliminate. So seconds you can eliminate, leaving meters.
> **Abe**: Oh, so this is seconds, I thought it was meters per second.

In the scenario, Abe does not accept a step on the solution he was shown. He critiques it and makes sure he understands why each step was done.

Once this explanation phase is over (it takes about 10 minutes), the students return to their seat and Ms. Lee picks someone to explain the solution. The girl she calls on does a good job of explaining the solution, satisfactory for the teacher and then they test their solution. The ball rolls down the ramp and hits the car straight on, so it's a success.

***The Practicum Lab in the Honors Class***

The practicum lab in the honors begins similarly to the academic class. The teacher gives an overview of what a practicum is in general stating that "it's a problem that [the students] have to solve" where they have to figure out a "mathematical solution" that will then be tested. She specifies that they cannot use a stopwatch and that they all have to agree upon a solution, which "is the part that your class has a problem with." Additionally, she gives the same speech that she gave in the academic class stating that this isn't a guess and check and "when NASA launches a satellite they don't just say 'let's build it for four million dollars and see if it works."

The class divides into three groups and they begin work.  One of the groups almost immediately figures out what needs to be done.  At first the group wants to avoid using a stopwatch by counting out loud, but then realizes (at the prompting of the teacher) that they can use the computers and the motion detectors to figure it out:

> **Ms. Lee**: I would use some of the $7,000 worth of equipment in the room.
> **Rachael**: We can use [*points to motion detectors]*
> **Ms. Lee**: Those are fair game.
>
> …
>
> **Rachael**: Let's just use the laptops and do it that way.

This group's idea is not heard because they do believe the others would listen to them; the one student even states, "no one's going to listen to us."  This group remains quiet and reserved after this small episode of activity.

The second group spends the beginning of the practicum trying to find shortcuts that will allow them to measure time and trying to figure out the problem.  They try to use a website with a clock as well as a website that has a metronome.  After the teacher provides a few hints the students finally ask her what else they have in the room that will help them.  The teacher mentions that Rachael has an idea, but she won't share:

> **Ms Lee**: Well Rachael had an idea.
> **John**: Rachael, what's your idea?
> **Rachael**: No, you guys are doing your own things, do it yourselves.

At this point, the second group approaches the third group, up front, and merges with them, further isolating the first group with Rachael.

The third group spends a lot of time in the beginning trying to figure out what needs to be done and trying to use some sort of equation to solve the problem. After a few minutes they realize that they can use the motion detectors:

> **Emily**: Hey, would our motion detector thingies do anything for us? *[Her suggestion is somewhat ignored]*
>
> …
>
> **Emily**: I don't know, would it, you think, do anything? *[Talking to another girl in the group]*
> **Brittany**: We could find how fast its going.
> **Emily**: If we set the motion detector up and we measure the ball as we drop if from the thing and towards it, we can see how long it takes to go down the ramp and towards that distance and that would give us the speed of it, wouldn't it?

The students seem to agree that they will need to use the motion detector eventually and this group begins setting up to take measurements of the cars velocity.

After getting a velocity for the car, the students pause to discuss the importance of the angle of the ramp before measuring the velocity of the ball. This is the point where two of the groups merge: the second group (with the metronome idea) becomes part of the group that measured the velocity of the ball. They want to use 45 degrees because they believe it will make calculations easier, but the teacher jumps in to question their logic:

> **Ms. Lee**: How important is it to have it at 45 degrees?
> **Anthony**: It makes it easier to calculate.
> **Ms. Lee**: Ok, you going to have to calculate something with the angle?
>
> …
>
> **Ms. Lee**: I don't know, you got lots of people spending lots of time on it, I just want to make sure that you all agree on what you're going to do with it.
>
> …
>
> **Bani**: We want to make it so it goes one meter per second so that we can find…

The students do not seem to verbally resolve this, but they do begin to make measurements. The students run into some technical difficulties and spend the next 15 minutes troubleshooting and getting a velocity for the ball. The students use the computer to get more accurate numbers for the velocity of the ball and then decide that they should do the same for the car. The students retake measurements for the car, which brings them to the end of the period. At the end, there is one interesting episode, which is triggered by the teacher. One of the students, Anthony, had been working alone for most of the period and the teacher encouraged him to share his work with other students:

> **Ms. Lee**: Anthony, do you have any ideas to share with anybody?
> **Anthony**: I mean other than, if we can find that, if we have the velocity, then we have the total distance that it travels. Cause the ball has to travel before the truck can hit it.
> **Bani**: What do you mean?
> **Ms. Lee**: Why don't you go write it for them so they know what you mean? Gonna need to get you guys talking to each other a little more to pull what's going on…
> **Anthony**: We have 1.21 meters here and 2.5. So it has to travel 3.71 meters before the car can hit the truck. We have the car at 1 m/s. If we have the car at 1 m/s we just need to figure out how fast the ball moves to know how far away to place the car.

The period ends after this conversation and the students continue the practicum 4 days later.

The second period of the practicum lab begins with the students completing a quick review of the first day of the lab. After this one group of students immediately jumps into the lab and picks up where they left off. Two of the females in the class are engaged in figuring out the method for getting a numerical solution, while 3 males with them work on getting more precise velocity measurements. The females devise the following solution to solve the problem:

> **Becky**: Well, we know the distance of the ball, and if we figure out the speed, so then we have to figure out…can we make a comparison? Like the speed of the car over its distance equals the speed of the ball over its distance?
> **Brittany**: Yea…

The students re-measure the velocities of the car and the ball. After some technical difficulties they arrive at two numbers. Once they have the numbers, they begin to solve the problem, but they have one little flaw in their solution. The academic class did not have to account for the time it took the ball to roll down the ramp, since the car started once the ball hit the ground. Under that scenario, the solution described by Becky is viable, however, the honors class was required to account for this time down the ramp. One of the students verifies when the car is supposed to start with the teacher. It is unclear if he realizes the flaw when he asks for this verification, but he eventually makes the connection that their solution will not work:

> **Jack**: Can we start the car anytime we want or does it have to be a certain distance away?
> **Ms. Lee**: You start the car when the ball is on the ramp.
> **Bani**: Then why did we take 2.5 [meters as the distance] if it was more than 2.5 [including the ramp]?
> **Becky**: No, cause we just took a section of the graph, we didn't take exactly 2.5 meters. Cause you can still get the same speed from this much rather than this much *[Showing 2 different distances with her hands. She thinks that Bani is talking about the section they used on the graph to calculate slope]*
> **Jack**: But Becky, we didn't account for how fast the ball is going off the ramp.

After a slight digression, the teacher brings them back to the problem at hand and challenges them to fix it:

> **Ms. Lee**: Jack raises a good point, how are you going to fix it?
> **Jack**: I'm trying to think of one, I don't know. Well, we're not allowed to use a stopwatch so we're not allowed to calculate how much time it takes for the ball to go down the ramp.
> **Ms. Lee**: Well, how did you get around that before?
> **Emily**: We used the computer
> **Becky**: We started when it hit the ground.
> **Bani**: Should we use that thing?
> **Jack**: I don't know how you're going to use it when the ramp's on a plane and that thing…
> **Bani**: You could angle it.

The students angle the motion detector and get a time for it going down the ramp. Once they have the numbers, two separate groups form to work on a solution and they arrive at the same answer, but two different ways. Becky and Brittany continue to use their ratio method (where the distance that each object travels is in a ratio with the velocity of the object allowing the students to solve for the distance that the car must travel), assuming that any difference in the velocity will not be significant enough to alter the results:

> **Brittany**: It's the average speed though, so I mean we can't…for us to figure out…
> **Becky**: Its close enough. This is close enough. The ramp is so short though, that does the change in speed vary that much? Is that significant?
> …
> **Becky**: This is close enough, because
> **Brittany**: Yea, I don't think we're going to get anything closer if we can't time it.

The other group's solution relies more heavily on the total time that it takes for the ball to roll down the ramp and along the floor. They are able to solve for the distance the car travels then using the velocity of the car. Here Jack explains the other solution to Becky:

> **Jack**: We figured out how much time it took this ball to go 2.5 meters and then we figured out how much time it took the ball on the ramp and then we added those two times.
> **Becky**: How did you go about that [finding the time for the ball to go 2.5 meters]?
> **Jack**: We took 2.5 meters divided by 1.0193 meters per second [the velocity]…

The group then tests the solution and it is successful. When the students explain the solution, later on, they use the ratio method to explain it

## RESULTS

### *The Role of Lab Structure and Teacher Support*

The first part of this study examined the guidance that a teacher provides to the students during a lab and the effect that it has on the discourse patterns of the lab. *It was found that the teacher can influence the discourse patterns of the lab through the structure of the lab and the support given in the lab, however, both the structure of the lab and the type of support given by the teacher must compliment each other or else there is relatively little change in the students' discourse pattern.*

The guidance given to the students in the lab can be divided into two categories: structure and support. Structure is any guidance the teacher gave through the directions provided for the lab, the introduction to the lab at the beginning of class or anything else that guides the students in the lab, but isn't an interaction that occurs during the lab. In this study, there were two different types of structure: a traditional lab structure and a practicum lab structure. In the traditional lab the structure has a procedural focus; the students were given a set of explicit directions to follow to complete the lab. There was no designing of procedure, and the lab did not force the students to make conceptual connections during the lab. The traditional lab could be completed simply by following directions and using "guess and check," which contributed to the procedural nature of the lab. The practicum lab structure had a more conceptual and communicative focus. The students were not given an explicit set of directions that told them the steps necessary for them to complete the lab. They were only given a problem, which forced them to complete conceptual tasks such as deciding what measurements were necessary, creating a solution plan and checking the validity of the solution. The practicum lab also specifies that the entire class must agree upon one solution and everyone must be capable of explaining the solution, since any of the students could be called upon. This structural aspect gives the practicum a communicative focus, since the students not only find the solution, but also explain it to their peers.

The second type of guidance was support. Support is defined as any interaction that the teacher has with the students during the lab that gives guidance. This can range from a subtle nudge or hint to the teacher actually connecting 2 concepts or ideas. For the purpose of this study, the teacher support was divided into 3 categories: procedural, conceptual and communicative, which are outlined in the design and procedure section. Any non-supportive interaction was considered to be a neutral interaction, however this type of interaction was not very prevalent.

The structure of the lab influenced the discourse pattern of the students. On a quantitative level this is evident in Table 3 below, which shows the percentages of time that the students spent doing each action before there was any teacher support given. Only these actions were considered (and not the ones after teacher support) in order to isolate the effect of the structure. The table shows the significant effect that the structure has on the discourse of the students. In the traditional lab, where the structure has more of a procedural focus, the students spend almost three quarters actions were procedural actions. In the practicum lab, which has the more conceptual and communicative focus, there is a huge increase in the amount of time spent completing communicative actions and a small increase in the time spent completing procedural actions. This is also accompanied by the decrease in procedural action, thus the structure alone has an impact on the discourse patterns, even without teacher support.

**Table 3 – Student Actions Before Support Across the Labs**

| | **Academic Traditional** | **Academic Practicum** |
|---|---|---|
| Procedural Action | **74.5** (13:24 of 17:58) | **21.6** ( 7:54 of 36:42) |
| Conceptual Action | **13.5** ( 2:24 of 17:58) | **23.8** ( 8:45 of 36:42) |
| Communicative Action | **12.0** ( 2:10 of 17:58) | **54.6** (20:03 of 36:42) |
| | **Honors Traditional** | **Honors Practicum** |
| Procedural Action | **73.0**(25:16 of 34:38) | **41.5** (19:05 of 45:57) |
| Conceptual Action | **24.7** ( 8:26 of 34:38) | **32.1** (14:46 of 45:57) |
| Communicative Action | **2.7** ( 0:56 of 34:38) | **26.4** (12:06 of 45:57) |

The impact of the structure was also evident from observing the labs and listening to the post-practicum lab interviews. In the traditional lab, all of the groups spent the first part of the lab just setting up the lab equipment as described in the directions, which is a purely procedural task. In the academic class this process took an average of about 13.5 minutes (for the two groups observed) and in the honors class this took an average of about 8 minutes (for the two groups observed). In all cases the groups were at the lab stations working, and were generally on task, but the procedural nature of the lab forced them to spend the first part of the lab doing solely procedural tasks. As the traditional lab continues, the students are constantly returning to these procedural tasks, which is evident from the numbers in Table 3.

The students do not spend a great deal of time completing procedural tasks in the practicum lab. In the practicum, the students are not given a set of instruction thus they cannot spend time reverting back to the procedure. Additionally, the students are forced to communicate with one another in order to agree upon one solution. This is a very important feature of the structure of the practicum; the teacher discusses in an interview following the lab:

> **Interviewer**: One thing I was thinking about, the decision to have 1 solution, that's a pretty powerful part of that does he, [the person who started the practicum], talk about why that versus…
> **Ms. Lee:** Communication, um, you have to be able to talk physics and explain to other people what you're doing.

The importance of the communication is also recognized by one of the students, Kevin, as he talks about the difficult parts of the practicum lab in an interview:

> **Kevin:** Yea, [the practicum lab] was a lot more challenging.
> **Interviewer:** Challenging?
> **Kevin:** Yea, especially since you had to work with everybody in the class, you had to get everybody involved and a lot of people didn't know what they were doing…and you had to explain it to everybody.
> **Interviewer:** So the main challenge is just trying to get everybody on the same page or just people that weren't understanding…
> **Kevin:** Yea, that and you had to have accurate measurements.

Both the teacher and the students mention that the practicum forces the students to explain the solution to other students. In the practicum lab the fact that the students must arrive at one solution is a key component to the structure and its impact is seen both in the percentages in Table 3 and in the post-lab interviews.

The other type of guidance provided to students, the support given by the teacher during the lab, also has an impact on the discourse patterns of the students. Table 4 below shows how the percent of time spent doing each action after support changed compared to before the teacher provided support (the change shown in a percentage point change). In this way, it is possible to isolate the effect that the teacher's support had on the student discourse. The full table showing the breakdown of time spent doing each action before and after support can be found in the appendix, but it is not included here for the sake of clarity.

**Table 4 – Percentage Point Increases/Decrease in the Discourse Pattern Relative to Before Teacher Support**

| | *After Procedural* | *After Conceptual* | *After Communicative* |
|---|---|---|---|
| **Academic Traditional** | | | |
| Procedural Action | **17.20** | **(-23.30)** | **N/A** |
| Conceptual Action | **(-7.90)** | **35.30** | **N/A** |
| Communicative Action | **(-9.20)** | **(-12.00)** | **N/A** |
| **Honors Traditional** | | | |
| Procedural Action | **17.30** | **(-32.20)** | **N/A** |
| Conceptual Action | **(-19.20)** | **34.50** | **N/A** |
| Communicative Action | **1.40** | **(-2.70)** | **N/A** |
| **Academic Practicum** | | | |
| Procedural Action | **33.20** | **(-10.90)** | **(-18.80)** |
| Conceptual Action | **(-2.40)** | **8.20** | **(-18.40)** |
| Communicative Action | **(-30.80)** | **2.70** | **37.10** |
| **Honors Practicum** | | | |
| Procedural Action | **25.30** | **(-27.20)** | **(-33.50)** |
| Conceptual Action | **(-7.70)** | **43.40** | **(-21.30)** |
| Communicative Action | **(-17.60)** | **(-16.20)** | **54.70** |

****There was no change shown for After Communicative in the traditional lab, because there wasn't enough data for this to be a valid representation**

The table shows that regardless of the class or type of lab, the teacher's support in a particular category (procedural, conceptual, communicative) is followed by an increase in the students discourse in the same category. The other 2 actions showed a decrease or minimal (less than 3 percentage points) increase. Its impossible to argue that this change is purely caused by the teacher's support, since its very likely that the teacher's support sometimes aligned with what the students were already talking about; but with such a noticeable change it seems unlikely to be coincidental that the teacher's support would regularly match up with the already existing discourse pattern. This suggests that the teacher's support was able to influence the discourse pattern.

On a more qualitative level the effect that the strong effect that teacher's support has on the students can be seen by their reaction to small suggestions made by the teacher. The following conversations exemplify the effect that a comment made by the teacher can have on the behavior of the students. In this situation the students in the academic class are trying to measure the velocity of the car, but are having trouble because that car keeps veering off to one side and the motion detector loses it. Ms. Lee, who is sitting on the other side of the room, offers some advice:

> **Ms. Lee**: Hey Stefan, why don't you have the car go that way *[implying that having it travel away from the motion detector would eliminate the problem of it veering off to the side]*
> **Stefan**: What?
> **Ms**. **Lee**: Why don't you have to car go that way?
> **Stefan**: Which way?
> **Ms**. **Lee**: That way *[motions to show the way the car was going]*. Is there something magical about having it go that way?
> **Nick**: It's going towards the motion sensor.
> **Ms**. **Lee**: What?
> **Nick**: It's going towards the motion sensor.
> **Ms**. **Lee**: Ok, I was just wondering why.
> **Stefan**: Ok, so obviously we need to make it go away from it.

In this conversation the teacher ask a small question. Even though there was an underlying suggestion to help the students, Ms. Lee did not tell them outright to have the car face the other direction. In the scheme of the lab, the direction that the car faces makes no difference, however it might have made the measure of the velocity easier. The students take this advice and assume that it means they were using improper lab technique before. This is evident in the last line that Stefan says, where he assumes that whatever they were doing before was incorrect and the teacher knows the correct way to take the measurement. As a figure of authority in the room, the teacher's suggestions have a lot of weight. This phenomenon is evident in the honors class as well. In this scenario, the students are once again taking measurements of the velocity of the car. They get a graph on the computer, but are dissatisfied with it:

> **Ms. Lee**: You don't like that data?
> **Bani**: That?
> **Ms. Lee**: Yea, is that any good?
> **Bani**: Why would it be good?
> **Ms. Lee**: I don't know.
> **Bani**: We only have like a…
> **Ms. Lee**: Ok.
> **Bani**: Its going like .00001
> **Ms. Lee**: Ok.
> **Bani**: Well, it could be, I don't know.

Once again, the teacher makes a small comment, that potentially has an underlying suggestion, but the students take it as a correction because it is coming from an authoritative figure. The students view quickly changes from "we have terrible data and need to take another sample" to "maybe this data is good and we can use it." These two examples show that the teacher's suggestion, even if they subtle or small, can have a significant impact on the student's thoughts and in turn impact the discourse patterns.

It has been shown that the teacher can provide guidance both through the structure of the lab and the support given through interactions during the lab. Additionally, it has been shown that both of these types of guidance have an impact on the discourse patterns and behaviors of the students. The interesting part of all this, however, is what happens when the teacher support and the structure of the lab do not compliment each other. When the two types of guidance are not aligned the discourse pattern does not change significantly.

In the traditional lab, the structure of the lab was very procedural-focused, but the teacher has a conceptual goal for the lab and the majority of the support the teacher gives in the lab is conceptual (50% in both classes). Thus, the structure had a procedural focus, but the teacher's support had a conceptual focus.

**Table 5 – Comparing Before and After Support in the Traditional Lab**

| **Academic Traditional** | *Before Support* | *After Support* |
|---|---|---|
| Procedural Action | **74.5** (13:24 of 17:58) | **83.7** (6:02 of 7:13) |
| Conceptual Action | **13.5** ( 2:24 of 17:58) | **11.5** (0:51 of 7:13) |
| Communicative Action | **12.0** ( 2:10 of 17:58) | **4.8** (0:20 of 7:13) |
| **Honors Traditional** | | |
| Procedural Action | **73.0** (25:16 of 34:38) | **76.1** (10:24 of 13:38) |
| Conceptual Action | **24.7** ( 8:26 of 34:38) | **20.8** ( 2:50 of 13:38) |
| Communicative Action | **2.7** ( 0:56 of 34:38) | **3.0** ( 0:34 of 13:38) |

Comparing the discourse of the students before support to after support shows the minimal effect that the support has, because it does not align with the structure. This lack of change is shown in table 5 above. In both classes the overall support has very little effect on the discourse patterns of the students. The effect of this support can be further broken down to show the effect each type of support has on the discourse patterns and is shown in table 6 below (note: there is no column for communicative support, because there was only 1 instance of this in the traditional lab.

**Table 6 – Effect of Procedural and Conceptual Support in the Traditional Lab**

| | *No Interaction* | *After Procedural* | *After Conceptual* |
|---|---|---|---|
| **Academic Traditional** | | | |
| Procedural Action | **74.5** (13:24 of 17:58) | **91.7** (4:35 of 4:59) | **51.2** (0:43 of 1:24) |
| Conceptual Action | **13.5** (2:24 of 17:58) | **5.6** (0:15 of 4:59) | **48.8** (0:41 of 1:24) |
| Communicative Action | **12.0** (2:10 of 17:58) | **2.8** (0:09 of 4:59) | **0.0** (0:00 of 1:24) |
| **Honors Traditional** | | | |
| Procedural Action | **73.0** (25:16 of 34:38) | **90.3** (9:03 of 10:01) | **40.8** (1:22 of 3:23) |
| Conceptual Action | **24.7** ( 8:26 of 34:38) | **5.5** (0:34 of 10:01) | **59.2** (2:01 of 3:23) |
| Communicative Action | **2.7** ( 0:56 of 34:38) | **4.1** (0:24 of 10:01) | **0.0** (0:00 of 3:23) |

From the table, it is evident that procedural support increased the already high amount of time spent doing procedural actions. The students performed almost no conceptual or communicative actions after the teacher gave procedural support. Here the support and the structure aligned so the discourse patterns of the students were significantly changed.

In the case of conceptual support in the procedural focused lab, there should be little change according to this assertion. Upon first glance, it appears that there was a dramatic increase in the percentage of time spent doing conceptual actions after the teacher gave conceptual support, however these numbers are skewed, because the total time spent engaged in discourse (any of the three actions) was minimal after conceptual support. As previously state, conceptual support accounts for half of the support given by the teacher in the traditional lab. Therefore it would be reasonable to expect that about half of the total time the students were engaged in any type of discourse after teacher support would be following conceptual support. This is not the case. In the academic class, there was 1:24 of discourse after conceptual support out of a total time of 7:13 of discourse after any support. Even though 48.8% of the actions performed by the students after conceptual support were conceptual, the total time spent performing these actions was only 41 seconds. The honors section ran into the same issue, with post-conceptual support discourse only accounting for 3:23 of the total post-support time of 13:38. The percentages might be high, but considering the fact that 50% of the support in both classes was conceptual, there was very little discourse of any type after conceptual support.

One possible explanations for this lack of discourse after conceptual support are that the procedural focus of the lab forces the students to return to procedural activities, which inhibits further discourse, especially conceptual discourse.  This can be observed when the teacher goes from group to group giving the students conceptual support to help connect the slope of the graph with the velocity.  Whenever the teacher gave this "spiel," it ended with the students returning to walking out one of the graphs. In this case, the students continued walking the graphs paying little attention to this relationship between slope and velocity, which is ultimately what the teacher wanted the students to derive from the lab.

In the traditional lab, the procedural structure of the lab did not align with the mainly conceptual support that was given.  In the practicum lab, while the structure had both a conceptual and communicative component, the main component was communicative. The students had to agree upon one solution, which everyone in the class had to understand; this makes the practicum have a communicative focus with a secondary conceptual focus; that being said, there was not the conflict between support given and the structure that was evident in the traditional lab.  There was evidence in the practicum lab, however, that supported this notion that structure and support need to align.  In the practicum lab, there were times where students had ideas and even though the structure of the lab facilitated communication, the support of the teacher was still necessary to facilitate communication.

In the academic traditional lab, there was one group of girls (Christine and Jessica) who worked on a solution, but their idea was not heard partly because of the dominant leadership of Kevin (as described in the vignettes). Once Kevin's solution was shown to be incorrect, the class searched for new solutions. When the new solution was found during day 2 of the lab, Jessica discovered that the final number was the same as a number as her solution from before. The teacher comments on this in an interview following the lab:

> **Ms. Lee**: I did have groups that said, "Well we figured that out on Friday, but no one would listen to us" for the academic. And I don't know whether they did or not, whether they actually had the number. You know, and they said, "but no one would listen to us." And I explained that "well part of this is communication and trying to get them to listen to you. You're not just sitting back and saying 'I have the answer but no one's talking to me." Well that's…
> **Interviewer**: To be assertive and…
> **Ms**. **Lee**: Yea, that's not, you know, that's not helping anybody to say "I have the answer but no one's coming to me." You know, go out and try and tell one person and another person and sometimes it works out that all of the sudden enough people are like, "Wait, she knows what's going on…"

Here the teacher recognizes that student ideas can go unheard. It is irrelevant whether or not the girls came up with the correct solution; the fact is that it went unheard. In a lab designed to foster communication, student's ideas were not spread to the masses, because there was not teacher support for that specific idea. Teacher support might not be necessary for assertive, leadership-oriented students, but for the majority of students the structure of the lab isn't necessarily enough for them to communicate their ideas.

Another example of a student's ideas going unheard is in the honors class. The one student, Anthony, spent most of the first day of the practicum working by himself, but he seemed to make significant progress. He was absent for the second day of the lab. It is unclear whether or not he actually solved the problem on the first, but in the interview the teacher acknowledges that he made large strides on the first day. When describing the students reaction to Anthony being absent the second day that teacher states, “At first is was, well Anthony has the numbers and he’s not here.” During the lab another student, Becky, makes a comment regarding the work that Anthony left saying, “He does have some useful stuff on here.” During the day Anthony was in class, however, he did not communicate his ideas with anyone. With 5 minutes left in the period the teacher tries to encourage Anthony to share his ideas:

> **Ms. Lee**: Anthony, do you have any ideas to share with anybody?
> **Anthony**: I mean other than, if we can find that, if we have the velocity, then we have the total distance that it travels. Cause the ball has to travel before the truck can hit it.
> **Bani**: What do you mean?
> **Ms. Lee**: Why don’t you go write it for them so they know what you mean? Gonna need to get you guys talking to each other a little more to pull what’s going on…
> **Anthony**: We have 1.21 meters here and 2.5. So it has to travel 3.71 meters before the car can hit the truck. We have the car at 1 m/s. If we have the car at 1 m/s we just need to figure out how fast the ball moves to know how far away to place the car.

This student, who was quiet almost all of class had a correct solution (or at least a plan to find the solution), but his idea was not heard until 5 minutes left in the class. The teacher acknowledges this lack of communication. The communicative focused structure of the lab in not enough to force the students to communicate. The support of the teacher is still necessary.

Another group of students in the honors class came up with a preliminary plan to solve the problem:

> **Rachael**: Well we can use the laptops and do that [to measure velocity].

**Anna**: Go tell them that
**Erica**: None of them are going to listen to us.

In this conversation, one possible reason for the lack of communication is shown: "no one will listen to us." Whether or not this is always the reason, the fact is not all the student's ideas are being heard. The practicum is useful and beneficial because it forces the students to discuss their ideas, but without teacher support many ideas are not heard.

The teacher provides guidance to the students during labs through the structure of the lab and the support she gives during the lab. Both types of guidance were shown to have an effect on the discourse patterns of the students, but it is important to note that for the guidance to truly be effective, the support and structure must compliment each other. In the procedural focused lab, it was difficult for the teacher's conceptual support to spark a sustained discussion (conceptual or otherwise), because the structure of the lab forces the students back into procedural tasks. In the practicum lab, although the structure encourages and fosters communication, the support of the teacher was still necessary to facilitate communication. Without it, many student ideas were not communicated to other students.

***Open Support vs. Closed Support***

It was already shown that the support the teacher provides is able to influence the discourse patterns of the students, but upon more in depth examination the role of conceptual support is not that simple. All of the procedural and communicative support observed was relatively similar, but there were 2 distinct categories within conceptual support: open and closed. These categorizations are based on the concept of open and closed chain patters as described by Mortimer and Scott (2006). *Open conceptual support* includes any conceptual support that does not make conceptual connections between ideas, but rather provides the students with nudges in the right direction. Two examples of open conceptual support is seen in the conversation below:

> **Ms. Lee**: How important is it to have it at 45 [degrees]?
> **Anthony**: It makes it easier to calculate.
> **Ms. Lee**: Ok, you going to have to calculate something with the angle?

This conversation is taken from the honors practicum lab. At this point in the lab the students are arguing over the angle of the ramp and trying to figure out a way to get it set at exactly 45 degrees. The teacher knows that the angle of the ramp does not matter and in an effort to move the students along she offers some support. She does not tell them that it does not matter nor does she make any conceptual connections for the students. Ms. Lee simply asks a question to bring to the students attention the importance (or lack of importance) of the angle. Open support is often in the form of a question, but it always serves to draw attention to something important or to spark discussion without making a conceptual connection or evaluation.

*Closed conceptual support* on the other hand does the opposite of open support; the teacher makes conceptual connections for the students or evaluation of student ideas in this type of support. Closed conceptual support is usually in the form of a statement and it is much more obviously that it is support than open support, which is subtle. The following is an example of closed conceptual support:

> **Chaz**: So we have to do the area [under the curve] of this?
> **Ms. Lee**: Um, I will give you this hint, you don't have to do area.

Here the students in the academic practicum lab were trying to figure out the distance at away to place the car to collide with the ball. They had position versus time graphs of both the ball and the car. The teacher does not nudge the away or subtly hint at the fact that area under the curve would not work, she explicitly states it. Closed support makes conceptual connections for students or "tells them the answer" instead of providing hints.

The reason that this is important and is even worth defining is that there is a different impact on the discourse patterns of the students depending on which type of conceptual support is given. Procedural and communicative support do not show this difference in impact, because open versus closed support was not observed for those types of support. *When the teacher provides open conceptual support it sparks further conceptual discourse; when the teacher provides closed conceptual support there is relatively little conceptual discourse that follows. Furthermore, closed conceptual support can take conceptual ideas transform them into procedural ideas, because it strips the idea of meaning.* For example, if the teacher is discussing the graphical relationship between position and velocity she might state that the position is the area under the curve on a velocity versus time graph so its equal to ½ (velocity)*(time) if there's constant acceleration. The students might only remember the latter part and believe that they can calculate position by using the equation ½ (velocity)*(time). Not only is this not always correct, but it has also transformed a conceptual idea (graphical relationship between velocity and position) and turned it into a procedural idea (position can be calculated using the formula).

The effect of open conceptual support can be seen in the change in discourse patterns after support of this kind is given. The table below shows the discourse patterns in the practicum lab after open conceptual support and after closed conceptual support compared to before interaction. Only the practicum lab is shown because there were only 2 instances of open conceptual support in the traditional lab. These instances will be discussed in specific detail later in the chapter.

**Table 7 – Open versus Closed Conceptual Support**

| | *No Interaction* | *After Open Conceptual* | *After Closed Conceptual* |
|---|---|---|---|
| **Academic Practicum** | | | |
| Procedural Action | **21.6** ( 7:54 of 36:42) | **4.2** (0:12 of 4:59) | **46.6** (1:50 of 3:57) |
| Conceptual Action | **23.8** ( 8:45 of 36:42) | **36.1** (1:48 of 4:59) | **19.0** (0:45 of 3:57) |
| Communicative Action | **54.6** (20:03 of 36:42) | **59.8** (2:59 of 4:59) | **34.5** (1:22 of 3:57) |
| **Honors Practicum** | | | |
| Procedural Action | **41.5** (19:05 of 45:57) | **5.4** (0:07 of 2:09) | **31.6** (0:24 of 1:18) |
| Conceptual Action | **32.1** (14:46 of 45:57) | **88.3** (1:54 of 2:09) | **52.6** (0:41 of 1:18) |
| Communicative Action | **26.4** (12:06 of 45:57) | **6.2** (0:08 of 2:09) | **15.8** (0:12 of 1:18) |

The table shows the drastic difference in the discourse patterns of the students after conceptual support depending on the type of conceptual support. Immediately after open conceptual support there was almost no procedural actions, but after closed conceptual support the students spent more than 30% of their time engaged in procedural actions. There is also a significant increase in the percentage of time spent doing conceptual actions after open support versus closed support. The total amount of time after any conceptual support is minimal in the honors class, however the numbers are consistent with the academic class. Additionally, the numbers are consistent with what was observed during the honors class.

As previously mentioned, there were only two examples of open support in the traditional lab, but they both offer insight into how open support can foster conceptually focused discourse amongst the students. In both of these examples, students generated a novel idea because the support given was open. The first example comes from the academic class and it is actually the cameraman providing the support. The students are struggling with the basic concept of how to walk the motion graphs:

> **Cameraman**: [The sensor] is measuring how far you are from it. So if it's a straight line, what's happening with how far you are from it? Like the parts where its flat across.
> **Samantha**: Does that mean you're just…does that mean you're walking…you're standing still.
> **Cameraman**: Cause if you moved, you changed your distance so it changed.

Here, the cameraman starts by providing procedural support (what the sensor is measuring) and he then provides open conceptual support by asking what a horizontal line on the graph means. While it may not have been a huge conceptual leap, the cameraman does not actually make the connection between standing still and a horizontal line on the graph. The student is the one to make the connection. The cameraman then provides closed support, by confirming that Samantha was right, but the fact that Samantha reasoned through the connection is key. Another example of how open conceptual support can foster conceptually focused discourse was observed in the honors class. One of the groups arrived at a position versus time graph where acceleration was involved. The group was analyzing the graph and discussing how they know when to speed up or slow down when the teacher came over to talk with them:

> **Ms. Lee**: Talk to me about this, cause this one's a little different.
> **Becky**: It slows down.
> **Ms. Lee**: How do you know it slows down by looking at it?
> **Becky**: Because it curves this way.
> **Jack**: Slope goes back up towards you.
> **Ms. Lee**: Yea, it gets flatter, it gets towards zero.
> **Becky**: Yea, its longer
> **Ms. Lee**: Cause if the slope is zero you're stopped, right? So this is getting closer to zero.

> **Jack**: I think about it like sledding. I mean, you're pushing yourself and then you go really, really, really fast and then you slow down.
> **Ms. Lee**: That would work.
> **Jack**: And it's the same thing with walking, you got to go really, really fast then slow down.

As in the conversation with the cameraman before, the teacher eventually gives closed support by confirming what the students said, but she opens with open support and it sparks an interesting conversation. The analogy that Jack makes at the end is a key point and is a good example of the thinking that needs to be fostered for effective discourse.

The practicum lab also has examples of open conceptual support generating conceptually focused discourse patterns and the generation of student ideas. In the practicum lab, after the students realize that they did not account for the time it takes the ball to roll down the ramp, the following conversation takes place:

> **Ms. Lee**: Jack raises a good point, how are you going to fix it?
> **Jack**: I'm trying to think of one, I don't know. Well, we're not allowed to use a stopwatch so we're not allowed to calculate how much time it takes for the ball to go down the ramp.
> **Ms. Lee**: Well, how did you get around that before?
> **Emily**: We used the computer
> **Becky**: We started when it hit the ground.
> **Bani**: Should we use that thing?
> **Jack**: I don't know how you're going to use it when the ramp's on a plane and that thing…
> **Bani**: You could angle it.
> **Jack**: Alright
> **Becky**: I don't know, I think this is close enough
> **Brittany**: I don't think we're going to get much closer

The teacher begins this conversation by acknowledging that Jack raised a good point, thus it is support, but she does not offer any insight on how to fix the problem that they encountered. When Jack seems stumped, she offers some more support indicating that maybe something the students did previous could help them out in this situation. At no point does she state what they need to do, which makes this support open. The teacher has the opportunity to turn this into closed support when Bani asks for confirmation that they should use the motion detector ("Should we use that thing?"), but the teacher does not respond. Out of this open support, two separate ideas were formed: ignore the change in velocity down the ramp (Becky and Brittany) and measure the velocity with the motion detector (Bani and Jack). These two ideas continue to play out for the rest of the practicum lab.

Both the statistics and examples from the lesson show that open conceptual support can spark student generation of ideas and conceptually focused discourse. Closed support on the other hand does not encourage conceptually focused student discourse, which is evident in table 7 above. In addition to not fostering this discourse, closed support sometimes led to *tunnel vision.* In this study, *tunnel vision* means that the students became so focused on one concept or idea that they ignored all other ideas. When this occurs, conceptual tasks can become procedural because instead of seeing the bigger picture or trying to understand how multiple ideas come together the student is focused on making sure one condition is met regardless of everything else. This was observed during the practicum lab. The teacher would provide the students with an important idea through closed conceptual support and the students would focus on that single idea, ignoring everything else. This was seen after the teacher gave closed support to the academic class near the end of the first day of the practicum. At this point the teacher had shown that the students initial answer was incorrect, because the units were wrong. She tells the students, "The units tell you whether you did the math right." She then challenges them to find a way to solve for time given a distance and a velocity and she later checks in to see how they are doing:

> **Ms. Lee**: So we've got meters divided by meters per second, and we flip it right *[referring to flipping the fraction and then multiplying instead of dividing].* So, how…what do I do? Right? *[Writing this information on the board].* Does that equal seconds?
> **Students**: Yea.
> **Ms. Lee**: There you go, units don't lie. I don't know whether your numbers are right, but at least now you have a unit of seconds.

Here the teacher has done two things with her closed support. She has emphasized the importance of finding the correct units and she has confirmed that the students need to divide distance by velocity to solve for time. These two pieces of support cause some of the students to have tunnel vision the next class period when the lab is continued.

The following conversations show the effect that this closed conceptual support had on the students. In this first conversation, one of the students (who was present for the closed support) remembers that something needs to be divided but does not show evidence that she remembers what needs to be divided nor why it needs to be divided:

> **Andrea**: Remember at the end of the period how she said like what we measured was the thing that we divided by?
> **Stacy**: Yea, I remember that. Jessica was up there but I don't remember what she said about it.

Here both Andrea and Stacy remember that they must divide, but do not show any understanding of why. As the lesson continues there is no evidence of them having an understanding of the reasoning behind why they should divide, thus it appears that they only remember that division is necessary to solve the problem. The conceptual idea of solving for time when given a distance and velocity has become a procedural task where the student know that they have to divide, but are not sure why. Their *tunnel vision* has hindered the students from thinking on a conceptual level. Another example of *tunnel vision* is seen in the academic class as well, resulting from the same piece of support given at the end of day one of the practicum. Here the students are trying to figure out a solution with the numbers that they have:

> **Chaz**: We need to find the area.
> **Larry**: We'll let's graph it then.
> **Chaz**: We need to find the area, because then we can get meters. We got meters per second and meters, we have to get area.
> *[The group moves to a new location and continues the conversation]*
> **Chaz**: I'm telling you, dude, we need to find the area.
> **Abe**: What would area give you though?
> **Chaz**: Meters, that's what we need this to be.
> **Abe**: So how are we going to find the area?
> **Chaz**: I don't know, we need to know what to find the area of.

This example shows Chaz's focus on finding the correct units, but ignoring the reasoning behind finding the correct units. He is not sure what to take the area of, but knows that the end result must have the units of area. His *tunnel vision* blocks the more important conceptual understanding and he is only focused on one thing: units. This focus on units was evident amongst many of the groups during the second day of the practicum and it can be linked to the support given to the students at the end of the first day in the academic class.

It was already shown that conceptual support can have an influence on the discourse patterns of the students, but there is an important distinction between *open conceptual support* and *closed conceptual support.* Open conceptual support fosters conceptually focused discourse, but closed conceptual support tends to hinder discourse especially conceptually focused discourse. Additionally, closed conceptual support can create *tunnel vision*, where the students are overly focused on one idea and ignore other important ideas and concepts. *Tunnel vision* transforms conceptually focused tasks into procedurally focused tasks.

***Productive Failure and the Resulting Shift in Discourse***

In both of the classes that were observed during this study, there was a failure in the practicum lab. The academic class incorrectly solved for the time it takes the ball to roll 2.5 meters and the honors class ignored the acceleration of the ball down the incline. In both cases the failure can be considered productive, because the failure influenced the discourse patterns of the students to better align with Bereiter's 4 commitments to progressive discourse (1994). Specifically, the discourse pattern showed more of a commitment to mutual understanding, expansion and openness. The fourth commitment, the commitment to empirical testability was not observed, however the practicum structure itself always has an empirical testability component. It would be difficult to see a shift in discourse to better align with this commitment, because of the restrictions imposed on the students which force them to reason out a solution before testing.

The mutual understanding commitment is "a commitment to work toward common understanding satisfactory to all" (Bereiter 1994, p. 7). The practicum lab structure fosters this commitment, however before the failure there was more of a commitment to *mutual agreement* rather than *mutual understanding*. The key difference is that before the failure the students strived to agree or accept one answer, but there was no indication of any effort put towards understanding the answer. In the academic class students could be heard making statements such as:

- "I don't know where we got these numbers, but I don't really care."
- "I'm just going to write this down; this better be right"
- "I didn't really pay attention.  I'm not going to get called on, so I'm good."

These quotes exemplify the mentality of many of the students before the failure.  They all knew that someone had a solution and while some of them made an effort to find out what the solution was, very few made an effort to understand the solution.  Some of the students did ask questions, however they were mainly clarifications of the numbers questions such as, "What was the 3 point yada yada you said?"  A small group of students asked how the number was figured out, but for the majority of the class it was mutual acceptance without understanding.

In addition to the lack of a commitment to mutual understanding by the students trying to learn the solution, this commitment was also non-existent with the student who figured out the solution.  This mentality of not wanting to explain his solution is evident when he first presents the solution:

> **Kevin**: Alright, everybody's got to look and me and listen, so we all know.  You set the car at 3.22126 meters.  When the ball hits the floor at the bottom of the ramp you start the car and they should meet at 2.5 meters.
> **Christine**: How'd you find the 3…
> **Kevin**: Because we're smart.

It takes a few attempts and intervention by the teacher to finally get any explanation of the solution.  There is a lack of commitment to mutual understanding by both the solution presenter and the students who are listening to the solution.

After the solution was shown to be incorrect, the students worked to find a new solution. Once a new solution is obtained, the students go through the same process of explaining the solution to everyone, however there is now a commitment to mutual understanding. The students no longer simply accept the solution; they analyze it for mistakes and make an effort to understand it as is evident in the conversation below. In this conversation, the students are presented with a paper containing the solution and they reason through it:

> **Jon**: Well we know the car starts right here, the ball starts right here, this is exactly…
> **Abe**: Right here you divide it.
> **Jon**: …2.5 and we need to find this one out.
> **Abe**: But that gives you seconds, right?
> **Mike**: Ok, seconds times meters per second…that's right. That does give you meters.

Here the students analyze the solution some and are able to conclude that this is a plausible answer because it has the correct units. The students take their initial understanding of the problem ("we need to find this one out") and by examining the solution decide that the solution could be the answer to what they need to know.

One of the students who figured out the solution is asked a number of questions that show that the other students are making an effort to understand the solution and showing a commitment to mutual understanding. Examples of these questions are:

- "Woah, how do we do that?"
- "Wait, we have to divide that?
- "I know we're being redundant, but where did you get this one at?"

Before the failure, the majority of student questions were clarifications on what the numbers were, but after the failure the questions are more focused on understanding the reasoning behind the solution. The student who figured out the solution also shows a commitment to mutual understanding and it is evident in his initial explanation of the solution. Unlike the incorrect solution from before where the student reasoned that he had the correct solution "because we're smart," this student takes the time to explain the process:

> **Patrick**: Alright you take the 2.5…
> **Stacy**: 2.5 what's that?
> **Patrick**: 2.5 is how many meters away they want to meet. So the ball traveled 2.5 meters from the bottom of the ramp to the 2.5 [meter mark] at a speed of 1.065. You take 2.5 divided by 1.065 and the units cancel out and you're just left with seconds so that's how long. So then that answer would be 2.347.
> **Stacy**: Woah, how do we do that?
> **Patrick**: 2.5 divided by 1.065. That's the time it would take for the ball to go from the bottom of the ramp to the 2.5 [meter mark]. Ok, to get the car, you take the time it takes for the ball to travel that…so that time you have to take that times 1.211, cause that's how fast the cars going. Then you would multiply those two, everything would cancel out and you would get meters. So that's how far away, and its 2.84 meters.

Notice how Patrick explains how he got each number and what each number in the solution represents. He has taken the time to show his classmates how he arrived at the solution. After the failure, both the person explaining the solution and the students in the class show a greater commitment to mutual understanding.

The second commitment that is affected by a failure is the *expansion commitment.* Bereiter describes the expansion commitment as:

> "A commitment to expand (in number, scope, or connectedness) the body of the collectively valid implies a willingness to maximize the basis from which new conclusions may be drawn, thus increasing the possibilities of an advance in understanding over the understandings originally brought into the discourse" (1994, p. 7)

As with the mutual understanding commitment, the failure in the practicum lab served to increase the almost non-existent commitment to expansion that was observed before the failure. In both classes, only a few students were engaged in generating new ideas and formulating the solution. This lack of participation and in turn the lack of ideas that were being considered was sometimes caused students not having the motivation to participate or by a feeling that ideas would not be accepted by other students. Either way, the number of ideas was limited. Students in both the honors and academic class observed this lack of a commitment to expansion:

> **Jack**: But Becky, we didn't account for how fast the ball was going off the ramp.
> **Becky**: I don't know guys, why are you looking at me?
> **Jack**: I was just saying cause we're the only ones talking.
>
> ----
>
> **Erica**: None of them are going to listen to us…no one ever listens to us *[said after her group came up with an idea]*
>
> ----
>
> **Jessica**: Ms. Lee, I had this answer [last class], but no one believed me *[after seeing the 'new' solution that was obtained on the second day]*

These quotes show the student recognition that there is a lack of ideas. In the first quote, the student acknowledges what is observed in the honors lab: only a few students are working on the problem. The other two quotes show the problem that ideas that some students have are either not accepted or the student does not think they will be accepted. There is a lack of commitment to expansion before the failure.

After the failure in both classes, there is a better commitment to expansion of ideas. One piece of evidence observed in both classes was that two different groups came up with a solution for the problem after the failure. In the academic class the two groups came up with the same solution. The teacher announces this to the class, which encourages the commitment to expansion: "Looks like we got groups that have a number; they may even have the same number." In the honors class, two groups came up with the same answer but had very different ways of arriving at the solution. The teacher acknowledges these differences in an interview following the practicum:

> "The ratio people in a way did something more sophisticated, they said oh well with that time its about the same velocity as the velocity going along the floor so it doesn't matter. And the other group actually took that into account. So they did like distance is velocity times time and they took that time into account."

In both classes there was one accepted solution before the failure in the practicum and it was a solution that represented the work of either one student or three students in the academic and honors classes respectively. After the failure, there were 2 solutions that were both correct, but more importantly were both considered "collectively valid" to use the same terminology as Bereiter. Further more, both classes had other groups working on a solution in addition to the 2 groups that finalized solutions. The fact that they did not actually arrive at a solution does not diminish the fact that it shows a commitment to expansion. The two conversations below (one from the honors class and one from the academic) show the effort to find a solution from groups who did not ultimately find the solution:

> **Jon**: It'd be easy enough if we just took that number divided by that number. Wait, don't we have to eliminate the meters, just to get seconds? And then you could eliminate the seconds and just get meters.
> **Abe**: Yea.
> **Jon**: Wouldn't that be it?
> **Larry**: We got to graph…*[one of their solutions involved finding the area under the curve]*
> **Jon**: Wouldn't that be right?
> **Abe**: What are we finding the area of?
> **Stefan:** That should just get us seconds, right? If it's dividing…
>
> ----
>
> **Erica**: And then the car's going to be coming here. So honestly, all we have to do is find out how long it takes the car to go that and then see how long it takes the…*[cut off by Becky explaining her solution]*

Both classes have evidence of other people working on solutions in addition to the groups who came up with the correct solutions. Before the failure there was only one solution in each class only worked on one solution, and only a few people had input on that solution.

After the failure multiple groups worked on solutions and the result was two viable solutions in both classes in addition to other in-progress solutions. The failure resulted in an increased commitment to the expansion of ideas.

The last of Bereiter's commitments that is fostered by failure in the practicum lab is the commitment to openness. In this commitment the discourse participants are required to allow their ideas and beliefs "to be subjected to criticism if it will advance the discourse" (1994, p. 7). This commitment is not evident before the failure, especially in the academic class. In that class, the student who solved the problem, Kevin, does not provide detailed reasoning as to how he solved the problem, which in turn prevents the idea from being criticized. When asked to explain his idea he responds with answers such as "because we're smart," "it's a long process," or "I don't have the numbers written down, I did it all in my head." It is impossible to criticize his solution because he does not open up his logic for criticism. In the end, the teacher must step in and disprove his solution, because he won't allow any students to disprove it. There is no commitment to openness.

After the failure, the commitment to openness is evident in the discourse patterns of the students. One of the new students who solves the problem, Patrick, explains his solution thoroughly allowing it to be subject to criticism and it is criticized. The conversation below between Patrick and Jessica (who was in the other group that found a solution) shows this criticism and commitment to openness:

> **Jessica**: Hey Patrick, you'd have to add the 2.5 plus the 2.4.
> **Patrick**: Why?

**Jessica**: To get the distance from…or where to place the car. You'd have to…
**Patrick**: No, you'd have to set this number that far away from the mark, you don't have to worry about the…the 2.5 has nothing to do with the car, it just has to do with how far the ball has to travel and the car has to travel so far to meet the ball at the 2.5.

Jessica challenges Patrick's solution here. She is able to because Patrick has explained it in enough detail to allow it to be criticized and because Patrick is open to criticism. This commitment to openness does not occur before the failure, but is present after the failure.

The role of failure in the practicum lab is a productive role. In this study, the discourse patterns observed better aligned with the 4 commitments to progressive discourse as described by Bereiter after the students had a failure. The specific commitments that were observed after the failure but were not present before the failure were the commitments to mutual understanding, openness and expansion. The fourth commitment, the commitment to empirical testability, did not show a change in the level of commitment when comparing pre- and post-failure. This commitment is built in to the structure of the lab in a way that it forces the testing to occur at the end of the lab. The teacher initially creates a question, which has the potential for empirical testability, but the actual testing of the students' hypothesis does not occur until the end of the lab. Thus there is an inherent commitment to empirical testability within the structure of the lab, but the structure of the lab also prevents an observable change in the commitment to empirical testability caused by a failure. It is possible that a failure would also increase the commitment to empirical testability in other circumstances, but it was not observed in this study.

**CONCLUSION**

This study examined the role of teacher guidance as well as the effect of a failure during an open-ended inquiry lab. The first result showed the importance of aligning support with the structure of the lesson. When these two pieces of teacher guidance do not align, the teacher is not able to influence the discourse patterns nearly as much as when the structure and support were aligned. This was observed in the traditional lab, where the conceptual support of the teacher did not have a significant influence on the discourse pattern because of the procedurally focused structure of the lab. Additionally, the practicum lab structure fostered communication between students, but without the communicative support of the teacher there were still communication problems.

The second result showed the difference in student discourse following open conceptual support as opposed to closed conceptual support. When the teacher provided closed conceptual support the discourse either was terminated or it transformed a conceptual task into a procedural one. This transformation occurred because students were excessively focused on a piece of support and failed to see the bigger conceptual picture; the task became algorithmic. This transformation from conceptual to procedural was termed tunnel vision because the students were focused on a single idea or piece of support. Open conceptual support, on the other hand, fostered conceptual discussions and prevented tunnel vision from occurring.

The last result showed how failure could be productive in the practicum by leading to progressive discourse (or discourse that was more closely aligned with progressive discourse as described by Bereiter, 1994). In both cases that were observed the students had a conceptual failure and there was a marked change in the overall discourse patterns following the failure. After the failure the students showed greater commitments to mutual understanding, expansion of the number of valid ideas and openness to criticize any idea brought into discourse (three of the four commitments outlined by Bereiter). This discourse was considered to be more productive and authentic, therefore the failure was deemed to be productive.

***Fostering Student Discourse***

The results suggest two implications for a theory of teaching. The first implication is that the teacher is able to influence the discourse pattern of the students and foster inquiry through the activity structure and the support given by the teacher during a lesson. It is important to be aware of the goals for a lesson and ensure that the goals are reflected in *both* the activity structure and support given during a lesson. The importance of having consistency between structure and support was shown in this study. Without this consideration, the activity structure and support maybe be counterproductive to the goals of the lesson.

In addition to considering how the structure and support align with the goals of the lesson, the manner in which support is given must also be considered. Open support aligns with the dialogic communicative approach and it encourages discourse amongst the students. Closed support better suits an authoritative approach since it does not foster discourse. Once again, the goal of the lesson is important in considering how to support the student discourse. It is not an issue of which approach is better for learning, but rather which approach better supports specific learning goals. The focus of the lesson, along with the desired communicative style for the lesson, must be considered when determining how to structure and support the activity.

The findings of this study regarding the impact of structure and support are consistent with prior research. The impact of the support of the lesson was examined by Krystyniak & Heikkinen (2007) as well as Berg et al. (2003). Krysyniak & Heikkinen found that students relied less on their instructors during inquiry-based activity structures and when they did ask questions they were regarding conceptual topics. Berg et al. found the there was more student reflection and reflective question during inquiry-based lessons. The fact that the students are asking more conceptual and reflective questions suggests that they were engaged more in conceptual discourse. This study did not examine student questions, however it did find that the structure impacts the discourse and a conceptually focused structure will increase the amount of time the students spend engaged in conceptual actions which is consistent with the findings of Krystyniak & Heikkinen and Berg.

Other studies have shown that the support that the teacher gives can influence the discourse actions of the students. McNeill and Pimentel (2009) found that open-ended questions promoted dialogic interactions between students. Chin (2006) found that when the teacher provided feedback (as part of an open dialogic interaction) that included a thought provoking question the students were more actively engaged. Both of these studies agree with the finding in this study that open conceptual support sparks further conceptual discourse amongst the students. In the case of Chin and McNeill & Pimentel the support given by the teacher that was studied was limited to questions, but the findings regarding the openness of support are consistent. This study served to provide further support for some of the research done on structure and support as well as draw attention to the interrelatedness of structure and support.

***Productive Failure***

The first implication examined the importance of structure and support for fostering student discourse. The second implication examines the effect of removing or fading out the structure and support to allow the students to fail; this failure was found to be productive for student discourse. When the students were stripped of the guidance provided in the classroom and they failed it resulted in "better" discourse that more closely aligned with the progressive discourse model.

It may be tempting or seem logical to intervene before a failure to prevent it, and there is a lot of research (including part of this study) that examines how the teacher prevents this failure. The fading of support and the role of failure is a much less studied phenomenon. It is imperative for educators to realize that temporary failure can be useful in the end. While it is still unclear exactly what conditions are needed for this failure to be productive, the possibility for failure to be productive does exist. Thus, it is not necessary for teachers to immediately rush to provide structure for the students should an incorrect idea or hypothesis arise. The students may actually benefit from being allowed to fail temporarily.

This implication provides evidence for Kapur's (2008) theory of productive failure, however there are three significant differences between the findings of this study and the Kapur study.  Kapur measured the productivity of the failure using a post-test and he examined it as a structured, laboratory study with a computer supported collaborative learning environment.  The failure was found to be productive because the students who were engaged in solving ill-structured problems and failing at solving them were able to outperform their peers on the post-test that included both well-structure and ill-structured problems.  The first difference is that this study examined failure during an ill-structured problem (the practicum lab), but looked at it in a more naturalistic way – within the context of a classroom.  The failure in this study was not the result of an experiment designed to produce failure, but rather it arose naturally.

The second key different is that this studied measured the productivity based on the discourse that occurred during the solving of the problem.  Kapur measured the productivity based on post-tests given to the participants, but the immediate impact of the failure during the solving of the ill-structured problem was not examined.  Thus this study provides evidence for a new way that failure can be productive.

The last key difference, which could be linked to the fact that the productivity was seen during the problem solving, is that the students were able to actually solve the problem in this study.  In the Kapur study the students did not initially solve the problem.  This is partly because in that study the ill-structured problems were considered to be beyond the ability of the students. In this study, the problem was within the ability of the students even though it was challenging. The failures experienced were temporary setbacks instead of complete failures. Overall, this study compliments the study done by Kapur (2008), but adds a new dimension to productive failure. Productive failure can occur in a naturalistic setting, where the failure is temporary; but in this case the failure leads to better discourse, instead of better performance on future tasks.

It is important to consider the impact of this finding in the classroom and be careful to not view the results in the wrong light. This study does not suggest that the teacher should attempt to force the students into failure. As Kapur (2008) suggests as well, this study simply provides evidence that failure can serve a purpose during open-ended or ill-structured activities. The conditions under which the failure occurred in this study are key. The teacher did not intentionally lead the students towards a failure, but rather fostered discourse amongst the students and faded the scaffolding to allow them to fail. While it is still unclear what conditions are necessary to have productive failure, it is imperative to note that the failure occurred because the students were given the opportunity to fail, not because the lessons lead them to failure.

This study provides evidence for conclusions that were found in previous research. Both the structure of the lesson and the support given during the lesson are able to influence the discourse patterns of the students. The importance of open support in fostering further discourse was confirmed by this study. Additionally, the theory of productive failure was verified in a naturalistic setting and a new way that failure can be productive was found.

### *Future Research*

This study examined the discourse of students in an open-ended practicum lab. All of the study was conducted in the same classroom. One of the main limitations of this study was that only one teacher was examined. While failure was shown to be productive in her classroom, the teacher was an expert teacher with many years of experience, which could have had a significant impact on the ability of the failure to be productive. Another limitation was that the failure was only examined within one type of open-ended inquiry based lab. Lastly, unlike the Kapur study, the failure was not examined over time. While it was shown to be productive during the problem-solving process, the study provides no evidence for the failure to be productive in the long term.

One direction for further research on the topic of productive failure should focus on trying to finding new contexts for which failure can be productive. Activity structures other than the practicum lab provide the potential for failure and thus they should be examined to see if failure could be productive in these structures. Varying the teacher studied, specifically examining a less experienced teacher, would also be a useful variable to change. In further research it could also be beneficial to examine the immediate impact of the failure as well as the long-term impact of the failure. This study showed the immediate impact while the study conducted by Kapur (2008) showed the long-term impact. Combining these two foci could prove to be insightful.

In addition to finding new context that allow for productive failure, it would also be useful to examine the details of how productive failure occurs. It would be unrealistic to believe that failure can be productive in any situation. In this study, the students were well prepared for the challenges of the practicum lab. They had already completed the motion graph discovery lab among other activities, which provided them with the conceptual knowledge necessary to solve the practicum. One of the important points regarding the practicum, as stated by the teacher and the practicum guide, is for the problem to be challenging, but solvable. The role of the activities leading up to the practicum cannot be overlooked. The students were able to solve the problem eventually, because they were prepared for the challenge; without this preparation this failure might not have been productive.

The way that the teacher faded the scaffolding also has the potential to affect the productivity of the failure and thus it should be examined. Providing too much support could have eliminated the possibility for failure, but fading out the support too quickly could have lead to unproductive failure. This study only examined the introduction to a unit (the motion graph lab) and the concluding assessment (the practicum lab). This fading of support is a key concept and serves an important role in productive failure along with the preparation the students are provided with before the failure.

This study shows the impact that both structure and support of a lesson have on student discourse patterns. It also provides evidence for positive outcomes that result from a teaching removing support structures and allowing the students to fail temporarily. Continued research needs to be done to examine the context and conditions under which failure can be productive.

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**Teacher Support Given During Labs**

| **Support Given** | *Honors Traditional* | *Honors Practicum* |
|---|---|---|
| Procedural | **41.7** (10 of 24) | **60.3** (38 of 63) |
| Conceptual | **50.0** (12 of 24) | **11.1** (7 of 63) |
| Communicative | **0.0** (0 of 24) | **27.0** (17 of 63) |
| Neutral | **8.3** (2 of 24) | **1.6** (1 of 63) |
| | *Academic Traditional* | *Academic Practicum* |
| Procedural | **33.3** (8 of 24) | **26.9** (25 of 93) |
| Conceptual | **50.0** (12 of 24) | **34.4** (32 of 93) |
| Communicative | **4.2** (1 of 24) | **30.1** (28 of 93) |
| Neutral | **12.5** (3 of 24) | **8.6** (8 of 93) |
| | *Traditional Overall* | *Practicum Overall* |
| Procedural | **37.5** | **40.4** |
| Conceptual | **50** | **25** |
| Communicative | **2.1** | **28.8** |
| Neutral | **10.4** | **5.8** |

**Comparing Practicum Lab and Traditional Lab**

| **Action** | *Honors Traditional* | *Honors Practicum* |
|---|---|---|
| Procedural | **73.9** (35:40 of 48:16) | **40.0** (32:07 of 80:22) |
| Conceptual | **24.3** (10:16 of 48:16) | **28.3** (22:44 of 80:22) |
| Communicative | **3.1** (1:30 of 48:16) | **31.7** (25:31 of 80:22) |
| | *Academic Traditional* | *Academic Practicum* |
| Procedural | **77.2** (19:26 of 25:11) | **17.8** (15:17 of 85:48) |
| Conceptual | **12.9** ( 3:15 of 25:11) | **17.9** (15:19 of 85:48) |
| Communicative | **9.9** ( 2:30 of 25:11) | **64.3** (55:11 of 85:48) |
| | *Traditional Overall* | *Practicum Overall* |
| Procedural | **74.5** | **28.6** |
| Conceptual | **20.2** | **22.9** |
| Communicative | **5.2** | **48.5** |

**Open Support vs. Closed Support in the Practicum**

| | *No Interaction* | *After Open Conceptual* | *After Closed Conceptual* |
|---|---|---|---|
| **Academic Practicum** | | | |
| Procedural Action | **21.6** (7:54 of 36:42) | **4.2** (0:12 of 4:59) | **46.6** (1:50 of 3:57) |
| Conceptual Action | **23.8** (8:45 of 36:42) | **36.1** (1:48 of 4:59) | **19.0** (0:45 of 3:57) |
| Communicative Action | **54.6** (20:03 of 36:42) | **59.8** (2:59 of 4:59) | **34.5** (1:22 of 3:57) |
| **Honors Practicum** | | | |
| Procedural Action | **41.5** (19:05 of 45:57) | **5.4** (0:07 of 2:09) | **31.6** (0:24 of 1:18) |
| Conceptual Action | **32.1** (14:46 of 45:57) | **88.3** (1:54 of 2:09) | **52.6** (0:41 of 1:18) |
| Communicative Action | **26.4** (12:06 of 45:57) | **6.2** (0:08 of 2:09) | **15.8** (0:12 of 1:18) |

**Summary of Student Discourse After Interactions**

| | *No Interaction* | *After Interaction* | *After Procedural* | *After Conceptual* | *After Communicative* | *After Neutral* |
|---|---|---|---|---|---|---|
| **Academic Traditional** | | | | | | |
| Procedural Action | **74.5** (13:24 of 17:58) | **83.7** (6:02 of 7:13) | **91.7** (4:35 of 4:59) | **51.2** (0:43 of 1:24) | **62.5** (0:19 of 0:30) | **77.2** (0:32 of 0:41) |
| Conceptual Action | **13.5** (2:24 of 17:58) | **11.5** (0:51 of 7:13) | **5.6** (0:15 of 4:59) | **48.8** (0:41 of 1:24) | **0.0** (0:00 of 0:30) | **0.0** (0:00 of 0:41) |
| Communicative Action | **12.0** (2:10 of 17:58) | **4.8** (0:20 of 7:13) | **2.8** (0:09 of 4:59) | **0.0** (0:00 of 1:24) | **37.5** (0:11 of 0:30) | **22.8** (0:09 of 0:41) |
| **Honors Traditional** | | | | | | |
| Procedural Action | **73.0** (25:16 of 34:38) | **76.1** (10:24 of 13:38) | **90.3** (9:03 of 10:01) | **40.8** (1:22 of 3:23) | **No Instances** | **0.0** (0:00 of 0:15) |
| Conceptual Action | **24.7** (8:26 of 34:38) | **20.8** (2:50 of 13:38) | **5.5** (0:34 of 10:01) | **59.2** (2:01 of 3:23) | **No Instances** | **100** (0:15 of 0:15) |
| Communicative Action | **2.7** (0:56 of 34:38) | **3.0** (0:34 of 13:38) | **4.1** (0:24 of 10:01) | **0.0** (0:00 of 3:23) | **No Instances** | **0.0** (0:00 of 0:15) |
| **Academic Practicum** | | | | | | |
| Procedural Action | **21.6** (7:54 of 36:42) | **15.1** (7:23 of 49:05) | **54.8** (4:45 of 8:45) | **10.7** (0:47 of 7:10) | **2.8** (0:46 of 26:47) | **7.7** (0:17 of 3:37) |
| Conceptual Action | **23.8** (8:45 of 36:42) | **13.4** (6:34 of 49:05) | **21.4** (1:53 of 8:45) | **32.0** (2:19 of 7:10) | **5.4** (1:27 of 26:47) | **21.2** (0:44 of 3:37) |
| Communicative Action | **54.6** (20:03 of 36:42) | **71.5** (35:08 of 49:05) | **23.8** (2:06 of 8:45) | **57.3** (4:04 of 7:10) | **91.7** (24:34 of 26:47) | **71.2** (2:35 of 3:37) |
| **Honors Practicum** | | | | | | |
| Procedural Action | **41.5** (19:05 of 45:57) | **37.8** (13:02 of 34:01) | **66.8** (11:03 of 16:31) | **14.3** (0:31 of 3:28) | **8.0** (1:10 of 15:39) | **0.0** (0:00 of 0:08) |
| Conceptual Action | **32.1** (14:46 of 45:57) | **23.1** (7:58 of 34:01) | **24.4** (4:00 of 16:31) | **75.5** (2:35 of 3:28) | **10.8** (1:35 of 15:39) | **0.0** (0:00 of 0:08) |
| Communicative Action | **26.4** (12:06 of 45:57) | **39.0** (13:25 of 34:01) | **8.8** (1:28 of 16:31) | **10.2** (0:21 of 3:28) | **81.1** (11:54 of 15:39) | **100** (0:08 of 0:08) |

**Summary of Change in Student Discourse After Interactions**

| | *No Interaction* | *After Interaction* | *After Procedural* | *After Conceptual* | *After Communicative* | *After Neutral* |
|---|---|---|---|---|---|---|
| **Academic Traditional** | | | | | | |
| Procedural Action | 74.5 | **9.20** | **17.20** | **(23.30)** | **N/A** | **N/A** |
| Conceptual Action | 13.5 | **(2.00)** | **(7.90)** | **35.30** | **N/A** | **N/A** |
| Communicative Action | 12 | **(7.20)** | **(9.20)** | **(12.00)** | **N/A** | **N/A** |
| **Honors Traditional** | | | | | | |
| Procedural Action | 73 | **3.10** | **17.30** | **(32.20)** | **N/A** | **N/A** |
| Conceptual Action | 24.7 | **(3.90)** | **(19.20)** | **34.50** | **N/A** | **N/A** |
| Communicative Action | 2.7 | **0.30** | **1.40** | **(2.70)** | **N/A** | **N/A** |
| **Academic Practicum** | | | | | | |
| Procedural Action | 21.6 | **(6.50)** | **33.20** | **(10.90)** | **(18.80)** | **(13.90)** |
| Conceptual Action | 23.8 | **(10.40)** | **(2.40)** | **8.20** | **(18.40)** | **(2.60)** |
| Communicative Action | 54.6 | **16.90** | **(30.80)** | **2.70** | **37.10** | **16.60** |
| **Honors Practicum** | | | | | | |
| Procedural Action | 41.5 | **(3.70)** | **25.30** | **(27.20)** | **(33.50)** | **N/A** |
| Conceptual Action | 32.1 | **(9.00)** | **(7.70)** | **43.40** | **(21.30)** | **N/A** |
| Communicative Action | 26.4 | **12.60** | **(17.60)** | **(16.20)** | **54.70** | **N/A** |

*****NOTE: The No Interaction Column does not show change, but provides the base percentages for the discourse for which the changes are based on. Also, N/A means that there was not a significant amount of discourse time for the category for the change to be meaningful***

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| | |
|---|---|
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