**Characteristics of classroom discourse in physics lessons**

**Abstract**

Discourse is the teacher’s principal pedagogical tool in class. The purpose of this study was to investigate characteristics of the classroom discourse in lessons on physics. The classroom discourse was studied in five classes at five high schools in Israel, 110 students in all. The discursive characteristics examined were patterns of discourse episodes and their frequency in each lesson, the initiator of discourse (teacher or student), and types, frequency, and initiators of questions asked. Altogether, seventeen lessons comprising 373 discourse episodes and 1,892 questions were analyzed. The findings show that despite variance in teachers’ and students’ traits, all lessons were similar in various discourse parameters. Most classroom discourse was dynamic and continual; many questions were asked and were of diverse types that induced large numbers of discourse episodes. The lessons differed mainly in the number of teacher-initiated higher-order thinking questions and the number of open discourse episodes—elements indicative of dialogic teaching. However, even among teachers who asked more high-order questions and initiated open discourse with higher frequency, the discourse episodes were brief and rarely led to meaningful discussions and deep thinking. Investing more in dialogic discourse may abet the building of knowledge and effective learning of abstract ideas in a challenging subject such as physics.

**Keywords**: classroom discourse, closed discourse, dialogic discourse, higher-order thinking questions, open discourse.

**Introduction**

Enhancing the teaching of science and mathematics has been a major goal in many countries’ education policies since the early 1960s (Kilpatrick, 2012) and much effort has been invested in alternative proposals for the advancement of learning, teaching, and thinking in science education )Bransford, Brown, & Cocking, 2000; Reiser, Duschl, Schweingruber, & Shouse, 2007(. The current study analyzes the classroom discourse in physics lessons. It is important to investigate classroom discourse because both theoretical and empirical research on classroom discourse patterns serve as bases for understanding how children learn in class (Mercer 2008). Teaching is an interactive process and classroom discourse is its operative mechanism. Studies stress the importance of research on discourse in science education and demonstrate its cruciality for understanding science.

Classroom discourse in teaching science may have a direct effect on students’ understanding of concepts, phenomena, and processes, and on their ability to enunciate arguments, draw conclusions, and solve problems (Hogstrom, Ottander, & Benckert, 2010; Mortimer & Scott, 2003; Thompson et al., 2016). A fruitful and dialogic classroom discourse allows teachers to assess their students’ understanding continually, as they teach, and to give them immediate feedback. It may also play an important role in detecting misunderstandings and may abet conceptual change (Mercer & Littleton, 2007).

 Even though the importance of the quality of the classroom discourse and its utility for effective learning are widely acknowledged, not enough is being done to improve this discourse. The potential of classroom discourse is underused in most classrooms in most parts of the world and in most teaching time (Mercer & Dawes, 2008).

Various studies examine the effect of intervention programs on classroom discourse (Howe et al., 2007; Mercer & Sams, 2006; Ruthven et al., 2017). Fewer studies, however, track the kind of classroom discourse that ensues without outside intervention and describe discourse that occurs naturally in class. Studies that investigate the classroom discourse in physics lessons, a subject considered challenging, are also few. Not many students elect to study physics in high school or in higher education. Thus, investigating discourse in physics lessons is an important step that may help encourage youngsters to study physics.

Traditional teacher-centered teaching or frontal teaching is still common in most classrooms in Israel and abroad (Goodlad, 1983; Wells, 1999), hence the immense importance of research on whole-class discourse. Analysis and recognition of patterns of whole-class discourse are among the most sensitive instruments by which teaching methods and perceptions can be evaluated. Teachers who see learning as a socio-communicative process will encourage their students to get involved in the classroom discourse. Teachers who invoke a continuum of questions and answers not only to check students’ knowledge but also to encourage them to develop new insights, master problem-solving processes, and acquire learning strategies will elicit an open and dialogic discourse. Such a discourse, which emphasizes a constructive approach to learning, is differentiated from the closed discourse typified by brief feedback by the teacher and teacher’s dominance in the learning process (Rojas-Drummond & Mercer, 2004; Mortimer & Scott, 2003).

The purpose of this study is to investigate the characteristics of classroom discourse in frontal physics lessons—natural, uninterrupted discourse in class, among students and teachers who exhibit a variety of traits. Teachers’ understanding of their discourse patterns as reflections of the way they perceive their teaching is the key to promoting more learning-effective discourse patterns.

**Characteristics of classroom discourse**

Research on classroom discourse has attracted growing interest in recent years and has demonstrated its importance in science education and its cruciality for understanding the nature of science (Hogstrom et al., 2010; Mortimer & Scott, 2003; Roychoudhury & Roth, 1996; Thompson et al., 2016) The study of classroom discourse reflects a conceptual change in science education, in which it is considered important to relate not only to the individual student’s learning and comprehension but also to the dialogue and discourse that take shape in the social context of the science class (Duit & Treagust, 2003). The study of science is in fact a discursive process, in which the investigation of scientific ideas and ways of reasoning takes place in parallel processes of social interaction and individual activity. This convergence offers advantages for the learning process and the development of scientific understanding (Mercer, Dawes, Wegerif, & Sams, 2004). It has been found that the way teachers conduct the discourse may influence the manner in which students speak and interact as they learn and may also affect their ability to “talk science” (Nussbaum & Edwards, 2011). Many studies have been written about teaching approaches based on the discourse that unfolds in a science classroom where students learn collectively, e.g., group learning and models of argumentation (Duschl & Osborne, 2002; Kim & Hand, 2015). Fewer studies, however, concern themselves with discourse at the whole-class level.

Effective whole-class discourse is quite a challenge. Discourse between a teacher and a class may be examined in view of the extent of involvement in and leadership of the discourse by the teacher or the students as the lesson progresses. This range may begin with a “lecture” approach, in which the teacher controls the contents and progression of the lesson, via encouraging students to ask questions in order to stimulate discussion and elicit different viewpoints, to a model of teaching that allows students to contribute equally to constructing the course of the lesson (Alexander, 2008; Tanner, Jones, Kennewell, & Beauchamp, 2005). The last-mentioned approach reflects the epitome of “dialogic teaching,” in which exchanges of ideas take place between the teacher and the students and among the students themselves. Dialogic teaching that encourages open classroom discourse has been described as a reflective and critical form of teaching and learning that promotes meaningful learning (Ford & Wargo, 2012; Pimentel & McNeill, 2013).

In dialogic teaching, special emphasis is placed on conceptual flexibility. This model, in contrast to traditional teaching that focuses on the teacher and presents only his or her outlook, encourages a range of perspectives and ideas (Scott, Philip H., Mortimer, & Aguiar, 2006). In science teaching, dialogic discourse has become a central characteristic. The widespread recognition of the importance of constructive learning and the realization that students develop alternative ways of grasping scientific concepts has led to emphasis on the need for dialogic teaching through which the teacher can influence the shaping of students’ conceptual outlooks (Ruthven et al., 2017).

According to Scott et al. (2006), the teacher–student discourse features continual tension between the dimension of teacher authoritarianism and salience and that of dialogue. Any sequence of a science lesson, they say, should accommodate both dimensions in order to induce meaningful learning tailored to the purpose of the learning. Authoritative interaction may induce dialogue or may have the opposite outcome. In certain situations, vibrant interaction may occur in which the teacher’s authoritarianism and viewpoint are definitively non-dominant (in what Scott et al. call interactive/dialogic interaction). In other possible situations, however, a teacher presents various and diverse outlooks that typify dialogic teaching without engaging the students in discourse. Therefore, to attain a deeper understanding of classroom discourse, additional characteristics, such as the structure of the discourse, should be addressed.

**Structure of classroom discourse**

A conspicuous pattern of dialogue-building in science classes is the three-stage heuristic first described by Mehan (1979), comprised of a point or a question being raised by a teacher, student’s response, and teacher’s feedback. This is known as IRE—I=initiates; R=student responds; and E=teacher evaluates. Gamoran & Nystrand (1991) sort teacher feedback into two levels: low and high. Low-level feedback is given, for example, by repeating the student’s words and affirming his or her response. In high-level feedback, the teacher integrates the student’s response into the continuation of his or her remarks and further expands on it or asks a question pursuant to it. By basing their statement on students’ responses, teachers send a message that identifies students’ contribution to the class discussion, to learning, and to the joint construction of knowledge that a dialogic discourse may elicit.

If so, in higher-order feedback, when the teacher responds to a student’s remarks with a question and the student reacts repeatedly to the teacher’s words, or when several students respond and the teacher instigates an open discussion, a multi-stage discourse continuum is produced (Scott, Philip H. et al., 2006). This kind of dialogic discourse is typified by a chain of open continua and has fewer IRE sequences that stop once the teacher obtains the response that he or she expects—sequences that inhibit students in creating new knowledge on their own terms (Christodoulou & Osborne, 2014(. In the view of McNeill et al. (2010), science is learned through a process in which students participate in a discourse, challenge and criticize the ideas of the teacher and of their fellow students, and play an important role in the development of the discussion.

In a discourse grounded in numerous IRE iterations, the teacher is dominant, facilitates the class in the direction of his or her choosing, and focuses on eliciting right answers from students irrespective of the depth of their understanding. This closed pattern is highly common in high-school science classes, where many teachers strive to obtain fixed responses (Polman & Pea, 2001).

According to Wells (1999), three-stage IRE sequences should not be characterized as desirable or undesirable forms of discourse; instead, they should be judged by their intended purpose in each stage of the lesson. These stages may have different goals that are determined in accordance with the goals of the classroom discourse (Mortimer & Scott, 2003). Abundant use of IRE sequences, however, may suggest that the teacher perceives learning as the memorization of sets of facts. Most questions asked in these three-stage sequences are short and entail memorization; the teacher uses the short answers to prime students to respond to questions for which the teacher expects a certain answer and to evaluate students’ knowledge (Mercer, 2008).

**Questions asked in classroom discourse**

The most common way of developing a classroom discourse is by asking questions. A teacher’s questions help to structure students’ knowledge and gradually to bring information into clear focus. They help students to focus and elucidate their thinking, develop their ability to present grounded arguments, and even whet their learning motivation (Chin & Kayalvizhi, 2005). Students’ questions, particularly those that look for depth, indicate their thinking about the topic and mark an attempt to link ideas with existing knowledge and seek comprehension (Frtak & Ruiz-Primo, 2008). Students’ questions also alert teachers to the quality of their knowledge, reveal their misconceptions, indicate what they want to know, and may even change the direction of teaching in the lesson (Chin & Osborne, 2008; Watts, Gould, & Alsop, 1997).

One way of sorting types and levels of questions is by the level of thinking that is needed to answer them. One familiar sorting method is predicated on Bloom’s taxonomy (1956), which offers a hierarchy of questions ranging from knowledge questions, expressing the lowest order of thinking, to comprehension questions, application, analysis, synthesis, and evaluation. Anderson et al. (2001) revised this taxonomy by emphasizing the differences between the cognitive processes and classifying questions along an axis of remember, understand, apply, analyze, evaluate, and create.

In another perspective on sorting questions, three categories are proposed, each capturing a distinct stage in the process of comprehension and conceptual change among students (Watts et al., 1997): consolidation questions, in which students confirm and elucidate information in order to understand a new idea; exploration questions, in which they wish to broaden and examine their knowledge, and elaboration questions, in which they attempt to confront arguments, resolve conflicts, and examine ideas from all directions.

In another taxonomy, a general distinction is made between lower-order thinking questions, which examine factual knowledge—usually the kind retrieved from memory and related to something already learned—and questions that entail higher-order thinking. Questions of the latter type require comprehension and the ability to analyze, generalize, and synthesize (Zohar, 2004). In an earlier and very similar taxonomy, two broad categories of questions are presented: confirmation questions and transformation questions. Confirmation questions are those meant to elucidate information and define and explain concepts; transformation questions concern reconstructing and reorganizing the student’s knowledge and comprehension (De Jesus, Teixeira-Dias, & Watts, 2003). Transformation questions are high-order thinking questions that include the analysis, synthesis, and evaluation that appear in the taxonomies of Bloom and of Anderson and Krathwohl.

Transformation questions are of particular importance in creating fruitful classroom discourse. The more challenging a question is and the more subversive it is of existing views, the more likely it is to trigger debate and draw more students into classroom discourse (Scott, Phil, 2008). Open discourse cannot be based only on rhetorical questions that resolve to one foreknown answer; it must include questions that elicit different responses and present the teacher’s stance as one of many (Christodoulou & Osborne, 2014). Confirmation questions, in contrast, may crimp students’ discourse and entails rapid recollection of facts and using IRE sequences (Galton, Hargreaves, Comber, Wall, & Pell, 1999).

Studies show that, notwithstanding their importance, high-order thinking questions are infrequent in frontal, teacher-centered lessons (Alexander, 2008). Teachers do not often ask thinking questions (Barnes, 2010), and most questions that students ask in class are confirmation questions about basic knowledge that entail repetition and clarification of information (Chin & Brown, 2002; Middlecamp & Nickel, 2005). Nystrand et al.(2003) find that fruitful dialogic classroom discourse is uncommon, lasts fifty seconds on average in eighth grade and fifteen seconds in ninth grade, and usually comes about after the teacher or the students ask authentic open-ended questions.

**Goals of the study**

The purpose of this study is to learn about the characteristics of classroom discourse in physics lessons taught by five different teachers to students of differing characteristics. We analyzed various aspects of the classroom discourse, asking what common characteristics they share despite the differences among and diversity of the research participants. We asked whether it is possible to detect typical discourse patterns among the physics teachers that may originate mainly in the characteristics of the discipline of physics and the way teachers perceive physics teaching, as opposed to other factors.

Various factors participate in and have an effect on the classroom discourse. Therefore, comparison of the characteristics of the discourse in different classes may abet the development of meaningful elements that affect the quality of the discourse in physics lessons and, in turn, the quality of learning.

The discourse episodes in each lesson were investigated, sorted by initiator (teacher or student), and analyzed for their patterns. As most classroom discourse revolves around questions raised by teachers or students, the types and frequency of the questions were analyzed as well.

Our research questions were the following:

1. What classroom discourse patterns come to light and how frequently are they encountered? Who initiates the discourse episodes in each class and is there a significant similarity or difference among the classes?
2. What kinds of questions did the teacher and the students in each class and ask? Is there a significant similarity or dissimilarity among the classes?

**Methodology**

**Design**

We examined classroom discourse in high-school physics lessons as it unfolded naturally and without outside intervention. The study used a mixed quantitative-qualitative paradigm based on five case studies. Our quantitative and qualitative analysis of various aspects of discourse in five different classes yielded a broad picture of verbal interaction in class. The parameters that we examined were the number of words stated by teacher and students, the number of lesson segments in which students took part in discourse—discourse episodes—the identity of the instigator of each discourse episode in each lesson, a profile of the discourse pattern in each episode, and the number and type of questions that the teacher and the students asked in each lesson.

**Participants and Setting**

Five classes comprising five physics teachers and 110 students participated in the study. The classes were in five different high schools in central and southern Israel. The participating schools represent two important sectors of the Israeli education system: the religious and the secular. Three of the schools belong to the religious school system and are attended by girls only; two are secular and are attended by boys and girls together. Thirty physics teachers were contacted; only five of them agreed to participate in the study. These teachers gave us permission to use audio-recording to document their lessons in class but asked us not to film. The camera, they claimed, might affect the natural atmosphere and the class discourse. They did, however, tell their students that the lessons would be recorded for research purposes.

Table 1 itemizes each teacher’s characteristics. Three female teachers and two male teachers, aged 30–49, took part in the study. All had academic credentials in physics and at least four years’ experience in teaching the subject.

Table 1: *Teacher* *Characteristics*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| % of full-time post | Education | Experience in teaching physics (years) | Age | Gender | Teacher |
| 80 | Electronics engineer, masters in science education | 4 | 38 | Male | Ger |
| 100 | Master’s degree in physics | 26 | 49 | Female | Shem |
| 100 | Master’s degree in physics | 8  | 32 | Female | Adi |
| 100 | Engineer with master’s degree in science education | 7 | 35 | Female | Nur |
| 40 | Masters in neuroscience, Ph.D. in teaching physics | 6 | 30 | Male | Asaf |

Table 2 presents the characteristics of each teacher’s students, class, and school. The students were aged 14-18 and attended schools of various characteristics. Two classes were gender-integrated and belonged to non-religious schools; in three classes there were girls only and the schools were part of the religious school system. Enrolled in the two integrated classes (taught by Nur and Asaf) were outstanding physics students who had been screened and chosen to be part of an advanced class. There was also variance in the topics of study: in each class, the topic chosen accorded with the students’ age, the curriculum, and the teacher’s decision. Common among all students was that they had elected to study physics at an expanded level.

The lessons were all frontal; there were no laboratory classes or exercise lessons in which most of the time would be devoted to students’ work. The students sat in rows.

Table2: *Student, School, and Subject Characteristics*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Class | Age | Students (N) and gender | Characteristics of students in class | Topics of study in lesson | Location and characteristics of school |
| Ger | 16–17,11th grade | 20 girls | High socioeconomic status, preparing for matriculation in physics at 5-point level | Newton’s laws, voltage, normal kinematics, friction | Religious girls’ high school in central Israel |
| Shem | 17–18, 12th grade | 8 girls | Medium socioeconomic status, preparing for matriculation in physics at 5-point level | Receptor discharge/load, in-line and parallel connecting of resistors, complex circuits | Religious girls’ high school in southern Israel |
| Adi | 17–18, 12th grade | 22 girls | High socioeconomic status, preparing for matriculation in physics at 5-point level | Kinematics, Newton’s laws, electrical circuits | Religious girls’ high school in central Israel |
| Nur | 14–15, 9th grade | 30 boys and girls | Middle-high socioeconomic status, scientific reserve class, outstanding students | Mechanical motion, Newton’s laws, kinetic energy, coils | Non-religious high school in southern Israel |
| Asaf | 15–16,11th grade | 30 boys and girls | High socioeconomic status, class for outstanding physics students | Optics, refraction in various media, lenses | Non-religious scientific high school in central Israel |

**Data analysis**

Seventeen lessons were recorded, three or four consecutive lessons with a class for each teacher (four lessons for Ger and Adi and three for Shem, Nur, and Asaf). Care was taken to choose successive lessons, the topic being introduced in the first lesson being the one that introduced given more intensive treatment in the ensuing; it was also necessary to obtain a range of questions and discourse patterns that were directly influenced by the goals and continuity of the lesson. Each lesson was forty-five minutes long and was fully transcribed in the following way: it was divided into one-minute segments and everything stated during that time interval was written down, with the speaker—teacher or student—identified. When more than one student took part in the discourse, the remarks of each were marked in different colors for differentiation purposes.

For every lesson, the words enunciated by each teacher and their students were counted; we calculated the average number of words said by each teacher and their students over the course of three or four lessons. The total number of words in a lesson ranged from approximately 3,000 to 5,000. Disciplinary remarks or procedural words were not counted; only words related to the content taught were included. In addition, we examined how many minutes of classroom time involved student discussion; this allowed us to determine how continual the students’ speaking was.

In addition, we analyzed the discourse episodes that took place in each lesson. We defined a discourse episode as a speech event between the teacher and one or more students or between two or more students, associated with the topic taught. The discourse episodes identified are familiar and recurrent in most classes (Leinhardt & Steele, 2005). An episode may be one that exhibits the IRE pattern, i.e., a very brief episode in which, for example, a student asks a clarification question and the teacher answers and then immediately goes back to teaching; or a more protracted episode in which different students are involved in discourse. An episode was identified and counted when the dialogic or multi-participant discourse ended and the teacher continued to teach the topic at hand. The next episode related to a different topic or appeared after a lengthy spell—at least five minutes—in which only the teacher spoke. In fact, most classroom discourse episodes were differentiated from each other because they dealt with different subtopics. Different episodes in the flow of a lesson were usually separated into speaking by a teacher or a student about a new subtopic because the teachers hardly ever spoke uninterruptedly for five minutes. An episode usually appeared after a teacher or a student asked a question; a discourse—almost always brief—was conducted about it, and an answer was given. Additional questions about the same aspect or flowing from it, if any, were included in the same episode, which was numbered as a single episode. If, however, the teacher began to explain a new aspect of the topic, asked questions about the new aspect, and a discourse evolved again, this discourse was counted as an additional episode.

Each discourse episode was analyzed on the basis of two criteria: who initiated it—teacher or student—and the pattern of discourse (Scott, Philip H. et al., 2006): a three-stage IRE sequence or a multi-stage pattern that comprised a chain of interactions or involved several students. We categorized the first pattern of discourse as closed, and defined all other episodes as open. We subjected the open discourse episodes to an additional analysis in order to distinguish between those in which only one or two students participated and those in which two or three students took part and that lasted more than thirty seconds. We categorized the latter as multi-participant open discourse episodes. There were dozens of discourse episodes in each lesson; we analyzed 373 episodes altogether. Again, it is important to stress that only discourse episodes associated with the content of the lesson were counted and analyzed.

As most of the classroom discourse episodes were outgrowths of questions and based on questions, we analyzed all questions in each lesson in order to check the frequency of all teacher questions and student questions and to define each question by type. To determine the types of questions, we used the taxonomy of De Jesus Pedrosa et al. (2003), who divided questions into two main groups: confirmation questions, meant to clarify, define, and explain information, and transformation questions, high-order thinking questions that blend comprehension and reconstruction of knowledge. Altogether, we analyzed 1,892 questions—912 confirmation and 980 transformation questions. Each of the two authors sorted the questions separately; afterwards, we compared the outcomes. An 85 percent fit was found between the sortings, and we discussed the others until we attained consensus.

To check variance among the classes in respect of the various parameters, we ran a one-way analysis of variance (ANOVA) with three categories (low, high, medium). We then ran a post-hoc analysis to determine whether a statistically significant effect existed among any of the five classes, using a Duncan adjustment for multiple testing.

Finding

Classroom discourse episodes

The analysis of discourse episodes in each class is summarized in Table 3. Although the classes were quite different, we found, to our surprise, strong similarity in several parameters of the classroom discourse. For example, despite the differences among the classes in students’ background and age, type of school, topic of study, gender, teacher’s seniority, and other characteristics, we found no statistically significant difference in the number of words that students in the various classes uttered and the average number of discourse episodes per class. All five classes engaged in lively discourse, with 18–26 discourse episodes in each class on average.

Table 3: *Analysis* *of Classroom* *Discourse Episodes*

|  |  |
| --- | --- |
| Discourse episodes | *Mean (SD)* |
| Ger | Shem | Adi | Nur | Asaf | *f* | *Sig.* |
| Total student words | 796.75(512.62) | 1225.33(337.06) | 1401.25(1489.62) | 922.00(465.15) | 1407.33(292.76) | .41 | .80 |
| Total teacher words | a2313.75(452.43) | b3740.67(279.19) | b3391.75(367.79) | a2192.33(591.76) | a2359.00(468.89) | \*\*8.67 | .002 |
| Total discourse episodes | 20.00(4.55) | 24.00(2.65) | 22.00(9.49) | 18.00(5.57) | 26.33(4.51) | .88 | .50 |
| Closed discourse episodes  | 9.50(2.65) | 8.33(1.53) | 13.50(13.48) | 12.00(4.00) | 10.00(4.31) | .28 | .88 |
| Open discourse episodes | a,b10.50(3.00) | b15.67(3.05) | a,b8.50(8.74) | a6.00(1.73) | b16.33(1.53) | \*2.68 | .056 |
| Open multi-participant discourse | 2.50(.57) | 4.67(1.53) | 2.25(2.87) | 1.33(1.15) | 3.00(1.00) | 1.58 | .24 |
| Teacher-initiated discourse | 11.75(.96) | 10.33(.58) | 13.75(6.60) | 16.00(4.0) | 12.67(2.08) | .98 | .46 |
| Teacher-initiated closed discourse | 4.25(1.50) | 1.67(.58) | 8.25(9.60) | 10.00(2.67) | 2.33(1.53) | 1.70 | .21 |
| Teacher-initiated open discourse | a,b7.50(2.38) | a,b8.67(1.15) | a5.50(4.04) | a,b6.00(1.73) | b11.33(.58) | \*2.43 | .057 |
| Student-initiated discourse | a,b8.25(4.19) | b13.67(2.31) | a,b8.25(5.68) | a2.00(1.73) | b13.67(3.21) | \*4.53 | .018 |
| Student-initiated closed discourse | 5.50(3.11) | 6.67(1.15) | 5.25(4.99) | 2.00(1.73) | 7.67(3.05) | 1.26 | .34 |
| Student-initiated open discourse | a,b2.75(1.26) | b7.00(2.00) | a,b3.00(4.76) | a.00(.00) | b6.00(1.73) | \*3.29 | .049 |

Post-hoc tests—homogeneous subsets by Duncan: a=Low Mean; b=High Mean; a,b=Medium Mean

In addition, despite perceptible differences among the classes in the average number of closed discourse episodes initiated by teacher or students, the differences were not found to be significant. The episodes were brief, at three to five seconds. Below are two examples of closed discourse episodes, one initiated by the teacher and another by a student:

1. Teacher: What’s your question?

Student: Why did you do “mg” for this one only?

Teacher: I did a sigma-F, summarizing forces; these are my equations. As always with this type of question, we’ll add up the forces and solve two equations with two unknowns (Ger, Lesson three).

1. Student: Why is this magnitude on the Y-axis and not on the X-axis? It’s as though….

Teacher: You can call it X. It doesn’t matter, you can call it what you like; the definition of the X-axis is arbitrary. It’s dependent on us (Adi, Lesson two).

In contrast to the closed discourse, we found statistically significant differences among the classes in open discourse episodes. Asaf’s and Shem’s classes led the way, with a high average of 16 open episodes per class. Ger’s and Adi’s classes, in contrast, were in the middle with eight to ten episodes, significantly different from the first two classes mentioned and from Nur’s class in which only six episodes were counted (Table 3). Similarly, there were statistically significant differences among the classes as to the initiator of the open discourse: teacher or student. Asaf initiated more open discourse episodes than did the other teachers, and Adi initiated the fewest, by a statistically significant margin. The students in Asaf’s class also initiated more open discourse.

Most open discourse episodes, among all teachers, were typified by strong teacher dominance as the teacher integrated the students’ responses into his or her remarks in order to move the discussion along. As an example, part of an open discourse episode in Asaf’s class is presented below:

Teacher: Who can explain what we’re seeing here?

Student A: A reflection….

Teacher: What do you mean by “a reflection”?

Student B: What we’re seeing here is the image of the track….

Teacher: OK. We’re really seeing the laser, but there’s something strange here: in fact, the laser is trapped.

Student B: It’s cut off at the point where….

Student C: Every time it touches the water.

Student B: No, like every time it touches the color.

Teacher: When it comes out of the water?

Student D: Yes, when it comes out of the water.

Student B: It breaks up below and then the mirror… aha….

Teacher: And then it hits the color of the water, right?

Student C: Yes….

Teacher: And then it actually comes back. Look at it from overhead. You really see the mirror, okay? How can this happen? What phenomenon is actually taking place here?

Student E: Refraction?

Teacher: It’s refraction but there’s something more than that.

(The debate continued in this manner for an additional four seconds) (Asaf, Lesson three).

The large majority of open discourse episodes, among all teachers, were rather short—less than thirty seconds—and only one or two students took part in them. Despite this brevity, such episodes were classified as open and not as closed because they included high-order thinking questions that were not answered immediately and because an attempt was made to encourage thinking and comprehension. There were few open discourse episodes, among any of the teachers, that lasted more than thirty seconds and that included three or more students; furthermore, we found no significant differences among the teachers in the number of multi-participant open discourse episodes. Multi-participant episodes in which students led the discussion and the teacher was not heavily involved were especially rare. An example of part of such an episode, initiated by Adi, is presented below. The full episode lasted about three minutes:

Teacher: What’s the potential difference between point A and point B in the circuit?

Student A: I want to solve it! Okay, so I said that the difference, like it comes out to 12. So from the whole right-hand side I get 12 and then I said that the voltage falls on the same split twice and then the same voltage falls, so….

Student B: But who told you that every resistor consumes exactly 2 ohms?

Student A: No one told me.

Student B: Why isn’t there any voltage here?

Student A: I say there’s 12 here, up to here, and here there’s zero, up to here and then something here falls.

Student C: An open circuit! There’s no voltage!

Student A: So what? And here it’s, like, not supposed to consume voltage?

(Several students express disapproval in unison)

Student C: But what’s the voltage?

Student A: There’s no voltage! There’s no voltage!

Student C: Why is there no voltage?

Student A: If there’s no current, there’s no voltage!

Student C: So what have we got here?

Student A: Nothing! *Nada! Gurnisht!*

Student D: But there you don’t do it that way!

Student A: That’s right. There’s no voltage because there’s no difference. But there’s a potential here!

Student D: There’s no potential here!

Student E: There’s a potential because it fell twice….

The discussion continued in this manner, with two additional students joining. Forty-five seconds later, the teacher participated in the discourse:

Teacher (turning to Student A): You explained something. It’s not perfect and I want to understand….

Student A: The voltage between this point and that point is six, and the voltage between the other two is six! Here it’s zero….

Student B (turning to Student A): But I want to tell you two things. First, how do you know it’s six? That answer isn’t perfect. Second, it’s not if I have….

Student F: X divided by two VR.

Student A: What’s that got to do with it? We have to calculate on the basis of R! On the resistor itself!

The lively debate continued tumultuously for another thirteen seconds, than the teacher tried to impose order on the discussion and summarized it by endorsing Student A’s response:

Teacher: I’ll continue to run the discussion in some manner (the students laugh)…. Voltage is a difference of potentials. Potential is a trait in which it’s the same along the same conductor. So Dina [Student A—an alias] did it right here: Along the same conductor, there’s the same potential. (Adi, Lesson 3)

In the part of the discourse episode presented above, six students participated and the teacher largely stayed out, allowing the students to conduct most of the discussion. As stated, lengthy discourse episodes were uncommon and, in fact, occurred only in Adi’s class. In most discourse episodes in all classes, short and open alike, the students’ statements were very brief and were often cut short by other students or by the teacher. Hardly any time to think or rephrase was given; the discussion proceeded very rapidly.

Characteristics of questions in class

The analysis of the characteristics of questions in each class is summarized in Table 4. In all five classes, the total number of questions was very large; plainly it was the questions that led to the classroom discourse. Teachers asked more than 60 questions per lesson on average; students asked 20–50 questions.

As in the discourse episodes, we found similarity among the classes in terms of the questions asked in the classroom. We expected the variance in the teachers’ and students’ characteristics to cause differences in the characteristics of the questions asked in class. However, we found no significant differences among the classes in the total number of questions and the number of questions asked by teachers and students in each class. We also found no significant differences among the classes in the total number of confirmation questions asked in class. As stated, confirmation questions are lower-order thinking questions that are meant to clarify or examine existing knowledge. An example follows:

Teacher: I’m going to do normal less W. This minus [sign]: what does it signify?

Student: The direction.

Teacher: The direction, that’s exactly right (Ger, Lesson four).

However, the questions were not similar in all of their characteristics. When we segmented the questions by types, we found significant differences among the classes in the total number of transformation questions. While many such questions were asked in Asaf’s class, it is important to note the proliferation of questions of this type in four of the five classes: between 60 and 80 per lesson! In Adi’s, Asaf’s and Ger’s classes, they even outnumbered confirmation questions (Table 4).

Table 4: *Characteristics* *of* *Questions* *in Classroom Discourse*

|  |  |
| --- | --- |
| Questions | *Mean (SD)* |
| Ger | Shem | Adi | Nur | Asaf | *f* | *Sig.* |
| Total questions | 110.50(19.33) | 118.67(25.38) | 116.25(39.70) | 79.00(22.07) | 130.33(26.27) | 1.42 | .29 |
| Total teacher questions  | 91.50(27.23) | 68.33(17.79) | 63.00(17.51) | 61.00(26.21) | 72.00(34.87) | .89 | .49 |
| Total student questions | 19.00(13.19) | 50.33(12.05) | 53.25(49.47) | 18.00(5.57) | 58.33(34.79) | 1.48 | .27 |
| Confirmation questions | 51.75(17.65) | 61.00(13.11) | 48.50(26.04) | 58.00(34.87) | 51.33(30.02) | .14 | .96 |
| Transformation questions | a,b58.75(27.44) | a,b57.67(12.72) | a,b67.75(17.35) | a21.33(12.17) | b79.00(18.74) | \*2.75 | .055 |
| Teacher confirmation questions | b38.75(21.36) | a,b26.67(2.08) | a15.75(2.22) | a16.67(4.51) | a10.33(10.97) | \*3.29 | .049 |
| Teacher transformation questions  | b52.75(23.12) | a,b41.67(19.55) | a,b47.25(15.43) | a21.00(12.53) | b63.77 (22.50) | \*2.85 | .052 |
| Student confirmation questions | 13.00(8.92) | 34.33(11.06) | 32.75(17.22) | 13.67(8.50) | 41.00(22.38) | 1.34 | .31 |
| Student transformation questions | 6.00(5.03) | 16.00(13.59) | 20.50(22.81) | 1.67(1.53) | 17.33(2.52) | 1.31 | .32 |

Post Hoc Tests - Homogeneous Subsets by Duncan: a=Low Mean; b=High Mean; a,b=Medium Mean

Transformation questions elicit higher-order thinking. Generally speaking, they lend themselves to more than one correct answer, encourage thinking, and may abet the creation of a fruitful discourse. For example:

Teacher: Everyone’s heard that you can burn ants using a magnifying glass. Is it true? If so, how does it happen? (Asaf, Lesson four).

When we segmented the questions by their initiator—teacher or student—again we found significant differences among the teachers in the number of transformation and confirmation questions that they asked. Asaf and Ger asked significantly more transformation questions than did the other teachers. In contrast to the teachers, we found no statistically significant differences among students in different classes in the confirmation and transformation questions that they asked. Importantly, however, the average number of students’ questions varied widely. For example, Asaf’s students asked approximately 40 transformation questions on average in each lesson, whereas Nur’s and Gar’s students asked only 13 (Table 4). The large standard deviations in this parameter are indicative of sizable differences among lessons in the same class, which contributed to the lack of statistical significance.

**Discussion**

The underlying hypothesis in this study is that classroom discourse plays a meaningful role in students’ learning and comprehension processes. The goal of the study was to produce a profile of the discourse in five different physics classes.

The commonalities among all five classes that we investigated were that all students elected to take physics, the teachers had the education and training to teach the subject, and they engaged in traditional frontal teaching in an ordinary classroom (as opposed to a laboratory). In other characteristics, there were differences: teacher characteristics such as gender, age, and teaching experience; student characteristics such as, gender, age, class size, socioeconomic status; type of school (religious / non-religious); and topics of study. Since these factors can influence the classroom discourse (Shodell, 1995), we hypothesized that many discursive characteristics that we encountered in each class would be unique and typical to that class. The similarities that we found among the classes in various parameters are thought-provoking; they indicate that all five teachers had a similar teaching approach. Topics in physics are considered complex, hard to understand, and entailing abstract thinking. If a similar teaching approach is used despite the many differences among the teachers, it may indicate that the characteristics of the discipline itself, and the way the teachers perceive optimal teaching of the subject, have a powerful effect on the way they teach, as manifested in the patterns of the classroom discourse.

In all five classes, the discourse was lively and uninterrupted for almost the full duration of the lesson. In almost every minute of the lesson, in each of the seventeen lessons analyzed, at least one student in addition to the teacher spoke. Students participated in the discourse continually and teachers did not tend toward lengthy monologues. We found, on average, around 20 discourse episodes per lesson, and in each class that we investigated it was evident that the students spoke willingly amid mutual trust and respect. Their uninterrupted involvement in lessons should not be take for granted; it clashes with studies showing that teaching remains largely monologic—teachers talking and students listening (Alexander, 2008; Cazden, 2008; Nystrand et al., 2003).

We found, as expected, that teachers talked much more than students during the lesson. This, however, does not mean that one teacher who spoke more than another teacher was necessarily more dominant. Adi and Shem, for example, spoke much more than Nur did but allowed their students to initiate more discourse episodes than did Nur. Most discourse in all classes followed a question-and-answer pattern. The large number of questions asked by teachers—more than 60 per lesson on average—and by students yielded inexorably dynamic and rapid discourse in all classes. Our analysis of the types of questions showed that students in all classes primarily asked confirmation questions, whereas most questions put forward by teachers were transformational. This finding contradicts other findings showing that higher-order thinking questions appear very infrequently in class, notwithstanding their immense importance (Nystrand, 1997; Zohar, 2004).

By eliciting higher-order thinking, transformation questions encourage students to think independently and abet the development of open discourse episodes. Still, it is important to emphasize the indubitable need for confirmation questions. These questions, most of which yield short answers, focus attention on the topic of the lesson and are important in developing links between previous material and discussion of a new topic (Scott et al., 2006). In addition, the answers to these questions were terse and focused; often they induced correct answers. This may give students a sense of self-capacity and success. However, when teachers base most of classroom discourse on confirmation questions, they present less of a challenge to students’ thinking, keep the discussion from broadening, and crimp open discourse. Furthermore, this kind of teacher conduct may deny students encouragement to cope with difficulties and engage in lengthy inquiries, possibly precluding students’ more creative use of the language in which they express their opinions and ask questions (Mercer, 2008). Teachers who overuse these questions give evidence of their perception of teaching as its being the student’s job to memorize information and retrieve it from memory when needed (Nystrand et al., 2003). Thus, the teachers in our study who asked numerous transformation questions along with confirmation questions seem to have a more participatory and dialogic outlook on teaching.

The most important differences that we found among the teachers in the characteristics of classroom discourse concern the number of transformation questions that they asked and the number of open discourse episodes that they or their students initiated. These are prime indicators of dialogic teaching and learning based on open and fruitful discourse. Dialogic learning generates a different kind of encounter between the teacher, the students, and the scholastic material; it even has a material effect on conceptual understanding (Mercer & Littleton; Scott, 2008). Among the teachers, Asaf and Shem were those who treated closed discourse with particular paucity and initiated much more discourse of the open type.

However, even in Asaf’s class, where the largest number of transformation questions was asked, the use of IRE sequences was minimized, and open discourse episodes were the most common, we found that most discourse episodes lasted a few seconds and did not evolve into probing discussion, and that only one or two students took part. Among all teachers, in fact, few discourse episodes lasted more than thirty seconds and had more than two student participants. That is to say, even though the teachers asked higher-order thinking questions, the potential of these questions, which encourage deep thought and discussion, was not put to proper use. Namely, it is the physics teachers’ reasoning, generally speaking, students should always be challenged with questions in order to enhance their involvement in the learning process and to elicit their feedback about what they understand. Immediate feedback from the students in every minute of the lesson, however, precludes the development of a deep discourse that would verify meaningful understanding. This teaching method is indicative of a perception of teaching that sees learning science as something that should be based on mastering knowledge and remembering facts.

When students are “bombarded” with questions and are not given reasonable time to think, deep discussion cannot develop. When this happens, students concentrate on seeking the right answers to the teacher’s questions and not on more thorough examination of their thoughts. This kind of discourse is merely an ostensible dialogue or a monologue in disguise, in which the text that evolves in the dialogue is not a joint product of the students and the teacher.

Rowe (1974) emphasizes the importance of wait-time that passes between the teacher’s presenting an answer [asking a question?] and receiving an answer for the development of logical thinking. Prolonging the wait-time enhances students’ self-confidence, prompts more students to dare to take part in the classroom discourse and ask questions, and creates more interactions among students. After appropriate training, Rowe says, teachers can prolong their wait-times after asking questions and, in turn, may reduce the number of questions considerably.

Indeed, it seems that one possible reason for the superficiality of discussion that typified most discourses in all classes is that even though teachers asked open-ended questions, they expected one correct answer and thus squandered the opportunity to elicit thinking and encourage additional students to contribute to the debate. Therefore, even an open-ended question may become a closed-ended one, as Cazden (2008) claims, because students are used to the existence of one correct answer. Most teacher-initiated open discourse episodes in the classes that we studied flowed from a transformation question. In practice, however, the teachers limited the discourse by providing the answers themselves, thus forfeiting opportunities to develop discussion. Accordingly, these discourse episodes did not blossom into high-quality discourse.

Another reason for the superficiality of classroom discourse is the heavy burden of material that teachers are required to teach. In the sciences, physics in particular, teachers have to cover many topics within a given time—a problem that stands out particularly in matriculation classes. The sheer quantity of information that teachers must present makes rapid-fire teaching unavoidable. Teachers cut discussions short, give answers themselves, and leave insufficient time for thinking and more meaningful learning.

In sum, one may say that most discourse in all classes was lively and continual, not lecture-like but also not dialogic. It was typified by a constant flow of questions and answers and superficial, brief discussion. The teachers strove to involve the students asked diverse questions but too many, and the discourse episodes were too short and too numerous to induce meaningful discussions and deep thinking.

It is important to emphasize that although teachers face onerous pressure to present copious material rapidly, the students in almost all classes that we analyzed were continually involved and active, and the teachers generated interest and collaboration as they taught. Obviously, one cannot make a broad generalization on the basis of an analysis of five teachers’ lessons, particularly since only five of the thirty teachers whom we approached agreed to divulge their classes’ doings and have their lessons recorded. Even after we assured them that their names and those of their schools would stay confidential, most of the teachers remained apprehensive. Those who did agree to participate in the study were the ones who had strong self-esteem, were confident about their teaching, and enjoyed their colleagues’ appreciation. Therefore, the extent to which they are representative of the norm is even less clear. One presumes that discourse in classes run by less self-assured teachers would typically be more monologic than that found in this study.

Another limitation of the study was the confinement of our analysis to classroom discourse in frontal whole- class lessons. Presumably, an analysis of classroom discourse in laboratory lessons would yield a different and broader depiction of the traits of discourse in all physics lessons.

It is important to re-emphasize the complexity of the classroom discourse and the importance of characterizing it across a continuum from closed to dialogic. A discourse cannot be totally closed or dialogic; its nature varies in accordance with the goals of the lesson. Thus, a lesson meant to give background or summarize information, for example, will be more closed and monologic than would be one that centers on discussion of meaning and interpretation, which may yield a more dialogic discourse (Mortimer & Scott, 2003). In this study, three or four successive lessons of each teacher were examined, the first lesson devoted to introduction of the topic at hand and the subsequent lessons giving the topic broader and deeper attention. Our analysis of successive lessons allowed us to produce averages and obtain a general picture of the discourse in each class. In continuing research, we intend to do an in-depth analysis of each discourse episode in the direct context of the content and goal of the lesson, taking the investigation of classroom discourse to an additional level.

In conclusion, this study sheds light on the characteristics of discourse in physics lessons. Enhancing awareness of the nature and quality of classroom discourse may promote better learning. Greater emphasis on dialogic discourse may improve classroom discourse and abet the construction of knowledge and effective learning. Therefore, it is worth contemplating ways to facilitate dialogic discourse specifically in subjects such as physics—challenging subjects that are rich in abstract information and concepts.

**References**

Alexander, R. (2008). *Towards dialogic teaching: Rethinking classroom talk (4th ed.)*. Cambridge: Dialogos.

Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., . . . Wittrock, M. C. (2001). A taxonomy for learning, teaching, and assessing: A revision of bloom’s taxonomy of educational objectives, abridged edition. *White Plains, NY: Longman,*

Barnes, D. (2010). Why talk is important. *English Teaching: Practice and Critique, 9*(2), 7-10.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of Educational Objetives: The Classification of Educational Goals: Handbook I: Cognitive Domain,*

Bransford, J., Brown, A., & Cocking, R. (2000). How people learn: Brain, mind, experience and school. washington, DC: Commission on behavioral and social sciences and education, national research council.

Cazden, C. (2008). Reflections on the study of classroom talk. *Exploring Talk in School,* , 151-166.

Chin, C., & Brown, D. E. (2002). Student-generated questions: A meaningful aspect of learning in science. *International Journal of Science Education, 24*(5), 521-549.

Chin, C., & Kayalvizhi, G. (2005). What do pupils think of open science investigations? A study of singaporean primary 6 pupils. *Educational Research, 47*(1), 107-126.

Chin, C., & Osborne, J. (2008). Students' questions: A potential resource for teaching and learning science. *Studies in Science Education, 44*(1), 1-39. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/222853779?accountid=41238>

Christodoulou, A., & Osborne, J. (2014). The science classroom as a site of epistemic talk: A case study of a teacher's attempts to teach science based on argument. *Journal of Research in Science Teaching, 51*(10), 1275-1300. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/1651835963?accountid=41238>

De Jesus, H. P., Teixeira-Dias, J. J., & Watts, M. (2003). Questions of chemistry. *International Journal of Science Education, 25*(8), 1015-1034.

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*(6), 671-688.

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38*, 39-72. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/62206672?accountid=41238>

Ford, M. J., & Wargo, B. M. (2012). Dialogic framing of scientific content for conceptual and epistemic understanding. *Science Education, 96*(3), 369-391. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/1312424101?accountid=41238>

Furtak, E. M., & Ruiz-Primo, M. A. (2008). Making students' thinking explicit in writing and discussion: An analysis of formative assessment prompts. *Science Education, 92*(5), 799-824. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/61991489?accountid=41238>

Galton, M., Hargreaves, L., Comber, C., Wall, D., & Pell, T. (1999). Changes in patterns of teacher interaction in primary classrooms: 1976‐96. *British Educational Research Journal, 25*(1), 23-37.

Gamoran, A., & Nystrand, M. (1991). Background and instructional effects on achievement in eighth-grade english and social studies.*Journal of Research on Adolescence, 1*(3), 277-300.

Goodlad, J. I. (1983). What some schools and classrooms teach. *Educational Leadership, 40*(7), 8-19.

Hogstrom, P., Ottander, C., & Benckert, S. (2010). Lab work and learning in secondary school chemistry: The importance of teacher and student interaction. *Research in Science Education, 40*(4), 505-523. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/754905460?accountid=41238>

Howe, C., Tolmie, A., Thurston, A., Topping, K., Christie, D., Livingston, K., . . . Donaldson, C. (2007). Group work in elementary science: Towards organisational principles for supporting pupil learning. *Learning and Instruction, 17*(5), 549-563.

Kilpatrick, J. (2012). The new math as an international phenomenon. *Zdm, 44*(4), 563-571.

Kim, S., & Hand, B. (2015). An analysis of argumentation discourse patterns in elementary teachers' science classroom discussions. *Journal of Science Teacher Education, 26*(3), 221-236. doi:<http://dx.doi.org.mgs.hemdat.ac.il/10.1007/s10972-014-9416-x>

Leinhardt, G., & Steele, M. D. (2005). Seeing the complexity of standing to the side: Instructional dialogues. *Cognition and Instruction, 23*(1), 87-163.

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education, 94*(2), 203-229. Retrieved from <https://search.proquest.com/docview/742866488?accountid=41238>

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Havard University Press.

Mercer, N. (2008). The seeds of time: Why classroom dialogue needs a temporal analysis. *The Journal of the Learning Sciences, 17*(1), 33-59.

Mercer, N., & Dawes, L. (2008). The value of exploratory talk. *Exploring Talk in School,* , 55-71.

Mercer, N., Dawes, L., Wegerif, R., & Sams, C. (2004). Reasoning as a scientist: Ways of helping children to use language to learn science. *British Educational Research Journal, 30*(3), 359-377.

Mercer, N., & Littleton, K. (2007). *Dialogue and the development of children's thinking: A sociocultural approach* Routledge.

Mercer, N., & Sams, C. (2006). Teaching children how to use language to solve maths problems. *Language and Education, 20*(6), 507-528.

Middlecamp, C. H., & Nickel, A. L. (2005). Doing science and asking questions II: An exercise that generates questions. *Journal of Chemical Education, 82*(8), 1181.

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Maidenhead, UK: Open University Press.

Nussbaum, M. E., & Edwards, O. V. (2011). Critical questions and argument stratagems: A framework for enhancing and analyzing students' reasoning practices. *Journal of the Learning Sciences, 20*(3), 443-488. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/889924550?accountid=41238>

Nystrand, M. (1997). *Opening dialogue: Understanding the dynamics of language and learning in the english classroom. language and literacy series.* ERIC.

Nystrand, M., Wu, L. L., Gamoran, A., Zeiser, S., & Long, D. A. (2003). Questions in time: Investigating the structure and dynamics of unfolding classroom discourse. *Discourse Processes, 35*(2), 135-198.

Pimentel, D. S., & McNeill, K. L. (2013). Conducting talk in secondary science classrooms: Investigating instructional moves and teachers' beliefs. *Science Education, 97*(3), 367. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/1328436790?accountid=41238>

Polman, J. L., & Pea, R. D. (2001). Transformative communication as a cultural tool for guiding inquiry science. *Science Education, 85*(3), 223-238.

Rojas-Drummond, S., & Mercer, N. (2004). Scaffolding the development of effective

collaboration and learning. *International Journal of Educational Research,* 39, 99-111.

Reiser, B., Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). Taking science to school: Learning and teaching science in grades K-8. committee on science learning, kindergarten through 8th grade: National research council, board on science education, division of behavioral and social sciences and education.

Rowe, M. B. (1974). Wait-time and rewards as instructional variables, their influence on language, logic, and fate control: part one--Wait-time. *Journal of Research in Science Teaching, 11*(2), 81-94

Roychoudhury, A., & Roth, W. -. (1996). Interactions in an open-inquiry physics laboratory. *International Journal of Science Education, 18*(4), 423-445.

Ruthven, K., Mercer, N., Taber, K. S., Guardia, P., Hofmann, R., Ilie, S., . . . Riga, F. (2017). A research-informed dialogic-teaching approach to early secondary school mathematics and science: The pedagogical design and field trial of the epiSTEMe intervention. *ReseaRch PaPeRs in Education, 32*(1), 18-40.

Scott, P. (2008). Talking a way to understanding in science classrooms. *Exploring Talk in School,* 17-36.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*(4), 605-631. Retrieved from <https://search-proquest-com.mgs.hemdat.ac.il/docview/62035673?accountid=41238>

Shodell, M. (1995) The question-driven classroom. *The American Biology Teacher 57*(5): 278-281.

Tanner, H., Jones, S., Kennewell, S., & Beauchamp, G. (2005). Interactive whole class teaching and interactive white boards. Paper presented at the *Building Connections: Research, Theory and Practice, Proceedings of the 28th Annual Conference of the Mathematics Education Research Group of Australasia,* 720-727.

Thompson, J., Hagenah, S., Kang, H., Stroupe, D., Braaten, M., Colley, C., & Windschitl, M. (2016). Rigor and responsiveness in classroom activity. *Teachers College Record,*

Watts, M., Gould, G., & Alsop, S. (1997). Questions of understanding: Categorising pupils' questions in science. *School Science Review, 79*(286), 57-63.

Wells, G. (1999). *Dialogic inquiry: Towards a socio-cultural practice and theory of education* Cambridge University Press.

Zohar, A. (2004). *Higher order thinking in science classrooms: Students’ learning and teachers’ professional development* Springer Science & Business Media.