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One-on-one and Small Group Conversations With an Intelligent Virtual Science Tutor

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Abstract

In this study we investigated students' conversations with a virtual science tutor (Marni), either individually or in small groups. These constituted two treatment conditions. Students were presented with narrated multimedia science problems and explanations followed by question-answer dialogs with the virtual tutor. Students who received either one-on-one or small group tutoring received the same set of multimedia presentations and questions posed by the virtual tutor. Students in the small group condition discussed their answer before one student from that group responded to the tutor. We asked if students receiving tutoring using the virtual tutor in groups would demonstrate learning gains equivalent to those of students receiving one-on-one tutoring. We also asked if both groups would demonstrate greater learning gains from pretest to posttest than students in business-as-usual (control) classrooms who did not receive supplemental tutoring. One hundred eighty-three (183) students (in 13 classrooms at 4 schools) participated in the study. Of the 183 students, 114 were randomly assigned to tutoring in small groups using Marni; and 69 students received one-on-one tutoring with Marni. When compared with the control group, effect sizes for were d *= 0.61 for the group tutoring condition and* d *= 0.63 for the one-on-one tutoring condition. A two-way ANOVA suggested a main effect for tutoring group,* F *= 16.8, d*f *(4,1171),* p *< 0.001. In general, students reported benefiting from listening to one another, and from the small group interactions, even though they sometimes disagreed with the answer reported by the small group. We conclude our findings with a vision for a next generation of virtual, science tutors that can facilitate discourse and argumentation among students in small groups, leading students to build on each other's ideas to construction accurate science explanations.*

Keywords: virtual, tutoring, intelligent, learning, student, multimedia

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Highlights

- The lack of discourse in U.S. classrooms is puzzling given compelling evidence that effective programs exist in which teachers engage students in discourse, which in turn leads to significant gains in student motivation and learning.
- My Science Tutor (MyST) is an intelligent tutoring system that engages students in conversations with a virtual science tutor, leading to learning gains comparable to expert human tutors.
- Students in one condition engaged in a series of one-on-one tutoring sessions with a virtual science tutor, Marni. Following the multimedia presentations, Marni engaged students in question-answer interactive dialogs, during which students constructed explanations in response to Marni's questions. Students in a second condition interacted with Marni in small groups (2 - 4 students).
- Students in both one-on-one and small group conditions were presented with a problem scenario, and then a solution to the problem. These sessions coherently presented science content with follow-up discussions, questioning, and explanations. The learning gains reported in this investigation were similar to those observed in previous investigations.
- Students reported that they enjoyed arguing with their peers, believed they achieved a deeper understanding of the science as a result of the discussions, even though most students reported they sometimes disagreed with the answer presented to the virtual tutor following the discussion.

1. Introduction

In this article, we describe a project in which we developed and evaluated a program to help students gain proficiency in scientific discourse leading to improved science achievement. Helping students learn how to engage in scientific discourse and argumentation has become a major focus of science education in the U.S. An influential report, *Taking Science to School: Learning and Teaching Science in grades K–8* (National Research Council, 2007), used evidence on child development and learning, advocating for four strands of scientific proficiency for all students. Specifically, they noted that "Students who understand science 1. know, use, and interpret scientific explanations of the natural world; 2. generate and evaluate scientific evidence and explanations; 3. understand the nature and development of scientific knowledge; and 4. participate productively in scientific practices and discourse" (pg. 2).

Our study was designed to a) engage students in one-on-one conversations with a virtual science tutor, and b) engage students in small groups in conversations stimulated by questions posed by a virtual tutor. In both groups, students were presented with a set of narrated multimedia science presentations, and engaged in conversations about the science. We hypothesized that students who received either one-on-one or small group tutoring sessions with a virtual tutor would demonstrate greater science learning gains than students who received similar classroom instruction, but did not engage in one-on-one or small group tutoring sessions.

The article is organized as follows. Section 1 provides an introduction to, overview of, and scientific rationale for the study. Section 2 describes the two experimental conditions used in the 3rd, 4th and 5th grade classrooms, then presents and briefly summarizes the results. Section 3 discusses these results; Section 4 identifies and describes the main conclusions from the investigation, and briefly describes implications for future work.

1.1 Overview of the Study

Students participated in this study in one of two conditions. Students in one condition engaged in a series of one-on-one tutoring sessions with a virtual science tutor, Marni. In these sessions, Marni asked each student questions about science presented in narrated multimedia presentations, including follow-on questions designed to stimulate students' reasoning about the science and construct accurate explanations. Students in a second condition interacted with Marni in small groups, of 2 – 4 students. Students in small groups received the same multimedia presentations individually, but were asked to discuss the questions with the other students in their group before the student in control of the microphone during the session provided Marni with a spoken response to her question. We asked students in each condition about their learning experiences, and compared learning gains of students in each condition to students in business-as-usual (control) classrooms. These control classrooms received similar classroom instruction to treatment students, but did not receive supplemental tutoring with Marni. Our main research questions were:

1. Would students in both one-on-one and group conditions achieve significant and equivalent learning gains relative to students in control classrooms who did not receive tutoring?
2. Would students in small groups engage in meaningful discourse and argumentation, and report that those discussions were beneficial?

1.2. Scientific Foundations

1.1.1 Theory and Research on Scientific Discourse and Argumentation

Historically, research in argumentation and collaborative discourse has acknowledged the strong influences of the theories of Vygotsky (1978, 1987) and Bakhtin (1975, 1986), who argued that all learning occurs in and is shaped by the social, cultural, and linguistic contexts in which they occur. Roth (2013, 2014) provided an excellent integration of Vygotsky's and Bakhtin's theories and their relevance to research on collaborative discourse. He argued that, when considered in the context of these theories, "currently available analyses of science classroom talk do not appear to exhibit sufficient appreciation of the fact that words, statements, and language are living phenomena, that is, they inherently change in speaking" (Roth, 2014, in online Abstract). The seminal writings of Vygotsky and Bakhtin have had a profound influence on subsequent research in discourse and argumentation, including Wells' (1997; 2000; 2008) research on dialogic inquiry. We embrace this emphasis as a main focus of this study in helping children become comfortable using words as they express, support, defend, reflect on, and modify their ideas during scientific discourse.

The past 25 years have witnessed remarkable growth in research on discourse and argumentation in education. Kuhn (1993, 2000) argued that "a conception of science as argument has become to be widely advocated as a frame for science education" (pg. 1). Support for argumentation has codified into both a reform movement and framework for science education. It is supported by growing evidence of substantial benefits of explicit instruction and practice on the quality of students' argumentation and learning (Chin & Osborne, 2010; Harris, McNeill, Lizotte, Marx, & Krajcik, 2006; Kulatunga & Lewis, 2013; Kulatunga, Moog, & Lewis, 2013; McNeill, 2011; Nussbaum, Sinatra, & Poliquin, 2008; Sampson, Grooms, & Walker, 2009; Schworm & Renkl, 2007; Simon, Erduran, & Osborne, 2006; Voss & Means, 1991). Evidence from these studies indicated that argumentation can be improved by providing professional development to teachers or knowledgeable students (Berland & Reiser, 2009; Bricker & Bell, 2008, 2014; de Jong, Linn, & Zacharia, 2013), this in turn explicitly teaches students the structure of good arguments, and provides students with scaffolds during argumentation that helps them produce evidence for their own arguments and critiquing others' arguments (e.g., Kulatunga & Lewis, 2013; Kulatunga et al., 2013).

Furthermore, there is strong evidence that having students communicate with each other about science concepts taught during classroom instruction improves learning. A classic study by Hake (1998) compared pretest vs. posttest performance of a diverse sample of over 6500 high school and college students on a standardized test of conceptual knowledge of physics in two conditions: *traditional classes* that involved lectures and little or no interaction among students, and *interactive classes* where teachers stopped their lectures to ask students to discuss questions. Students in interactive classes demonstrated 48% learning gains relative to 24% learning gains in classrooms where teachers lectured but did not ask questions.

Moreover, Black & Wiliam's (2009) synthesis of over 250 research studies indicated that administering formative assessments to students, and providing teachers and students with feedback on their performance, produced effect sizes 0.40 to 0.70 on standardized tests, relative to students in classrooms who were not administered formative assessments. Therefore, students

benefited from feedback on their understandings of the science they were learning, and teachers benefited from feedback that informed their instruction.

Also, a meta-analysis by Chi (2009) indicated that students whose instruction involves *interactive tasks* that included collaborative discourse and argumentation learned more than students whose learning involved *constructive tasks*, (e.g., classroom investigations and written reports), or *active tasks* (e.g., classroom science investigations). Two other studies investigated the impact of interactive instruction versus constructive, active, or passive instruction. Menekse, Stump, Krause, & Chi (2013) obtained strong evidence supporting their hypothesis; that is, interactive instruction led to higher scores on deep reasoning questions relative to constructive, active, or passive instructional methods.

In sum, despite the paucity of discourse in most classrooms, there is compelling evidence that when teachers are trained to initiate and manage classroom conversations in which students share, compare, and modify their ideas, those students and their teachers become more engaged and excited about learning, and overall student achievement improves.

1.1.2 Discourse in US Classrooms

Large-scale studies of discourse in U.S. classrooms have indicated that extended conversations, in which students do most of the talking, are rare (Nystrand & Gamoran, 1991). Over a period of 2 years, trained observers paid 4 visits to 58 8th grade and 54 9th grade English classes in parochial and public schools in rural, suburban and urban settings. The observers recorded the amount of time spent on different instructional activities, and recorded and coded over 23000 teacher and student questions to form a set of variables contrasting monologic and dialogic dialogs. Questions were coded for *authenticity* (a question was authentic if the answer was not known in advance by the asker) and *uptake* (previous answers were incorporated into new questions). The study found that "in virtually all classes, the teacher asked nearly all the questions; few about literature were authentic, and equally few followed up on student responses" (Nystrand, 1997, p. 44). Specifically, on average, there was less than 50 seconds of discussion per 8th grade class period and 20 seconds per 9th grade class period. Approximately 60% of all classes had no discussions; the single classroom with the most discussion averaged 2 minutes of it. Interestingly, there was a significant positive correlation between the amount of discourse in individual classrooms and student achievement in language arts. These were results were replicated in a second, large-scale study (Nystrand, Gamoran, Kachur, & Prendergast, 1997). Extended conversations about science are also rare in science classrooms; as Osborne (2010) noted, "argument and debate are common in science, yet they are virtually absent in science education" (online abstract).

This lack of discourse in U.S. classrooms is especially puzzling given compelling evidence that effective programs have been developed in which teachers engage students in discourse leading to significant gains in student motivation and learning (Murphy, Wilkinson, Soter, Hennessey, & Alexander, 2009; Soter et al., 2008). One of these programs, Questioning the Author (QtA) (Beck, Isabel, McKeown, & Margaret, 2006), was identified as likely to promote high-level thinking and comprehension of text. Relative to control conditions, QtA showed effect sizes of 0.63 on text comprehension measures, and of 2.50 on researcher-developed measures of critical thinking/reasoning (Murphy & Edwards, 2005). While QtA was originally developed as an intervention to facilitate classroom discourse, our research team worked with Margaret McKeown, one of the co-developers of the approach, to incorporate QtA dialog moves into

tutorial dialogs with a virtual tutor (details of how Marni uses QtA to facilitate tutorial dialogs with children are presented in Ward et al 2011; 2013).

1.3.1 Benefits of Individualized Instruction: Human Tutoring

Over three decades of research have indicated that learning is most effective when students receive individualized instruction, either one-on-one, or in small groups. Bloom (1984) summarized studies that reported 2 Sigma learning gains for students who received one-on-one or small group tutoring, relative to students who received regular classroom instruction. Evidence that tutoring works has been similarly obtained from dozens of well-designed research studies and meta- analyses (Cohen, Kulik, & Kulik, 1982) and positive outcomes were obtained in large-scale evaluations of specific tutoring programs (Slavin & Madden, 1989; Topping & Whiteley, 1990).

Factors that contributed to the effectiveness of individualized instruction, measured by gains in student achievement were associated with tutoring aligned with classroom instruction, asking students authentic questions, scaffolding learning with hints after questions, follow-on questions, and media designed to stimulate reasoning and help students' build on prior knowledge. These factors helped students continually generate explanations in response to deep reasoning questions (Butcher, 2006; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Craig, Gholson, Ventura, & Graesser, 2000; Driscoll et al., 2003; King, 1989; King, Staffieri, & Adelgais, 1998; Palinscar & Brown, 1984; Pine & Messer, 2000; Soter et al., 2008). Hausmann and VanLehn (2007) noted that: "explaining has consistently been shown to be effective in producing robust learning gains in the laboratory and in the classroom" (pg. 418).

1.3.2 Benefits of Individualized Instruction: Intelligent Tutoring Systems

Research in intelligent tutoring systems addresses a current, critical need to provide teachers and students with accessible, inexpensive, and reliably effective tools for improving young learners' interest and achievement. They enhance learning by providing students with individualized and adaptive instruction similar to that provided by an expert human tutor. Advances in Intelligent Tutoring System (ITSs) during the past 15 years have resulted products that have produce learning gains comparable to those achieved with human tutors. A recent review by Van Lehn (2011) compared learning gains in studies in which students received human tutoring or interacted with an ITS. They each participated in tasks that required students to engage in problem solving and constructing explanations. When compared to students who did not receive tutoring, the effect size of human tutoring across studies was d=0.79 whereas the effect size of ITSs was d=0.76. Van Lehn (2011) concluded that "intelligent tutoring systems are nearly as effective as human tutoring systems" (pg. 197).

1.3.3 Benefits of Spoken Dialogs between Children and a Virtual Science Tutor

My Science Tutor (MyST) is an intelligent tutoring system that engages students in conversations with a virtual science tutor, leading to learning gains comparable to those obtained with tutoring via expert human tutors (Ward et al., 2011, 2013). To our knowledge, MyST is the only system that currently supports spoken tutorial dialogs with children (aged 7 to 10). MyST dialogs are aligned with science concepts encountered in small-group, classroom science investigations, using the Full Option Science System (FOSS) program. FOSS is a kit- and inquiry-based program, used by over 1 million students in 100000 classrooms in the U.S. (FOSS, 2007). During evaluations of MyST, students engaged in conversations with the virtual tutor,

Marni, soon after they participated in classroom science investigations; the dialog session was designed to help students construct explanations about the content of the classroom science investigations.

A defining feature of the tutorial dialogs was that Marni asked students open-ended questions about science presented with media—static illustrations, silent animations, or interactive simulations; asking questions, like "What's going on here?" or "What would happen if…?"). Sessions lasted between 15 and 20 minutes; Marni asked questions and presented media with the goal of stimulating reasoning about the science content of classroom investigations and constructing accurate explanations of it. Summative evaluations of MyST demonstrated learning gains of about one-half of one grade, which was similar to learning gains associated with human tutoring, relative to students who did not receive tutoring as a supplement to classroom instruction (Ward et al., 2011, 2013).

What we describe below differed from previous MyST evaluations in that students were presented with *narrated* multimedia science presentations, and were then asked questions about the science in the presentations. Hereafter, we refer to spoken dialogs in our previous MyST studies (Ward et al. 2011; 2013) as MyST-SLS to distinguish the dialog approach used in MyST-SLS (silent animations) from the tutoring strategy used in the current study (MyST-MP&D), which incorporated both narrated multimedia presentations and dialogs with students.

2. Investigating One-on-One and Small Group Conversations with a Virtual Tutor

In MyST-MP&D students were presented with a narrated animation that posed a science question or problem, followed by Marni asking questions about that science question or problem. Students were then presented with a second, narrated multimedia presentation, which provided an explanation of the science. This second presentation was followed by a series of questions designed to elicit explanations. Students were randomly assigned to one-on-one or group tutoring conditions. Students in each condition were presented with the same multimedia presentations, and the same questions following the presentations. At the end of each session, students engaged in a short (2 to 5-minute) dialogs with Marni. During this dialog, Marni asked students the same deep reasoning question, with follow-on questions that depended on students' responses to previous responses/answers to prior questions. This final dialog was a greatly reduced version of MyST dialogs used in our prior studies, described in Ward et al. (2011; 2013), aligned to science investigations in FOSS Measurement, and Magnetism and Electricity. For ease of exposition, we use examples from the Measurement sessions to describe the study; results, however, are reported for both modules.

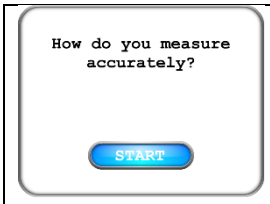
2.1.1. *Sequence of MyST-MP&D Activities*

2.1.1.1. Title Screen

Each MyST-MP&D session began with a title screen that presented a deep reasoning question. In all cases, the printed question was read aloud by Marni. Examples included: What do magnets stick to? What is an electrical circuit? How can we measure length (volume, mass, temperature) and get the same answer each time? The tutoring session was introduced with an authentic question. This corresponds with research that has indicated that presenting authentic questions that require students to think about the topic before instruction begins improves learning (Driscoll et al., 2003; Gholson et al., 2009; Sullins, Craig, & Graesser, 2010).

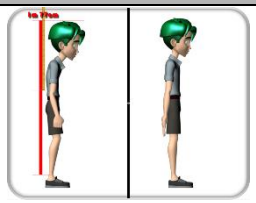
2.1.1.2. Engaging Real-life Scenario

The first multimedia presentation was a narrated animation that introduced the science content. It associated the science with materials and situations probably familiar to most or all of the students (based on observations of classroom instruction). The Scenario was followed by an open-ended question by Marni, like "What's going there?" or "How are do you think Jack and Jill will solve the problem?" The real-life scenarios and Marni's questions were designed to help students make meaningful connections between the science content and their own experiences and knowledge, to introduce and discuss scientific vocabulary and concepts, and to help them make connections between the scenario they were provided and the deep reasoning question introduced on the title screen of the MYST-MP&D session (see Figures 1 and 2).



The session begins with a deep reasoning question. The student clicks on the start icon to begin the multimedia presentation. Marni appears on screen at the beginning of the session to introduce the topic. After each narrated multimedia presentation, Marni appears on screen, and asks students questions about the science in the presentation.

"Today I measured how tall Jack was."



"The first time I measured him he was 1 meter 77 cm tall."

"The second time I measured him he was 2 meters tall."

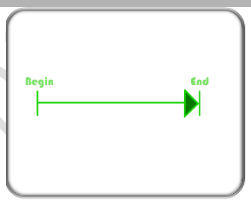
"What's going on here?"

"How do you measure accurately?

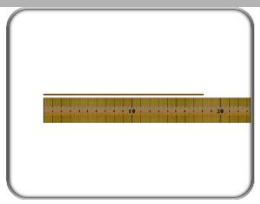
Students can decide to replay the narrated multimedia presentation, or press continue, at which point Marni asks an open-ended question, such as "Why do you think Jill got different answers each time she measured Jack?" After students answer the question (automatically recorded) Marni produces a prompt like: "Let's see what they figured out."

Figure 1. Sample of narrated, multimedia presentation.

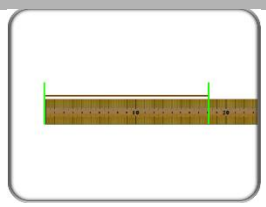
EXPLANATION



"When measuring length, it is important to begin and end your measurement at the right places."



"Here we use a meter stick as an example with our line."



"It is also very important to make sure things are flat and lined up with your meter stick."

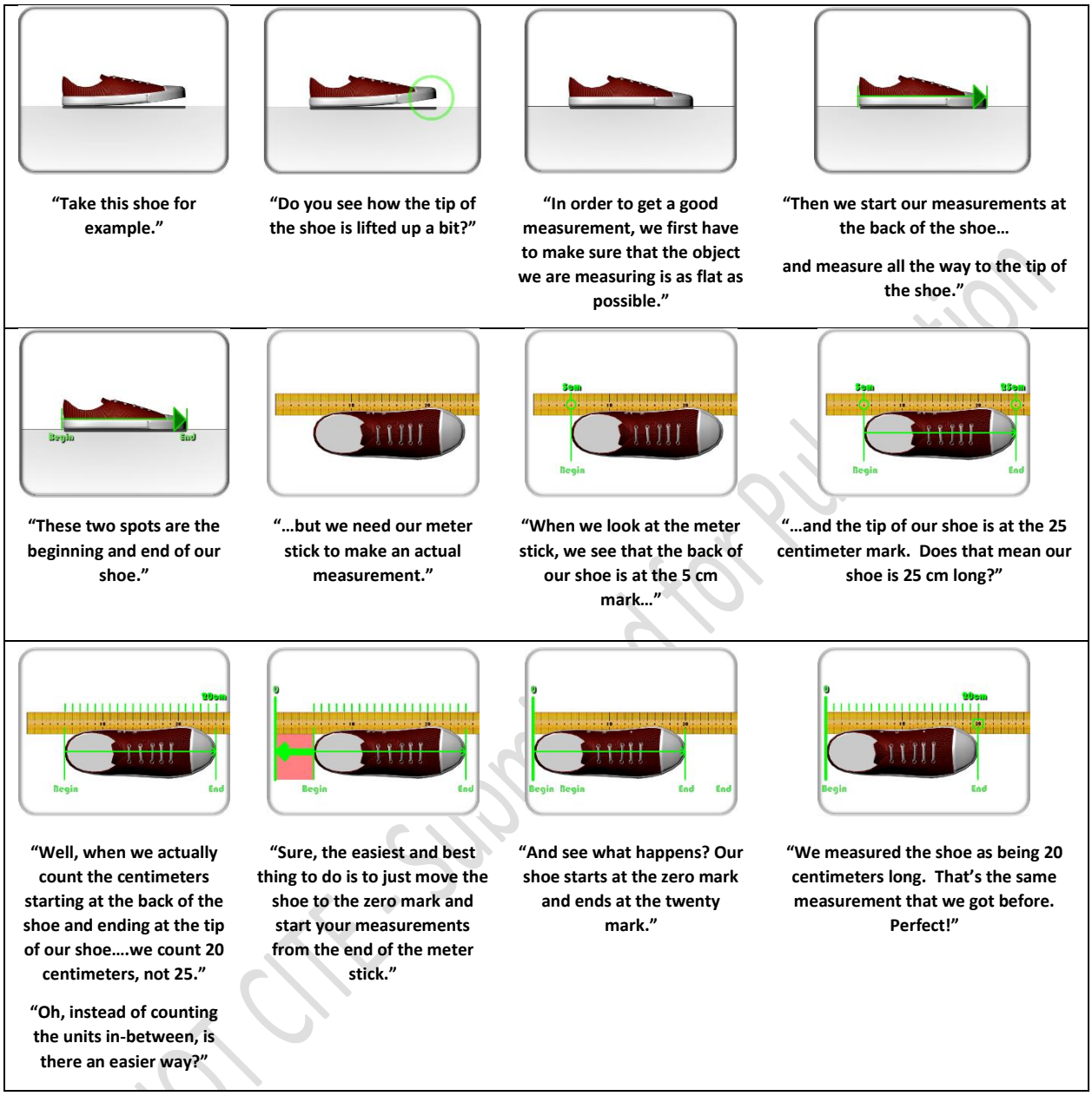
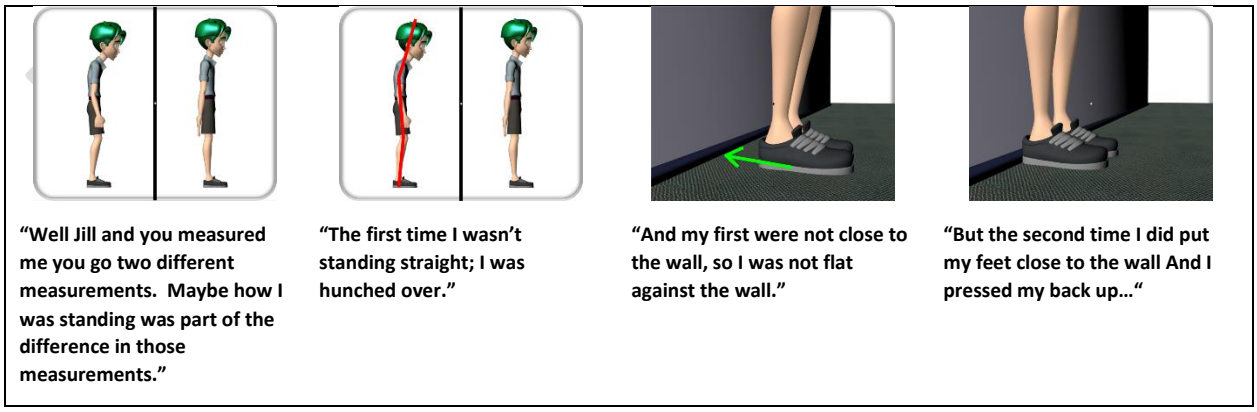


Figure 2. Sample of multimedia explanation and demonstration.



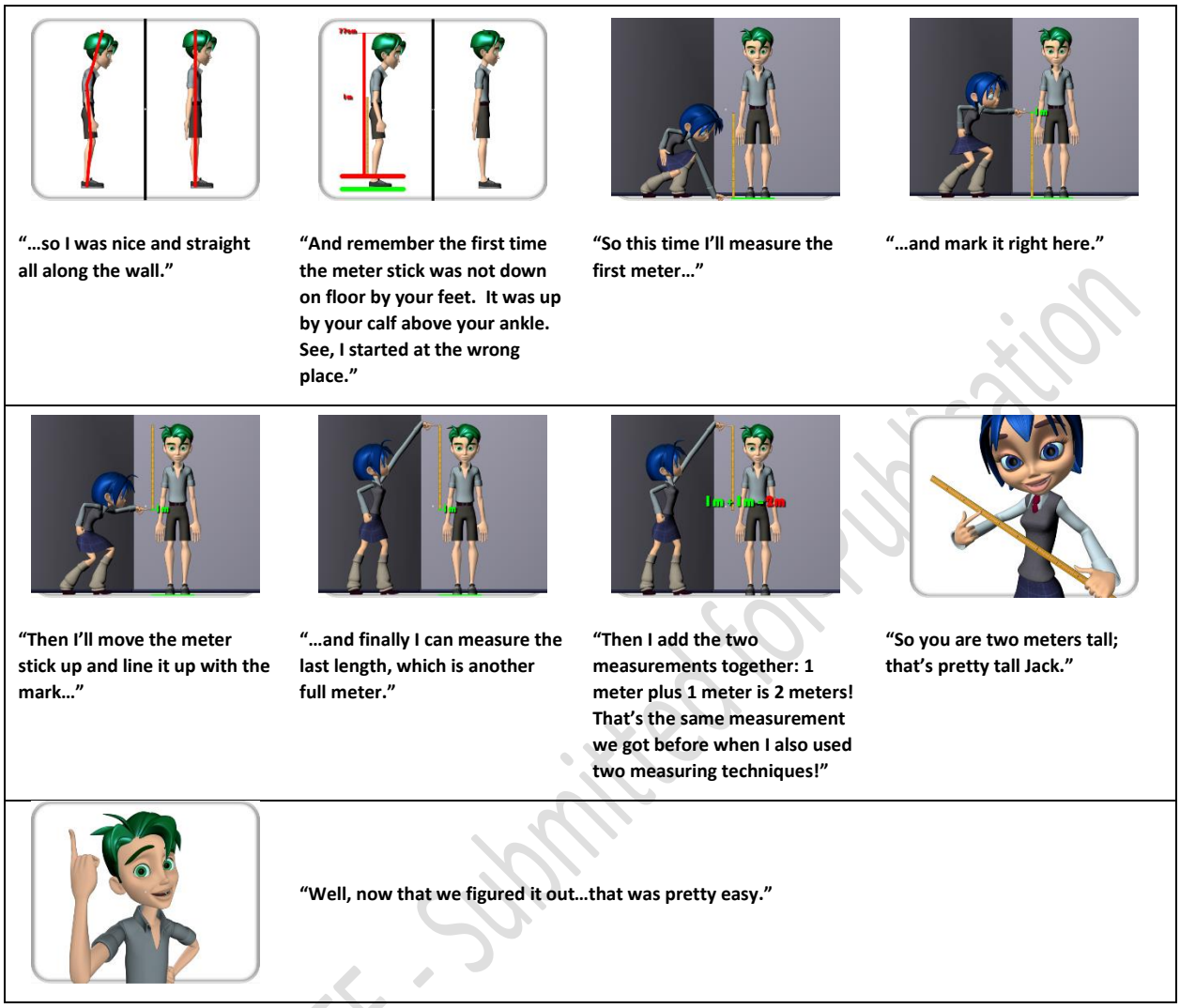


Figure 3. Sample multimedia explanation.

2.1.1.3. Multimedia Science Explanation

Students were presented with a multimedia presentation that explained the science content. The design of the narrated multimedia presentations was informed by a substantial body of theory and research in multimedia learning. We sought to optimize learning and support the development of rich multimodal mental models that integrated verbal and visual information, leading to deep learning and transfer of knowledge to new contexts (Mayer, 2005). Presentations were sequenced, when necessary, with brief pauses between the key ideas so students had time to process each of key points in the presentations. Figures 2 and 3 present an example of a multimedia explanation for measurement.

2.1.1.4. Formative Assessment

After the multimedia presentation was completed, students were presented with an authentic question that could be answered if students had achieved a deep understanding of the science content. The question was sometimes the same as the deep reasoning question that introduced

the overall MYST-MP&D session. In some tutoring sessions, however, a different question was presented. Questions were often accompanied by illustrations, and required answers that demonstrated application of science content knowledge to the situation shown in the picture with the newly provided, deep reasoning question.

2.1.1.5. Spoken Response to the Authentic Question

Following the questions, students were asked to produce a spoken answer to the question *before four answer choices were presented.* The goal was make students think about the question, and express their understanding in words. We note that students in the small group condition were encouraged to discuss the question and to attempt to converge on a single explanation. After producing a spoken response, students were presented with the question a second time, along with four possible answer choices.

This time, students were required to listen to Marni read each answer choice aloud and select the best answer. All possible answer choices were presented for two reasons: a) sometimes several answer choices were technically correct, but were not the best (e.g., most complete) answer to the question, and b) students in small groups were required to listen to each question, thereby discussing the answer choices. After an answer was selected, Marni immediately provided formative feedback on the answer choice that was selected. If an incorrect answer was selected, Marni explained why it was incorrect, presented the correct answer, and expanded upon/explained why it was the correct one.

2.1.1.6. Spoken Dialogs with Marni

Each session concluded with a spoken dialog with Marni lasting less than 5 minutes. These were truncated versions of MyST-SLS dialogs, in which Marni asked an open-ended question designed to elicit a complete and accurate explanation of the science phenomena or systems shown in the multimedia presentations. If the explanation was not complete, Marni asked follow-up questions. Students in small groups were encouraged to discuss their answers before the designated speaker responded.

2.1.2. Results

To quickly recapitulate the study, the two hypotheses were:

1) *Students receiving computerized tutoring in groups will achieve learning gains similar to students receiving one-on-one tutoring.*
2) *Both groups receiving tutoring will demonstrate greater learning gains than students without supplemental tutoring (based on pretest vs posttest scores).*

We did not expect statistically significant different learning gains between group and one-on-one tutoring students; rather, we expected both groups to benefit from tutoring, and achieve gains similar to those obtained in previous studies.

2.1.2.1. Research Design and Data Collection Procedures

The assessment of the MyST-MP&D treatments was conducted from November of 2011 to May of 2012 in 3rd, 4th, and 5th grade classrooms in the Boulder Valley School District (BVSD). All students in the study received in-class instruction in either the FOSS module *Magnetism and Electricity (4th grade)* or *Measurement (3rd grade).* Participating teachers followed module-

based lesson plans and had their students conduct all science investigations as stipulated by the FOSS curriculum. The duration of instruction using the FOSS science modules varied from 1 to 3 months during the school year.

One hundred eighty-three (183) students in 13 classrooms at 4 schools participated in the study. Of the 183 students, 114 were randomly assigned to Group tutoring, and 69 were assigned to one-on-one tutoring -- with 100 students completing the FOSS *Magnetism and Electricity* module and 83 students completing the *Measurement* module. Students in the group tutoring condition were encouraged to discuss answers to Marni's questions in those small groups. Each student sat in front of a laptop computer wearing headphones so they could look at and listen to Marni when she talked, and view and listen to the narrated, multimedia presentations. In each session, only one of the students in the group communicated with Marni; students took turns being the speaker. We note that the MyST-MP&D system did not record and process discussions among students in small groups. Marni listened to and responded only to the designated speaker in each session. Project tutors observed each group session, and coded students' conversations, as discussed below (see Table 1).

Table 1. Means, Standard Deviations (SD), Pre/Post Scales for the FOSS-ASK tests.

Module		Pre (raw)	Post (raw)	Pre/Post Average	Scale
Measurement	Mean	27.8	44.6	36.2	9 – 63
	SD	8.7	7.9	8.3	
Magnetism & Electricity	Mean	21.2	29.6	25.4	7 – 39
	SD	7.4	8.8	8.1	

Students in the group tutoring condition worked in groups of 3 (except when a student was absent) and responded to questions about the multimedia science presentations. . After discussion, the group leader provided the agreed upon answer to Marni. Students in the one-on-one condition interacted directly with Marni by answering questions verbally, or by selecting answers using multiple choice questions.

2.1.2.2. Data and Data Cleaning

The FOSS – assessing science knowledge (ASK) assessments for the two modules used in the assessment have identical pre and post versions with open-ended, short answer, multiple choice, and graphing items. Tests were administered before the beginning of the FOSS lessons, and immediately after tutoring ended at the school. Students completed pre/post FOSS-ASK assessments for *Measurement* and *Magnetism & Electricity* modules before and after the classroom instruction and tutoring. Learning gains from pretest to posttest for students in the individual and small group tutoring treatment conditions in MyST-MP&D were compared to learning gains of students in classrooms in the 2010-2011 MyST-SLS study who received classroom instruction for *Measurement* & *Magnetism & Electricity* who did not receive supplemental tutoring.

Because module tests had different scales (see Table 3), scores were standardized with a common metric. All standardization used scores from both years of the study with outliers and other spurious data removed. "Test-wise" standardization subtracted the mean of each test (over all students and pooling pre/post data) from each students' score. This difference was then divided by the weighted, average standard deviation for both pre- and post-test score. Information about each test is presented in Table 2.

Table 2. Means, Standard Deviations (SD), Sample Sizes (n), and Effect Sizes for Tutoring Groups across the two years: 2011 and 2012.

Tutor Condition	Mean	SD	n	Effect Size
MyST-SDS Tutor (2011)	0.34	0.84	83	0.51
Human Tutor (2011)	0.47	0.73	69	0.65
Control (Whole Class) (2011)	-0.13	0.93	1015	
Group MyST-MP&D (2012)	0.43	0.72	103	0.61
One-on-one MyST-MP&D (2012)	0.45	0.72	61	0.63

Pairs of raters scored all assessments from tutored students. The raters were project tutors from Boulder Language Technology who were blinded to subjects' treatment conditions, and whether the assessments they scored were pre- or post-tests. Raters calibrated by working together using the scoring rubrics provided by FOSS, followed by independently scoring the assessments. Inter-rater reliabilities for two raters were high (counting only the open-ended items) with intra-class correlation coefficients ranging from 0.89 to 0.94, with averages for pre- and post-test being 0.91 and 0.94. Internal reliabilities (Cronbach's Alpha) were lower, ranging from a = 0.66 to a = 0.87 for both pre- and post-test versions of the assessments, with averages for pre-test = 0.78 and post-test = 0.78. Internal reliability varied for each module. Scores used for outcome analyses were the averages across both raters.

Table 3. Means, Standard Deviations (SD), Sample Sizes (n), and Effect Sizes for Tutoring Groups across the two years: 2011 and 2012.

Tutor Condition	Mean	SD	n	Effect Size
MyST-SLS Tutor (2011)	0.34	0.84	83	0.51
Human Tutor (2011)	0.47	0.73	69	0.65
Control (Whole Class) (2011)	-0.13	0.93	1015	
Group MyST-MP&D (2012)	0.43	0.72	103	0.61
One-on-one MyST-MP&D (2012)	0.45	0.72	61	0.63

2.1.2.3. Results

The overall results are presented in Table 3. We also include the results from the MyST SLS. When compared with business-as-usual group, effect sizes were d = 0.61 for the group tutoring condition and 0.63 for the one-on-one tutoring condition. These were both similar to those previously found for the year before for individual tutoring with MyST-SLS (d = 0.51) and for human tutors (d = 0.65). Pre- versus post-test gain differences among groups varied by FOSS

module with less relative gain for experimental groups on the *Measurement* module and greater gains for the *Magnetism and Electricity* module. Lower achieving students on the pre-test in the one-on-one tutoring group gained relatively more than students in the business-as-usual group, but gains for these students decreased for higher performing students on the pretest. Students in the group tutoring condition gained more than students in the business-as-usual group across the ability scale.

Gains were also assessed based on ability level on the pre-test. Group comparisons divided the pre-test score distribution into 5 equal parts. The resulting distribution showed higher gains for tutored groups in the lower pretest score blocks especially for the one-on-one tutoring group, with more uniform gains across ability for students in the group tutoring condition (Figure 4).

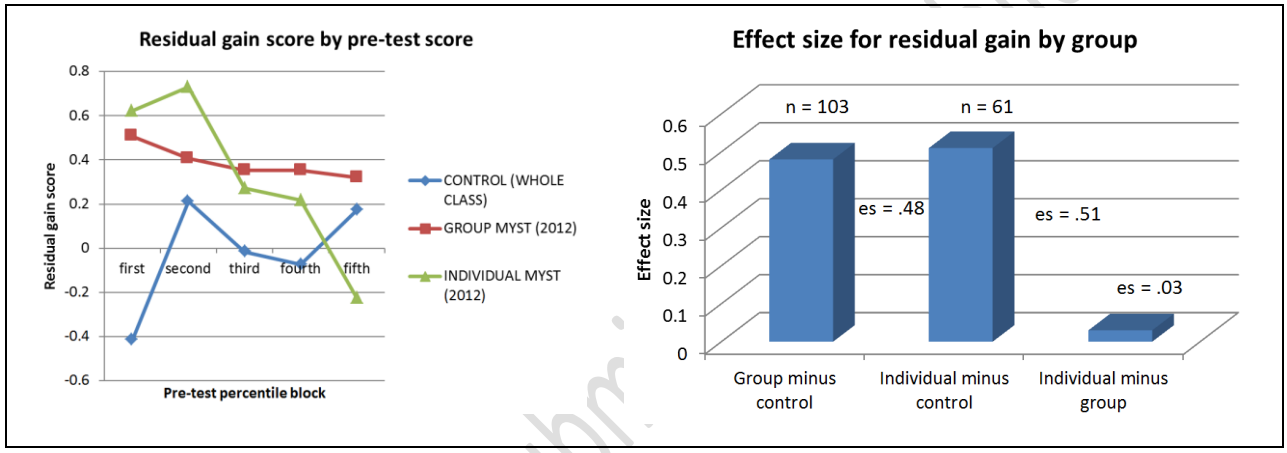


Figure 4. Residual gain scores over time and experimental groups.

Comparisons with previous treatment groups from 2010-2011. A two-way ANOVA tested if group means from both years differed significantly on residual gain scores. The main effect for tutoring group for all groups (2011, 2012) was statistically significant, $F = 16.8$, $df(4,1171)$, $p < 0.001$. No statistically significant interaction was present for the treatment by module effect, indicating that differences found were generalizable to each module. Post-hoc tests showed statically significant differences between all tutoring groups and the business-as-usual group, and no significant differences among any of the four tutoring conditions. Effect sizes for MyST tutoring were higher in 2012 than 2011, although students that received face-to-face "human" tutoring demonstrated the largest gains, although differences between human and virtual tutoring conditions were not statistically significant.

Observations of Interactions among Students in Small Groups. We conducted structured observations of students as they interacted with MyST-MP&D. Observers used a checklist to record the duration of student answers to questions from Marni, the types of questions asked by MyST, and characteristics of discussions between students. The checklist was completed using a portable digital assistant and electronic data were imported into an Excel database.

We tested the reliability of the observations by having two observers watch the same students. Agreement between raters varied from 70% to 89% for type of question and type of discussion. A sample of observations for the duration and number of student answers for a tutoring session were also checked against computer logs; differences were usually minor for number of observations (deviation of +/- 2 observations), and duration was highly correlated with observations and logs, $r = 0.87$. Data from two observers with low agreement and anomalous ratings were removed from the dataset. Five observers observed 64 students at 3 schools. Two hundred eight (208) tutoring sessions, 4749 group answers to questions, and 13,430 individual records were observed[1].

We observed how students in groups answered these questions. The group consisted of one "leader" (the student who talked with Marni using a headset microphone) and 2 other students who discuss the answers with the leader but did not respond directly to Marni. Students took turns across different tutoring sessions being the leader. The leader of the group was instructed to consult with the other students before answering questions. The resulting answers were divided into short *confirmational exchanges*, verses exchanges where students engaged in more *interactive discussions*. Confirmational exchanges were typically much shorter than interactive discussions and consisted of either the group leader providing an answer and then the listeners agreeing with this answer, or a listener providing an answer, with the leader repeating it to Marni. Confirmational exchanges typically occurred following presentation of the answer choices to a multiple choice question. Interactive discussions were usually longer in duration than confirmational exchanges, with students elaborating on each other's answers, disagreeing with each other, or referencing prior classroom instruction. A typical discussion had multiple back-and-forth exchanges culminating in an answer to which the students agreed and was spoken by the leader to Marni.

In some cases the group leader did not ask for input from the other students and just answered the questions. If the project tutors, who observed sessions, observed this occurring frequently, they reminded the group that all members should participate in discussing the answers.

2.1.2.3. Types of questions and responses

We wanted to know if specific types of questions were more likely to elicit interactive discussions and confirmational exchanges. Students' responses were analyzed across 3 different types of questions:

1. Initial question: This was the authentic question to which students produced a spoken response before being presented with four, alternative response choices.
2. Answers to Multiple Choice Questions: Discussions students had about the 4 different response choices that were read aloud following the authentic question.
3. Spoken Dialogs with Marni: Students' spoken responses to open-ended questions that concluded the dialog sessions. These questions followed the QtA format and were designed to elicit explanations for the science displayed in the multimedia presentations.

[1] Students were in groups of 2 -4 students; records in the databases were organized by individual observations, observation sessions, and by students themselves.

Characteristics of interactive discussions. On average, interactive discussions were 54% of all types of conversations between students, and accounted for 65% of total time observed. These percentages varied widely across observations. The average interactive discussion was 30 seconds long (versus 16 seconds for the average conformational exchange). When students did engage in interactive discussions, the majority of the time (81%) was spent elaborating on other students' comments. These comments often involved students adding new information to a leader's answers, or rewording or clarifying answers from another student (revoicing). Fewer discussions involved students disagreeing with each other, occurring in 10% of discussions; students infrequently, in 3% of discussions, referred or referenced prior classroom instruction (this is an interesting result, given that the majority of students reported that they sometimes disagreed with the answer the leader in each group ultimately provided to Marni on the follow-up questionnaire provided to each student).

In sum, observations of students working in groups examined length and characteristics of student interactions, and linked this information with computer logs and ASK assessment data. From these observations we found that lengthier student discussions with students elaborating on each other's answers, disagreeing about answers, or referencing classroom instruction occurred more frequently when a) questions were asked immediately after the initial multimedia presentations, and b) questions were asked during the final spoken dialog after Marni asked the first authentic question. Extended discussions were less frequent for follow-on questions during the spoken dialogs consideration of answer choices to multiple choice questions. The shorter discussions associated with students' examining alternative response choices to multiple choice questions were often confirmatory, in which the group quickly concurred with the answer choice selected by one of the members of the group. Based on students' responses to the questionnaire, we expect peer pressure may have been involved in these short exchanges, as students reported that they often disagreed with the answer that was given.

While students who scored higher on the pre-test tended to participate more frequently in extended student discussions, participating in discussions was not correlated with student achievement gains from pre- to post-test ASK assessment.

Links between FOSS-ASK assessments and types of responses in small groups. We also wanted to know if gains on the FOSS-ASK assessment were related to the frequency and duration of discussions. The average amount of time spent by students in interactive discussions was correlated (r = 0.23) with pre-test scores, but not with either pre-test vs. post-test gains or post-test scores. This result generalized for both FOSS modules. The correlation with pre-test scores suggested that students who scored higher on the pre-test were more likely to engage in discussions.

2.1.2.4. Students Experiences with MyST-MP&D.

All students in both the one-on-one and group tutoring conditions in the MyST-MP&D study were administered the same written questionnaire. In addition, students in the group tutoring condition each student responded to additional questions that were designed to gain insights about students' experiences when working with other students in those small groups. Results of the questionnaire indicated that students had very similar impressions in the two conditions. Specifically, students in group tutoring condition indicated that they benefitted from their group

discussions, and interestingly, indicated that they often disagreed with the answer that was provided by the designated speaker after the group discussion. These results are shown in Figures 5 and 6.

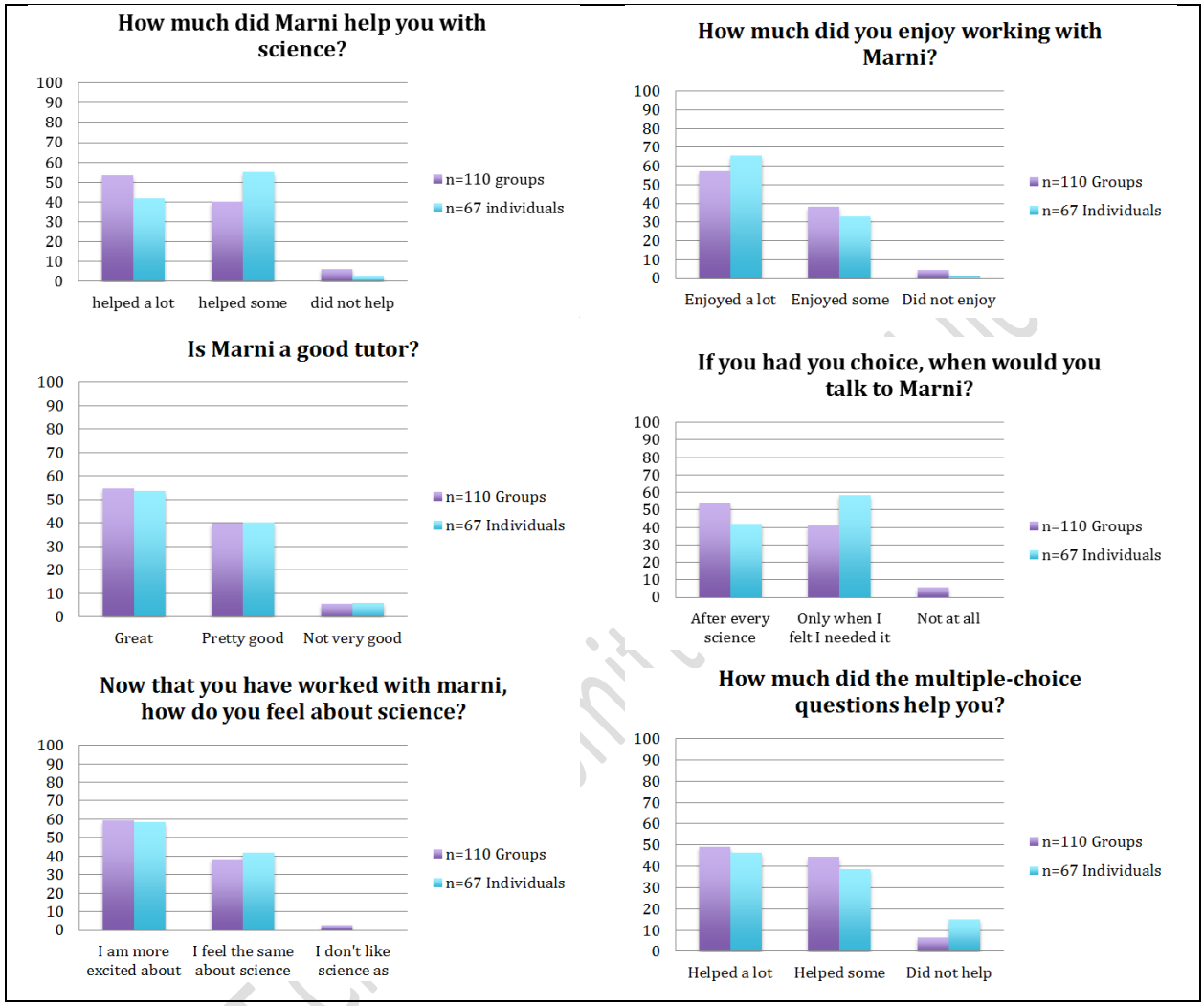


Figure 5. Students' response to surveys in One-On-One tutoring condition.

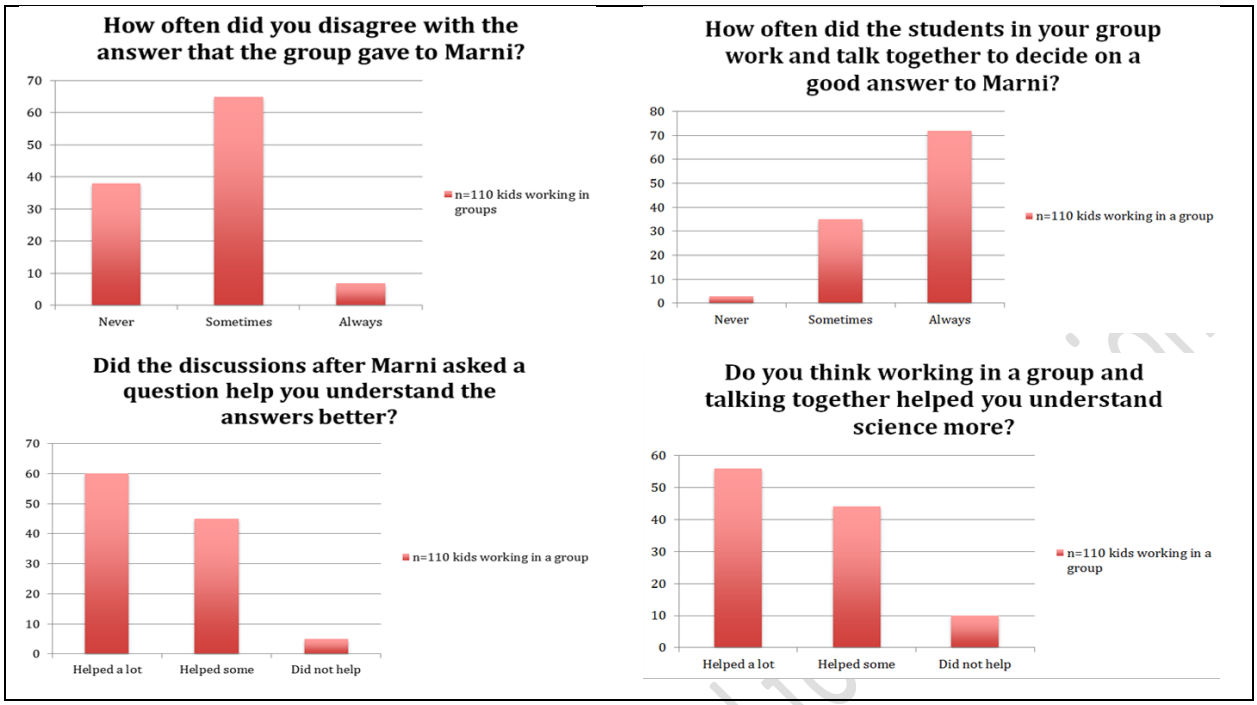


Figure 6. Students' responses to surveys in small group tutoring condition.

3. Discussion

This study investigated student experiences and learning gains following one-on-tutoring sessions with a virtual science tutor and small group tutoring sessions in which students were encouraged to discuss answers to questions posed by the virtual tutor before one of the students provided an answer for the whole group. The results indicated that learning gains were comparable for the 2 groups, and students in both groups had generally positive experiences. The magnitude of the learning gains were similar to those observed in previous investigations (see Ward et al., 2011; 2013).

This investigation addressed issues with how individual and groups of students interacted with multimedia, spoken dialogs with a virtual tutor about science — which was the special topic of the corresponding Journal Issue. The main difference between the one-on-one tutoring sessions in prior MyST-SLS studies, and the current MyST MP&D study, was that students in our prior MyST-SLS studies engaged in spoken dialogs during the entire tutoring session (rather than just part of it), as they explained science presented to them, answered questions about the science content, and conducted follow-up activities and questions posed by the virtual tutor. The assumption in these dialogs was that students had acquired sufficient prior knowledge during classroom science instruction to build on this knowledge with the virtual tutoring sessions. This would in turn enable them to engage and generate meaningful discussions about science content with a virtual tutor that scaffolded learning through questions and multimedia presentations.

In the current study, students in both one-on-one and group tutoring conditions were presented with a problem scenario, and then a solution to the problem. These sessions coherently presented science content with follow-up discussions, questioning, and explanations. Compared to MyST-SDS sessions, in which the vast majority of the session consisted of answering

questions posed by Marni, the present study was more "self-contained" insofar as students were presented with problem scenarios and problem solutions, and asked questions about the problems and solutions that were presented within the tutoring session. Interestingly, similar learning gains were obtained in the MyST-SDS and MyST-MP&D studies. Further research is required to understand the relative contributions of incorporating narrated, multimedia problem scenarios and science explanations into tutorial dialog sessions, compared to tutoring sessions that consist mainly of asking questions about science encountered during classroom instruction. At this point, we have concluded that both approaches have and will produce comparable learning gains, when compared to students in business-as-usual classrooms (who receive similar classroom instruction, but do not receive supplementary tutoring). We also have concluded that the relationship between student achievement and particular aspects of the virtual tutoring any student received was complex and required additional investigation.

Also, the study produced the prime facie case for the plausibility of using virtual tutors to facilitate small group discussions. Almost without exception, students in small groups engaged in discourse and argumentation with their peers. In our initial pilot study, no prior instruction was provided to students on how to engage in effective discourse and argumentation or correctly provide scientific answers to complex problem scenarios. Rather, we took an ecological approach, in which we observed how students communicated with each other given the opportunity to share their responses and answers to questioning (scaffolding). Students reported that they enjoyed arguing with their peers, believed they achieved a deeper understanding of the science as a result of the discussions, even though most students reported that they sometimes disagreed with the answer presented to the virtual tutor following the discussion. Future work will aim to extend the capabilities of the virtual science tutor, to foster effective discourse and argumentation, and to better understand the complex relationship between the types of multimedia support provided to students and changes in their science knowledge and achievement as well as their capacity to form and use scientific arguments and argumentation.

4. Conclusion

This study demonstrated that students who received one-on-one tutoring with a virtual tutor and students who engaged in small group discussions, following questions posed by the virtual tutor, demonstrated the same significant gains in achievement, relative to students who did not engage in supplemental tutoring. This result was encouraging, as it motivates future research in which virtual tutors can be provided with sufficient intelligence to facilitate conversations during which students' learn how to argue effectively, defend their arguments, and modify their ideas as they co-construct accurate science explanations with their peers.

4.1. Next Steps

We envision a near future where a virtual tutor uses dialog moves, based on principles of QtA, exactly as a master teacher versed in QtA would do to model scientific discourse, and address questions to individual students to foster effective argumentation. In this future, students sit around a table, with a clear view of each other and the virtual tutor, whose face appears on her own computer screen at the head of the table. Each student wears lightweight headphones with an attached, noise-cancelling microphone. Each student views and interacts with media on their own device. Students talk to the virtual tutor by pushing and holding the spacebar on their

computer, or button on their tablet, which causes a light to go on, indicating which student has the floor.

During small group discussions with the tutor, speech recognition and natural language processing systems construct a semantic representation of each student's expressed understandings, gaps in their knowledge, and potential misconceptions. The tutoring system also builds a representation of the distributed knowledge of the group (i.e., which semantic frames have been filled during the conversation by the different members of the group). By creating a unified representation of the group's knowledge from representations of each individual student's responses, the system is able to identify conflicting beliefs and commonly missing elements of the science content. It will identify parts of students' arguments that are based on their correct knowledge and parts of their arguments based on their misconceptions. It will ask follow-up questions to individual students or the group that aims the group discussion at misconceptions, and builds on valid differences in the way students think about similar scientific phenomena. In doing this, it will foster discourse and argumentation in which students listen to each other, consider each other's arguments, modify their ideas, and work together to co-construct explanations that result in a deeper understanding of science for the entire group.

A core principle of the system and its responses to students' interactions is that student-to-student interactions are valuable only if they involve students truly listening to each other and building on each other's ideas. QtA *dialog moves* are designed to do exactly this. The role of the teacher (virtual tutor) is to model this process, so students listen to each other, reflect on what other students have said, and self-assess and revise their ideas. Specifically, the tutor models the process of listening carefully, extracting meaning, and making connections between students' ideas using established dialog moves which paraphrase or elaborate on student's ideas. The tutor models scientific discourse by rephrasing what a student said. For example, when Roger says, "It flows in one direction from negative to positive", the tutor may respond with, "I think you said electricity flows from the positive pole to the negative pole of the battery". The tutor then asks a question to the same student, or to another student (e.g., Maria, do you agree with what Roger said?). The tutor can also pose questions or suggestions to the entire group (e.g., So what's going on here? or Why don't you discuss the different explanations Maria and Roger presented?).

We believe that current technologies are fully capable of facilitating such group discussions. Current speech recognition, language processing, and dialog modeling technologies demonstrably support graceful and effective dialogs between virtual tutors and students (Ward et al., 2011; 2013). Furthermore, we believe it is relatively straightforward to extend the representations used in MyST-SLS for one-on-one tutoring to model the expressed understandings of each member of a group, while maintaining a model of the groups' combined knowledge. Moreover, the dialog modeling currently applied to individual students' spoken answers in MyST-SLS can be extended to support conversations with multiple students, thereby faithfully generating QtA dialog moves for groups of students, which have been demonstrated effective in fostering discourse in 100's of classrooms (Beck, Isabel, McKeown, & Margaret, 2006).

Lastly, research in the tutoring literature has suggested that all students who participate in small group conversations may benefit from listening to other students as they argue about science, without necessarily contributing to the discussion. Recent studies have indicated that students who were waiting for their turn to use the virtual tutor, who observed tutorial dialogs in which

deep reasoning questions were asked of other students, achieved learning gains equivalent to students who actively participated in the tutoring sessions (Chi, Roy, & Hausmann, 2008; Craig, Gholson, Ventura, & Graesser, 2000). These studies suggest that a new generation of intelligent tutoring systems that can listen to and foster discourse and argumentation among groups of students, which in turn may benefit all participants.

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