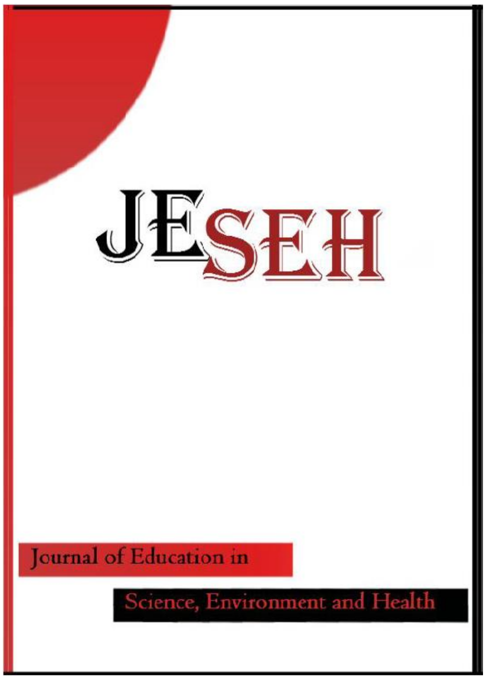

ISSN: 2149-214X

Journal of Education in Science, Environment and Health

www.jeseh.net

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To cite this article:

Arslan Buyruk, A. & Ogan Bekiroglu, F. (2018). Comparison of pre-service physics teachers' conceptual understanding of dynamics in model-based scientific inquiry and scientific inquiry environments. *Journal of Education in Science, Environment and Health (JESEH), 4*(1), 93-109. DOI:10.21891/jeseh.389737

Journal of Education in Science, Environment and Health
Volume 4, Issue 1, 2018 DOI:10.21891/jeseh.389737

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Article Info

Article History

Received:
06 June 2017

Accepted:
30 December 2017

Keywords

Conceptual knowledge
Dynamics
Inquiry
Model-based inquiry
Pre-service teachers

Abstract

The focus of this study was to evaluate the impact of model-based inquiry on pre-service physics teachers' conceptual understanding of dynamics. Theoretical framework of this research was based on models-of-data theory. True-experimental design using quantitative and qualitative research methods was carried out for this research. Participants of this study were 22 senior pre-service physics teachers. The instructional strategy in the experimental class was model-based inquiry (MBI) while it was inquiry in the control class. Data were collected by using Force Concept Inventory (FCI), video recordings, inquiry reports and the instructor's field notes. The results of Mann-Whitney U tests for two classes' pre-tests and post-tests indicated that there was not any significant difference between two classes' performances before and after the treatment. On the other hand, the results of Wilcoxon signed-rank test showed that the experimental class's post FCI scores were better than their pre FCI scores. The following conclusions can be drawn from the study: Putting modelling explicitly into the center of inquiry facilitates conceptual learning. Therefore, model building and formation in inquiry can be seen as a way not only to represent what learners have already known but also to generate new knowledge. Making associations with other phenomena under the framework of epistemic characters of knowledge and expanding on these associations with discussions in inquiry learning environment promote students' understanding. Finally, model quality may stimulate science learning; however, more research is needed to extend this conclusion.

Introduction

Since there was not consensus in the literature about the specific components of scientific inquiry, Minner, Levy, Century (2010) looked for similarities across existing definitions of inquiry by reviewing literature that had been written over the course of the past 30 years and concluded that scientific inquiry instruction could be characterized as having three aspects: (1) the presence of science content, (2) student engagement with science content, and (3) student responsibility for learning, student active thinking, or student motivation within at least one component of instruction—question, design, data, conclusion, or communication. However, scientific inquiry teaching and learning approaches pose challenges for students such as failures to focus on the scientific merit of questions generated and to systematically collect and analyze data (Krajcik et al., 1998). Moreover, Mumba, Banda and Chabalengula (2015) have been categorized challenges of inquiry according to students as difficulties in written expressions, ability to link ideas in chains of reasoning, difficulties working with numeric data, and difficulties in spoken expressions.

While standards are advocating inquiry as an instructional strategy, it is also seen as problematic by many science teachers and has not been widely accepted or enacted (Campbell, Zhang & Neilson, 2011). The problems that teachers identify when seeking to employ inquiry as an instructional strategy are as follows: lack of clarity with respect to what constitutes inquiry, lack of examples of how inquiry is facilitated as an instructional strategy in real classrooms, and lack of the explicit association of inquiry with science content (Windschitl, Thompson and Braaten, 2008a).

Models are representations of a system to make its central features explicit while model formation is the construction of a model of some phenomenon by integrating pieces of information about the structure, function/behavior, and causal mechanism of the phenomenon, mapping from analogous systems or through induction (Gobert & Buckley, 2000). Models are essential as both content products of science (Gilbert &

Osborne, 1980) and in the process of coming to understand the world scientifically (Boulter, 2000; Crawford & Cullin, 2003; Harrison & Treagust, 2000; Viennot, 2001). Consequently, involving learners in modeling practices can help them build subject matter expertise, epistemological understanding, and expertise in the practices of building and evaluating scientific knowledge (Ogan-Bekiroglu, 2007; Schwarz et al., 2009). An important meaning in the context of model-based learning is the idea that students must learn to be able to think with chains or networks of causal relationships that are larger than a single A causes B relation (Clement, 2000). Modelling can be embedded in inquiry to overcome some of the concerns about inquiry.

The scientific modeling involving construction, use, evaluation, and revision of models embedded in the inquiry process can be generally defined as the model-based inquiry (Schwarz et al. 2009). Thus, the focus of this study was to evaluate the effect of model-based inquiry on pre-service teachers' conceptual understanding. Since most science teachers have never directly experienced authentic scientific inquiry during their education in the sciences or within teacher education programs (Hahn & Gilmer, 2000) and professional development must not only teach inquiry knowledge, but it must also assess and address teachers' core teaching conceptions (Lotter, Harwood & Bonner, 2007), pre-service teachers were the target in this study.

Theoretical Framework

Models-of-data theory developed by Chinn and Brewer (2001) frames this research. Based on this theory, an experiment or other forms of research can be represented as a model that integrates theoretical explanations with the observations and with the details of the data gathering procedures. Authentic scientific inquiry refers to the research that scientists actually carry out; however, many current classroom inquiry tasks bear little resemblance to authentic scientific reasoning (Chinn & Malhotra, 2002). Models-of-data theory helps us understand the difference between authentic inquiry and simple classroom inquiry. According to Chinn and Malhotra (2002), while scientists aim to develop and refine theoretical models in response to evidence in authentic inquiry; students aim to uncover a simple surface-level regularity and to understand a provided theory. That is, scientists engage in inquiry other than controlled experiments, use existing models in their inquiries, engage in inquiry that leads to revised models, use models to construct explanations, use models to unify their understanding, and engage in argumentation (Passmore, Stewart, Cartier, 2009).

Windschitl and his colleagues (2008a) offer an alternative vision for investigative science—model-based inquiry (MBI)—to capture the features of authentic science because authentic forms of inquiry for school science can be grounded in the following five epistemic ideas: testability, conjecture, explanation, principled revision, and generativity. MBI is an instructional strategy whereby learners are engaged in inquiry in an effort to explore phenomena and construct and reconstruct models in light of the results of scientific investigations (Campbell, Oh & Neilson, 2012). Campbell et al. (2011) point out that MBI is valuable because it offers some clarity with respect to defining inquiry, provides an example of how inquiry can be facilitated as an instructional strategy in an authentic context, and reveals how inquiry and science content learning can be juxtaposed to show a more realistic model of the processes of science.

Model construction and revision is fostered by building, critiquing, changing, and expressing one's conceptions of phenomena and modeling can occur through inquiry (Khan, 2007). Therefore, engaging learners in modeling-centered inquiry enables them to revise their own conceptual models and to use those revised models in reasoning (Passmore, 2009) as well as helps them deepening their scientific knowledge (Schwarz et al., 2009).

Literature Review on the Role of Inquiry in Science Learning

Minner and her colleagues asserted that the term inquiry refers to at least three distinct categories of activities—what scientists do (e.g., conducting investigations using scientific methods), how students learn (e.g., actively inquiring through thinking and doing into a phenomenon or problem), and a pedagogical approach that teachers employ (e.g., designing or using curricula that allows for extended investigations). Inquiry instruction could make abstract concepts more concrete, and by providing a valuable context, could position students better to acquire, clarify, and apply an understanding of scientific concepts (van der Meij, van der Meij & Harmsen, 2015). Some studies looking into the effectiveness of inquiry as an instructional strategy (Apedoe, 2008; Brown & Campione, 1994; Hakkarainen, 2003; Wallace, Tsoi, Calkin & Darley, 2003) presented positive results for increasing students' understanding. For instance, the question that Hakkarainen (2003) addressed in his study was whether 28 Grade 5/6 students, collaborating within a computer-supported classroom, could engage in inquiry. Results of the study indicated that with teacher guidance, students were able to produce meaningful intuitive explanations about biological phenomena and to engage in constructive peer interaction that helped them go beyond their intuitive explanations and toward theoretical scientific explanations. Wallace, Tsoi, Calkin and Darley (2003) investigated how five non-major biology students learned from an inquiry experience. Findings indicated that students with constructivist learning beliefs tended to add more meaningful conceptual understandings during inquiry activities than students with positivist learning beliefs. In addition, Hofstein, Navon, Kipnis and Mamlok-Naaman (2005) focused on the ability of asking meaningful and scientifically sound questions of high-school chemistry students, who learned chemistry through inquiry. Students enrolled in a laboratory course that utilized inquiry instruction asked more frequent higher-level questions during a chemistry lab practical than did their counterparts enrolled in a traditional course.

The conceptual benefits of engaging in inquiry are well documented. Nevertheless, Furtak (2006) stated that while meta-analyses suggested a positive influence on student learning, more recent studies comparing scientific inquiry classrooms to more traditional classrooms did not find positive results. For instance, Germann (1989) conducted his research in four high-school biology classes to test the inquiry approach to learning science process skills and scientific problem solving curriculum. In the 11-month intervening time, the experimental group received the inquiry instruction while the comparison group received a more traditional approach. Analysis of covariance revealed that the inquiry instruction had no significant effect on the learning of science process skills or on cognitive development. Pine and his colleagues (2006) studied the degree to which students could do inquiries by using four hands-on performance assessments, which required one or three class periods. The students were from 41 classrooms in nine school districts. Their results presented little or no curricular effect and there was no difference on a multiple-choice test, which used items released from the Trends in International Mathematics and Science Study (TIMSS).

Moreover, in a case study, Maxwell, Lambeth and Cox (2015) examined the effects of inquiry instruction on the academic achievement of 42 fifth-grade science students. After six-week instruction, students in the inquiry group scored higher than students in the traditional group on the academic achievement posttest; however, the result was not statistically significant. Furthermore, Minner et al. (2010) compared the studies done between 1984 and 2002. In looking more specifically at the 101 studies of student science conceptual understanding, they found that there was no statistically significant association between amount of inquiry saturation and increased student science conceptual learning. Therefore, they concluded that the evidence of effects of inquiry instruction from the synthesis was not overwhelmingly positive.

Because of the fact that researchers identified difficulties in students' generating knowledge during inquiry (Edelson, Gordin, & Pea, 1999) and the challenges of inquiry for both teachers and students mentioned in the introduction section have directed researchers to spend efforts on creating effective support in inquiry learning environments. MBI was proposed as a result of these efforts to support learning. Some researchers have explored technology's potential as a model based inquiry to overcome barriers in implementing classroom inquiry (Kim, Hannafin & Bryan, 2007).

Literature Review on Model-Based Inquiry

Although researchers argue that situating modelling in inquiry frames is effective for learning science content and understanding scientific practices (Campbell et al., 2012), there are relatively small number of studies that have closely examined effects of MBI on learning. For instance, Löhner, van Joolingen, Savelsbergh & van Hout-Wolters (2005) studied 42 secondary school students' reasoning during modeling in an inquiry learning environment from three schools, who had chosen to participate in the experiment as part of their regular coursework. The experiment took three hours in total. Students worked on their task in small groups of two or three. They found that students spent most of their time during inquiry modeling on scientific reasoning activities, but not in a systematic temporal order. In Khan's (2007) study, a one-semester introductory chemistry course was offered to 33 first-year science and non-science majors. In-depth problem-solving sessions were designed to document student learning by capturing and elaborating on students' model-based inquiries in rich detail. Results of the study showed that students' mental models of molecular structures enriched. On the other hand, Campbell and his colleagues (2011) studied the effect of MBI as an instructional strategy in comparison to a traditional lecture and demo (TLD) instructional strategy on a variety of student outcomes. The class that would serve as the MBI and TLD classes were assigned randomly. The MBI class consisted of 28 students while that TLD class consisted of 26 students. The Repeated Measurement of Variances analyses revealed that no significant differences were found in student outcomes for any of the domains when comparing physics classrooms facilitated with differing instructional strategies. In their research, Campbell et al. (2012) explored the emergent discursive modes and their pedagogical functions found in model-based inquiry (MBI) science classrooms. A sample of four high school physics classrooms was video-recorded and analyzed. Their results indicated that exploring was one of the most frequently used discursive modes in the MBI classrooms. Sun and Looi (2013) designed a web-based science learning environment for model-based inquiry. The participants included 46 students from two secondary classes and studied some electricity concepts. Their analysis demonstrated that the system could have a positive effect on students' conceptual understanding. Additionally, in a research conducted by Barab et al. (2000), three-dimensional animations and modeling tools enabled students to find evidence and manipulate variables efficiently by visualizing scientific concepts dynamically and authentically.

Though a few studies indicate the contributions of enactment of models and modelling explicitly in inquiry on students' outcomes, research that investigates the effectiveness of model-based inquiry by constructing a control group where the instruction is inquiry is not a commonly used approach. This study adds to the current research by exploring whether model-based inquiry facilitates conceptual knowledge of science by comparing it with inquiry.

Purpose of This Study

Even if ample time is allotted to authentic reasoning tasks, there will be serious instructional challenges for fostering the development of complex strategies (Chinn & Malhotra, 2002). Since, much of what pre-service teachers learn about inquiry and about teaching also comes from their experiences as undergraduates, there have been calls to integrate more authentic inquiry experiences into not only undergraduate science courses but into teacher education courses as well (Windschitl, 2003). An important aspect of addressing these experiences is enabling pre-service teachers to experience learning and teaching science by using model-based inquiry in a productive learning community (Schwarz et al., 2009). Therefore, the research question explored in this current study is as follows: Are there measurable differences in pre-service teachers' conceptual learning of dynamics when comparing two physics classes instructed with model-based inquiry and inquiry? In order to make sure that the participants revised their models as an aspect of modelling process, the following research question was also set: Do pre-service physics teachers revise and change their initial models into final models? How?

Methodology

True-experimental design using quantitative and qualitative research methods was carried out for this study (Krathwohl, 1997). A pretest/posttest control group design was conducted to monitor the change in pre-service teachers' understanding of the concepts of dynamics over time and to measure the effect of implementation of modelling during inquiry on their conceptual learning. For the quantitative aspect of the study, the researchers compared participants' learning statistically. The purposes of the qualitative part were to validate the quantitative results, to examine participants' learning during instruction to provide justification for the quantitative research, and to evaluate their models.

Participants and Settings

The research was conducted in two classrooms, one was experimental and one was control. Participants of this study were 22 senior pre-service physics teachers, 13 of whom were females. Ages of the participants ranged from 22 to 24 years. The participants were distributed randomly to the experimental and control classes. The experimental class was randomly selected by drawing lots. The instructional strategy in the experimental class was model-based inquiry (MBI) while it was inquiry in the control class. There were six females and five males in the experimental class. Anonymity was preserved by using codes for the participants; therefore, MB1 through MB11 represented the pre-service teachers in the model-based inquiry class and I1 through I11 represented the pre-service teachers in the inquiry class.

The study took place in an elective course called Conceptual Physics in the physics teacher education program at a state university. The course aimed to develop participants' conceptual knowledge of dynamics and help them reformulate their views of effective science teaching. The pre-service physics teachers in both classes took the course for 2 hours per week and worked as groups when it was necessary. In the experimental class, MB1 worked with MB2, MB3 worked with MB4, MB5 worked with MB6, MB7 worked with MB8, and MB9 worked with MB10 and MB11. The students constructed their models and conducted experiments as groups;

however, they designed their initial models, wrote their inquiry reports, and made their presentations about daily life events or scientists' models individually.

Treatment and Instructional Context

Both the experimental and control classes studied the same dynamics concepts with the same instructor. Since the pre-service teachers in the program knew the traditional laboratory activities but were not familiar with inquiry (Arslan, Ogan-Bekiroglu, Suzuk & Gurel, 2014), the instruction in the first and second weeks of the semester focused on implementation of inquiry in the control class and implementation of model-based inquiry in the experimental class. The model-based inquiry class was requested to generate initial models, develop inquiry questions, propose hypotheses, do investigations and conduct experiments to test their models. They constructed three-dimensional models and revised their models. The inquiry class was also requested to develop inquiry questions, propose hypotheses, do investigations and conduct experiments to test hypotheses. However, they were not asked to generate initial models in the beginning of the inquiry. Models were not the center of the inquiry in the control class. Five epistemic characteristics of scientific knowledge stated in the theoretical framework were considered to make a difference in both classes. Therefore, in the inquiry class, hypotheses were tested and conclusions summarized patterns in the data. On the other hand, in the model-based inquiry class, models were tested and revised, hypotheses were evaluated based on the models, and models were used for explanations. Table 1 demonstrates the similarities and differences in two classes.

Table 1. Inquiry and model-based inquiry implementations in the control and experimental classes

Control Class - Inquiry	Experimental Class – Model-Based Inquiry
Worksheet for the activity was distributed. The students were started to work as groups. They determined the problem and developed inquiry questions.	Worksheet for the activity was distributed. The students were started to work as groups. They generated initial models suggested processes or structures potentially explanatory of the phenomenon. They developed inquiry questions in tandem with their models.
The students stated potential relationships between variables and proposed hypotheses. They conducted experiments and took measurements to test the hypotheses.	The students stated potential relationships between variables and used their models to propose hypotheses. They conducted experiments and took measurements to test the models.
The students collected data and recorded measurements. They started to write their inquiry reports.	The students used models to collect data and evaluated the hypothesis. They modified their models if it was necessary. They started to write their inquiry reports.
The students discussed and analyzed the data and drew conclusions in conjunction with patterns in the data.	The students used patterns in the data and models to explain the phenomenon. They discussed and revised their models by taking into account additional evidence or aspects of the phenomenon.
The students presented their experiments as groups and discussed how their experiments could be used to test different hypotheses. They argued about if their conclusions could be explanations for other phenomena. They handed their inquiry reports in.	The students presented their models as groups and discussed how their models could generate different hypotheses. They argued about if their models could apply to other phenomena. They handed their inquiry reports in.

The participants in both classes worked on two inquiry activities during the course period. Each activity lasted five weeks. The first activity was about a half pipe in a skate park. The question was as follows: The person sitting on the deck of the half pipe showing in the picture wants to send a ball to his friend sitting on the opposite deck by rolling it in the pipe instead of throwing the ball. If height, transition and flat bottom of the half-pipe can be changed, how can the person send the ball as fast as possible?

The second activity was based on the difference between Galileo's and Aristotle's ideas about falling objects. The participants were given a discussion in an unfinished dialogue among three people and asked to explain who was right and who was wrong by providing evidence. They were also asked to complete the unfinished dialogue. The dialogue given in appendix was taken from the book written by Galileo Galilei, which was translated by Crew and Salvio in 1914. The names in the dialogue were changed. The participants in both classes involved with thought experiments and conducted free fall experiments in air, non-air and viscous liquid mediums. They argued about whether the knowledge they generated could be used to explain other phenomena such as some sports activities including bungee jumping, zorbing and cliff diving. Group and class discussions were carried out in both classes whenever needed. Instructional context in two classes is given in Table 2 week by week.

Table 2. Instructional context in two classes

Weeks	Inquiry Class	Model-Based Inquiry Class
1-2	Inquiry was explained as a teaching strategy and some cases were given as examples.	Model-Based Inquiry (MBI) was explained as a teaching strategy and some cases were given as examples.
3	Force Concept Inventory (FCI) was applied as the pre-test.	FCI was applied as the pre-test.
4-8	Inquiry was implemented for the first activity. Experiments were related to an inclined plane.	MBI was implemented for the first activity. Experiments were related to an inclined plane.
9-13	Inquiry was implemented for the second activity. Experiments were related to free fall of various objects with different features in various mediums.	MBI was implemented for the second activity. Experiments were related to free fall of various objects with different features in various mediums.
14	FCI was applied as the post-test.	FCI was applied as the post-test.

Role of the Researchers

The authors of this paper were physics educators. The first author was the instructor of the course; therefore, she had two roles. One was as a teacher and the other one was as a researcher. Two researchers prepared the lesson plans and worksheets together both for the control class and for the experimental class to make sure that the only difference between the classes was modelling. The first author observed and guided the groups, started and led discussions, and prevented irrelevant talk during the activities. Her behaviors were the same during the administrations of the FCI in both classes. Both authors had roles in planning the activities, conducting the research, and analyzing the data.

Data Collection Methods

Data were collected from the control and experimental classes by using the same methods. The Force Concept Inventory (FCI) was administered in the pre- and post-tests during the third and fourteenth weeks of the course. The FCI was developed by Hestenes et al. (1992) and revised by Halloun et al. (1995), as cited in Mazur (1997). This inventory has been translated to many languages and used in much international research to measure learning of dynamics concepts (Savinainen & Scott 2002). The FCI measures the following six fundamental concepts in general: kinematics, Newton’s First Law, Newton’s Second Law, Newton’s Third Law, superposition principle, and kinds of force. Some of the questions measure more than one concept. There are 30 multiple-choice questions in the FCI.

In order to understand the students’ reasoning and to assess their conceptual learning in detail, the students were required to write their justifications for their choices of the questions during both applications of the inventory. The 11-week duration between the pre- and post-tests helped the researchers to control the effect of retesting (Krathwohl 1997). Internal consistency computed by the Kuder Richardson formula 20 was high (Salvucci, Walter, Conley, Fink, & Saba, 1997) with reliability coefficients of 0.75 for the pre-test and 0.79 for the post-test. Furthermore, the participants in both classes and the instructor were videotaped during the instruction.

The groups were also tape-recorded while they were working on the activities. The groups’ inquiry reports and the instructor’s field notes were also data sources. These multiple data sources were used to be make sure that the participants followed the inquiry and model-based inquiry processes, to assess their conceptual understanding, and to evaluate their models.

Data Analysis

A bidimensional coding scheme developed by Hogan and Fisherkeller (1996) was used to analyze the participants' responses in the pre- and post-tests. In order to do statistical analysis, scores from 0 to 6 were assigned to the codes. If a student chose the correct answer, her explanation was consistent with scientific knowledge and it was detailed or adequate, her response was coded as "compatible elaborate" and given "6". If a student chose the correct answer, her explanation was consistent with scientific knowledge but it was superficial or inadequate, her response was coded as "compatible sketchy" and given "5". If a student chose the correct choice but her explanation was not scientific, her response was coded as "compatible/incompatible" and given "4". On the other hand, if a student's choice was not correct, her explanation was inconsistent with scientific knowledge and it was shallow, her response was coded as "incompatible sketchy" and given "3". If a student's choice was not correct, her explanation was inconsistent with scientific knowledge and it was detailed with unrelated concepts, her response was coded as "incompatible elaborate" and given "2". If a student made a choice, whether it was correct or not, but she did not explain the reason, her response was coded as "no evidence" and given "1". If a student neither made a choice nor gave an explanation, her response was coded as "no response" and given "0".

Question 28 is provided as an example for each response code. The question is as follows: Student "a" has a mass of 95 kg and student "b" has a mass of 77 kg. They sit in identical office chairs facing each other. Student "a" places his bare feet on the knees of student "b". Student "a" then suddenly pushes outward with his feet, causing both chairs to move. During the push and while the students are still touching one another:

A. Neither student exerts a force on the other.
B. Student "a" exerts a force on student "b," but "b" does not exert any force on "a."
C. Each student exerts a force on the other, but "b" exerts the larger force.
D. Each student exerts a force on the other, but "a" exerts the larger force.
E. Each student exerts the same amount of force on the other.

Compatible elaboration: "The correct answer is "E" because mass does not have any effect here. Based on Newton's Third Law of motion, when student "a" exerts the force on student "b," student "b" exerts the equal and opposite force on student "a".
Compatible sketchy: "The correct answer is "E" because both students exert the same amount of force on each other".
Compatible/incompatible: "The correct answer is "E" because the same amount of force during the interaction makes the students stop".
Incompatible sketchy: "The correct answer is "D" because slim people lose rope-pulling contests.
Incompatible elaboration: "The correct answer is "D" because student "a" was heavier than student "b" and also because there was a pushing force, student "a" exerts the larger force".
No evidence: "The correct answer is "E". No reason is given.

The coding scheme of the students' knowledge before and after the instruction was made by the first author. To assess the reliability of this coding, the second author randomly selected 10 questions from the pre- and post-tests and coded the participants' knowledge. Then, the two authors compared their coding and were able to reach 92 % agreement. The reliability measured by Cohen's κ was 0.76. There seems to be general agreement that Cohen's κ value should be at least 0.60 or 0.70 (Wood 2007). Consequently, the coding done for the participants' knowledge had adequate reliability. The authors reviewed the knowledge levels that they could not have agreement on and the final coding scheme was constructed by reaching consensus. The first author then revised all the codes of the participants' conceptual knowledge one more time. Mann Whitney U tests were used to compare the experimental class's performances with the control class's performances. Wilcoxon signed-rank tests were performed in order to make comparisons within the classes.

Tape and video records were transcribed. Then, content analysis approach was used to analyze the instructor's field notes, transcripts and the participants' inquiry reports to identify any conceptual change in the participants' mental models and the justifications for that. The students' initial and final models were examined from three perspectives: the nature of models, the function of models, and the role of models in inquiry (Windschitl, Thompson & Braaten, 2008b). Their models were rated based on each of these perspectives and the criteria listed in Table 3. A rating of "3" represented models that were most congruent with those of experts, a rating of "1" represented models that were least congruent with those of experts, and "2" represented an intermediate level of sophistication for models. The participants constructed their initial and final models as groups.

Table 3. Criteria for model evaluation (Windschitl, Thompson & Braaten, 2008b).

Nature of Models	Function of Models	Role of Models in Inquiry
“3” Most congruent with experts’ models		
Can portray conceptual/theoretical as well as observable processes and relationships.	Tools to advance scientific ideas rather than only being a product of inquiry are generalizable, can be used to predict.	Research questions are conceived of within the context of a model.
Represent ideas rather than ‘things.”	Tools to advance scientific ideas rather than only being a product of inquiry allow novel insights into relationships, and help generate questions for inquiry.	Hypotheses are parts of models that will be tested.
Models fallible in concept because they are based on interpretation and inference.		Models are revised through argument that uses data and logic, must be consistent with evidence, other models, theories.
Models have logical limits and underlying assumptions.		Empirical data can be used to argue for theoretical ‘pieces” (structures or processes) of models.
Models can differ not only because of representational modes, but because a phenomenon is totally reconceptualized.		Models can change not only as result of empirical ‘fine-tuning” but also because target phenomenon is reconceptualized in new way.
“2” Intermediate		
Models portray processes and systems that may not be directly observable, but are taken to be real.	Facilitates understanding, helps others to understand what an expert knows.	Scientific inquiry is done first, then create a model based on data.
Models can take form of mathematical representation or set of rules.	Are generalizable, used to describe different situations.	Models can help one think of things to investigate.
Models of same thing can be different because there are different modes of representation.	Helps analyze effects/variables of some complicated system.	Hypotheses are models.
		Data can be collected from models themselves. It is important to collect data on actual phenomenon (rather than exclusively from a model) if possible. Models are changed only if they do not match/predict data.
“1” Least congruent with experts’ models		
Models are pictorial or physical replications of ‘things” considered to be real.	To simplify, illustrate, show	Model development not recognized as part of scientific inquiry; models function only to illustrate, simplify, help communicate ideas.
Object of model may be too small, too large or inaccessible to direct observation.		Hypotheses are ‘best guesses” from unspecified background knowledge.
Relation of model to thing being modeled: object of model is more complex.		Relationships between empirical observations and theory unspecified.
Models can be different from one another because of different ‘looks” at the object.		Fact that data can be collected from models themselves is unacknowledged.
		Argument may be synonymous with ‘conclusions;” directed toward determining if questions are answered rather than using patterns in data to support or refute models.

Results and Discussion

The results of Mann-Whitney U tests for two classes' pre-tests showing in Table 4 and post-tests showing in Table 4 indicate that there was not any significant difference between two classes' performances before and after the treatment. This finding is in line with the result of the research done by Campbell et al. (2011), who compared MBI with traditional instructional strategy. Table 5 illustrates that the difference between the control class's pre- and post-test performance based on Wilcoxon signed-rank test was not significant, either.

Table 4. The results of Mann-Whitney U test for the classes' pre-test and post-test scores

Groups	N	Mean Rank	Sum of Ranks	MWU	z	p
Inquiry Pre-Test	11	12.73	140.00	47.000	-.887	.401
MBI Pre-Test	11	10.27	113.00			
Inquiry Post-Test	11	12.27	135.00	52.000	-.558	.606
MBI Post-Test	11	10.73	118.00			

On the other hand, according to Table 5, the results of Wilcoxon signed-rank test for the experimental class were in the expected direction (z = -2.667) and sum of positive ranks was significantly higher than the sum of negative ranks ($p<.01$). That is, the experimental class's post FCI scores were better than their pre FCI scores (mean rank of 6.30 vs. mean rank of 3.00). These findings present that model-based inquiry supported the learning process. When the students were given a chance to generate and revise models, they tended to select the scientific choices of the questions from the FCI, made better explanations for their choices and reached higher level of conceptual understanding. This result is consistent with the results that emerged from the research by Khan (2007) and Sun and Looi (2013).

Table 5. The results of Wilcoxon signed-rank test for the control (inquiry) and experimental (MBI) classes

Cont. Post-Test – Cont. Pre-Test	N	Mean Rank	Sum of Ranks	z	p
Negative Ranks	4	3.75	15.00	-1.602	.109
Positive Ranks	7	7.29	51.00		
Ties	0				
Total	11				
Exp. Post-Test – Exp. Pre-Test	**N**	**Mean Rank**	**Sum of Ranks**	**z**	**p**
Negative Ranks	1	3.00	3.00	-2.667	.008
Positive Ranks	10	6.30	63.00		
Ties	0				
Total	11				

Table 6 enables to analyze participants individually by providing their mean scores of the fundamental six concepts measuring in both pre- and post- administrations of the FCI and their differences. Regarding Table 6, nine students in the model-based inquiry class and nine students in the inquiry class revealed overall conceptual progression from pre-test to post-test considering the sum of differences in mean scores of the fundamental concepts (see the last column). Overall improvement of seven students (MB1, MB2, MB5, MB6, MB7, MB9, and MB11) in the experimental class and overall improvement of five students (I, I2, I4, I10, and I11) in the control class were higher than the score of 3. On the other hand, there was a decay in conceptual knowledge of the following students: MB8, MB10, I6, and I8. Two activities did not directly cover all the subjects such as centripetal force in the questions. As a result, the students in both classes could not construct much new knowledge in every concept and did not establish remarkable significant differences between pre- and post-tests.

Table 7 shows mean values of ratings of the groups' initial and final models that they constructed in two activities based on three perspectives and also gives mean of these mean values. According to the table, the students in the model-based class revised and changed their models with regards to their nature and function as well as their roles in inquiry. Apart from Group 4, all the groups improved their models' roles in inquiry. Unfortunately, Group 4 whose members were MB7 and MB8 did not recognize model development as part of scientific inquiry. This finding illustrates that situating modelling in inquiry frames helped the participants understand building and testing of models was inquiry. It can be seen that all the groups increased their mean of mean values when they constructed final models. This finding is parallel with the finding that the students excepting for MB8 and MB10 in the model-based class increased their FCI scores (see Table 6). There might be a relation between students' model improvement and their conceptual development.

Table 6. The participants' mean scores of six fundamental concepts measured in the pre- and post- FCI administrations and their differences

P	Post MC1	Pre MC1	D1 = Post MC1 - Pre MC1	Post MC2	Pre MC2	D2 = Post MC2 - Pre MC2	Post MC3	Pre MC3	D3 = Post MC3 - Pre MC3	Post MC4	Pre MC4	D4 = Post MC4 - Pre MC4	Post MC5	Pre MC5	D5 = Post MC5 - Pre MC5	Post MC6	Pre MC6	D6 = Post MC6 - Pre MC6	D1 + D2 + D3 + D4 + D5 + D6
MB1	4.34	3.34	**1**	3.78	3.11	**0.67**	2.75	3	**-0.25**	3.75	1.25	**2.5**	5.17	3.33	**1.84**	5	3.8	**1.2**	**6.95**
MB2	5.5	5	**0.5**	5.89	5.89	**0**	5.5	5.25	**0.25**	4.75	2.5	**2.25**	5	5.33	**-0.33**	5	4.6	**0.4**	**3.07**
MB3	3.16	3.33	**-0.17**	3.44	2.55	**0.89**	3.75	4	**-0.25**	2.75	2	**0.75**	1.67	2	**-0.34**	2.8	3.13	**-0.33**	**0.55**
MB4	2.67	3.33	**-0.67**	3.33	3.44	**-0.11**	3	3	**0**	4	1.5	**2.5**	1.83	2.67	**-0.83**	2.93	3.2	**-0.27**	**0.62**
MB5	1.67	2.5	**-0.83**	3.11	2.11	**1**	3	1.5	**1.5**	5	2.5	**2.5**	2.5	1.5	**1**	3.2	2.93	**0.27**	**5.43**
MB6	3	2	**1**	2.33	2.67	**-0.33**	3.25	1	**2.25**	4	4.75	**-0.75**	2.33	2.33	**0**	4	2.47	**1.53**	**3.7**
MB7	4.67	3.67	**1**	2	2.44	**-0.44**	3.75	1.5	**2.25**	3	1	**2**	2.83	2.5	**0.33**	4.67	3.47	**1.2**	**6.34**
MB8	2.67	4.33	**-1.67**	1.89	2.11	**-0.22**	1	2.5	**-1.5**	4.5	2.5	**2**	2.17	1.83	**0.33**	3.33	3.33	**0**	**-1.05**
MB9	2.33	1.83	**0.5**	2.33	2.89	**-0.55**	2.25	1.75	**0.5**	5	3	**2**	3.33	2.5	**0.83**	3.47	3	**0.47**	**3.74**
MB10	2	1.83	**0.17**	2.11	1.78	**0.33**	1.75	1.5	**0.25**	2.25	4	**-1.75**	1.5	2	**-0.5**	2	2.8	**-0.8**	**-2.3**
MB11	3	1	**2**	3.55	2	**1.55**	4.5	1	**3.5**	3.25	1.5	**1.75**	3.17	2	**1.17**	2.53	2.6	**-0.07**	**9.90**
I1	3.67	3.17	**0.5**	4.22	3.55	**0.67**	3	3	**0**	4	3.75	**0.25**	4.5	3.17	**1.33**	4.6	2.2	**2.4**	**5.15**
I2	3.67	3.33	**0.33**	4.11	3.22	**0.89**	3.5	3.25	**0.25**	3	3	**0**	4.17	3.33	**0.83**	4.47	2.4	**2.07**	**4.37**
I3	4.33	3.33	**1**	3.22	3.78	**-0.55**	3.75	3.75	**0**	4.25	3.75	**0.5**	3	3.17	**-0.17**	4.13	3.27	**0.87**	**1.64**
I4	3.83	2.83	**1**	3.44	2.67	**0.78**	5	2.5	**2.5**	3	2	**1**	2.83	2.67	**0.17**	3.87	3.53	**0.33**	**5.78**
I5	3.33	2.83	**0.5**	3.78	3.23	**0.55**	3.25	2.5	**0.75**	6	6	**0**	4	3.5	**0.5**	2.8	4.27	**-1.46**	**0.84**
I6	2.5	4.17	**-1.67**	1.89	3.44	**-1.55**	3.25	3.5	**-0.25**	4.25	4.5	**-0.25**	1.83	3	**-1.17**	3.53	3.53	**0**	**-4.89**
I7	5.5	4.67	**0.83**	4.33	5.33	**-1**	5.5	4.75	**0.75**	4.75	4.25	**0.5**	3.83	5	**-1.17**	5.73	4.67	**1.07**	**0.98**
I8	1	1.83	**-0.83**	1.78	1.55	**0.22**	1	1.25	**-0.25**	2	2	**0**	1.83	1.83	**0**	1.6	1.67	**-0.07**	**-0.93**
I9	2.17	2.33	**-0.17**	2.22	2	**0.22**	3.5	2.25	**1.25**	3.25	2.75	**0.5**	1.67	2.33	**-0.66**	1.2	2	**-0.8**	**0.34**
I10	3.17	3	**0.17**	3.44	2	**1.44**	3.25	3	**0.25**	5	3.25	**1.75**	3.33	1.5	**1.83**	2.6	2.93	**-0.33**	**5.11**
I11	3	2.17	**0.83**	3.89	2.11	**1.78**	4.25	1.25	**3**	3.5	2.5	**1**	2.17	1.83	**0.33**	3.33	1.87	**1.47**	**8.41**

P: Participant. MB: The participant in the model-based inquiry class. I: The participant in the inquiry class. MC1: Mean scores for the first concept i.e. kinematics. MC2: Mean scores for the second concept. i.e. Newton's First Law. MC3: Mean scores for the third concept i.e. Newton's Second Law. MC4: Mean scores for the fourth concept i.e. Newton's Third Law. MC5: Mean scores for the fifth concept i.e. superposition principle. MC6: Mean scores for the sixth concept i.e. kinds of force. D: Differences between post-test mean scores and pre-test mean scores. Post: Post administration of the FCI. Pre: Pre administration of the FCI

Most of the participants in the experimental class showed great progression for the fourth concept i.e. Newton's Third Law. The reason for this finding might be that these students discussed Newton's models of motion. They demonstrated force diagrams on their models and came to a conclusion that action and reaction forces did not exert on the same object. Additionally, MB5's, MB6's, MB7's, and MB11's knowledge of Newton's Second Law (third concept) developed well from pre-test to post-test. The questions assessing the knowledge of Newton's Second Law in the FCI were associated with motion of an object under various forces. These students spent much time discussing the ball's trajectory while they were working on their models for the duration of the first activity, so that they wrote scientific explanations for their choices in the post FCI administration. These findings support Löhner et al. (2005)'s idea that in an inquiry-modeling task, learners can learn about the domain by doing experiments and by expressing their acquired ideas in a model.

Table 7. Mean values of ratings of the groups' initial and final models that they constructed in two activities based on three perspectives and mean of mean values

Groups and Members	Initial Models				Final Models			
	Nature	Function	Inquiry	Mean	Nature	Function	Inquiry	Mean
1 (MB1, MB2)	1.5	1.5	1.5	1.5	2	2	2.5	2.17
2 (MB3, MB4)	2	2	2	2	2.5	2.5	2.5	2.5
3 (MB5, MB6)	2	1.5	1.5	1.67	2	2	3	2.67
4 (MB7, MB8)	1	1	1	1	1.5	1.5	1	1.34
5 (MB9, MB10, MB11)	1.5	1.5	1.5	1.5	1.5	1.5	2	1.67

MB1, MB2, MB5, and MB6 enhanced not only their conceptual knowledge but also their models. For example, Figure 1 presents initial model of MB1 and MB2 for the second activity while Figure 2 illustrates their final model for the same activity. Revising their initial models might cause revising their mental models.

MB11 provided more correct answers with their scientific explanations for the questions related to the concepts of kinematics, Newton's First, Second, and Third Laws during the post-test. His answers to the FCI questions were more detailed and supported with visual diagrams during the post-test. He was very active during the discussions.

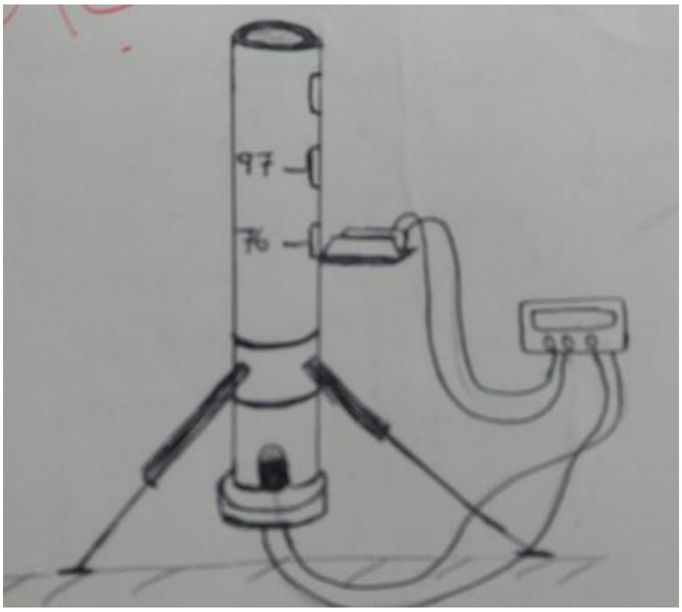

Figure 1. . Initial model of MB1 and MB2 for the second activity

He was the only one in the class who could generate mathematical model of acceleration. Besides, he could indicate in their initial model and explain how two objects having different masses drop on the floor at the same time in a frictionless medium.

Figure 2. Final model MB1 and MB2 for the second activity

MB3 and MB4 were in the same group and they showed little conceptual growth. The first model they created focused on the relationship between friction and heat. They tried to make a correlation between free fall and height in their second model. Since they did not analyze force diagrams in none of their models and could not take much measurement on their models, they might not improve their understanding. These findings seem to be in agreement with Löhner et al. (2005)'s expectation that the different representations used in modeling tools may have differential effects on students' reasoning processes. Likewise, Ogan-Bekiroglu (2007) concluded that the closer students' models were to the real situations, the more scientific conceptions they gained. The limitations of their models might not facilitate conceptual progress of MB3 and MB4. While MB3 and MB4 were presenting their second model, the following conversation occurred between them and the instructor:

Instructor: If action and reaction is equal to each other, why do we not fly? Or why does this glass stand on the table?
MB3: Because there is a gravitational force as an extra force.
MB4: To me it has an initial velocity.
Instructor: There is no movement. Can you explain to me what you are saying?
MB3: Our action force is not equal to our reaction force. Gravitational force is heavier.

Unfortunately, MB10 was not in the class most of the time. His mean scores of six concepts generally dropped or they increased very little from the pre-test to post-test of the FCI (see Table 6). He provided much explanation for his nonscientific choices during the pre-test. His choices were different but again nonscientific in the post-test. Moreover, this time he did not give detailed explanation for them. Moreover, the researcher realized that MB10 had some misconceptions during their informal conversation while the students were working on their models. An excerpt from the conversation is given below:

MB9: This is a reaction force. What would happen if this force does not exist? What would happen to the object if the reaction force does not exist?
MB10: The object would not exist.
MB11: One second! The object would not move; it would stand still.
MB10: It would be flying.
MB9: N = mg. There is a reaction force exerting on the object.
MB11: Yes, it's true.
.....
Instructor: Is the object standing still?
MB10: Yes.
MB1: The net force on the y axis is zero.
Instructor: Why?
MB1: Action and reaction forces are in balance.
Instructor: Do the action and reaction forces cancel each other?
MB9: Exactly
MB10: They are equal but they are in opposite directions.

MB7 and MB8 were in the same group and generated their models together. However, MB7 did most of the work while MB8 did not contribute much. MB8's involvement with modelling process might affect her conceptual development so that her overall scores fell by 1.05 points.

I1 and I2 demonstrated conceptually higher performance in the post-administration of the FCI for the concept of kinds of force (sixth concept) than in the pre-administration of the FCI. This result is compatible with the result presented by Hakkarainen (2003). I1 generally gave detailed explanations for her choices even her choices were scientific or not. Due to the fact that her choices were more scientific during the post-test, there appeared a big difference between her pre- and post-test scores. She was a teaching assistant in lab sections and could define dependent and independent variables correctly. She produced nine research questions for the first activity and five research questions for the second activity.

Both I1 and I2 participated in the class discussions enthusiastically. I1 related her second experiment with bungee jumping and explored the importance of tension of the rope as well as gravity. I2 could make fault analyses in their experiment and revised it. She expanded on Felix Baumgartner's jumping to Earth from a helium balloon in the stratosphere while examining free fall and gravity. These daily life connections and active participation might enable them to make improvement in their conceptual knowledge. The dialog given below passed between I1 and I2 during their first experiment:

I1: We considered coefficient of friction. It is important for us. Height of the point where the ball is held by the child is also important because the ball has a potential energy due to the fact that it does not have any initial velocity. If it has initial velocity, it is important too. We think that mass of the ball is negligible.
I2: Yes, mass of the ball is not taken into consideration.
Instructor: Why is that?
I2: When we construct an energy equation, the masses on the left and right cancel each other out.

I11 left his misconceptions and gained scientific knowledge for the concepts of Newton's First and Second Laws as well as kinds of force during the post-administration of the FCI. He searched for g-max experience and elucidated the physics laws working during this experience. Although he chose the scientific answer in the pre-test, he did not explain the reason behind his answer. He focused more on theory during the inquiry process and examined the system of a catapult by himself to perform his experiment. His research question was in line with his hypothesis unlike most of other students. Finally, he offered detailed statements for his scientific choices during the post administration of the FCI.

On the other hand, I6's scores decreased from pre-test to post-test for all the concepts apart from kinds of force. She always passed the deadline for handing inquiry reports in and could not attend most of the classes. She made connections with her past experiences but did not consider theoretical propositions and formulas during the inquiry activities. She could try to explain cliff diving but her explanations were weak in terms of including scientific schemes. These situations might cause regress in her reasoning.

Examination of Table 6 also allows us to compare experimental and control classes' performances based on the fundamental concepts assessed in the FCI. The number of students who gained scientific knowledge was equal in both classes for the concepts of Newton's Second Law, superposition, and kinds of forces. Regarding the concepts of kinematics and Newton's First Law, more number of participants in the inquiry class improved their understanding then the number of participants in the model-based inquiry class. The participants in the inquiry class extended their conclusions to the sportsmen's movement, their trajectory and the forces exert on them. These examples might cause shift in some of the students' misconceptions so that their answers in the post-test became more scientific. The students in the inquiry class also elicited buoyancy and drew force diagrams during the sports activities including jumping. In addition, I11 presented mathematical models allied with a catapult and rotational motion. These generations might cause the cognitive improvement for the students in the inquiry class for the concepts of kinematics and Newton's First Law.

The model-based inquiry class discussed Galilei's model and discovered how he reached the concept of acceleration by changing the angle of inclination. Moreover, they compared Aristotle's question "what causes an object to move" to Descartes's question "what causes an object to stop moving". These discussions might help some students' progress conceptually. On the other hand, more number of students in the model-based inquiry class gained knowledge of Newton's Third Law than the number of students in the inquiry class. This concept was argued in both activities in the experimental class. There might be a chance that the more time students involve in modelling process the more their mental models improve.

Conclusions

Keselman (2003) states that inquiry learning cannot be achieved merely by placing students in the midst of a complex scientific domain for free-reign investigation. Since simple inquiry tasks may fail to help students learn to reason scientifically (Chinn & Malhotra, 2002), it has been argued in this research that the process of revising models that learners themselves constructed through inquiry activities to reflect advances in their understanding was more effective than traditional inquiry activities. This argumentation is based on Passmore et al. (2009)'s hypothesis about model-based learning. The following conclusions can be drawn from the study: Putting modelling explicitly into the center of inquiry facilitates conceptual learning. Therefore, model building and formation in inquiry can be seen as a way not only to represent what learners have already known but also to generate new knowledge. Keselman (2003) also claims that it is important that teachers conclude classroom inquiry learning activities with discussion and clarification sessions, ensuring that students do not walk away from these activities with incorrect conceptual information. To reconceptualize school science inquiry, researchers (Smith, Maclin, Houghton, & Hennessey, 2000; Windschitl, Thompson, & Braaten, 2007) advocate for coordinating the language and activities in classrooms around five epistemic features of scientific knowledge. Consequently, making associations with other phenomena under the framework of epistemic characters of knowledge and expanding on these associations with discussions in inquiry learning environment promote students' understanding. In addition, if students involve in model-based inquiry activities in an adequate duration, their conceptual knowledge of science would reinforce. Finally, model quality may stimulate science learning; however, more research is needed to extend this conclusion because it comes from the group results.

Implications and Further Study

In this research, the students engaged in authentic inquiry like scientists do with the help of model-based inquiry. The current study contributes to the science education literature toward a better understanding of model-based inquiry as an instructional strategy in an authentic context. Model-based inquiry would be embedded in science teacher education programs to improve teacher candidates' science content knowledge and inquiry skills. For teachers and instructors, activities in this study would be examples of how inquiry and model-based inquiry can be implemented in science classrooms.

Further research would make comparison between learning and model quality in an individual basis. Moreover, studies would focus on how model-based inquiry capture the features of authentic science by examining participants' science process skills. Examination of participants' model understanding in a model-based inquiry environment would also make contribution in the area.

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APPENDIX

Dialogue used in the Second Activity

Jack: The argument is, as you see, ad hominem, that is, it is directed against those who thought the vacuum a prerequisite for motion. Now if I admit the argument to be conclusive and concede also that motion cannot take place in a vacuum, the assumption of a vacuum considered absolutely and not with reference to motion, is not thereby invalidated. But to tell you what the ancients might possibly have replied and in order to better understand just how conclusive Aristotle's demonstration is, we may, in my opinion, deny both of his assumptions. And as to the first, I greatly doubt that Aristotle ever tested by experiment whether it be true that two stones, one weighing ten times as much as the other, if allowed to fall, at the same instant, from a height of, say, 100 cubits, would so differ in speed that when the heavier had reached the ground, the other would not have fallen more than 10 cubits.

William: His language would seem to indicate that he had tried the experiment, because he says: We see the heavier; now the word shows that he had made the experiment.

George: But I, William, who have made the test can assure you that a cannon ball weighing one or two hundred pounds, or even more, will not reach the ground by as much as a span ahead of a musket ball weighing only half a pound, provided both are dropped from a height of 200 cubits.

Jack: But, even without further experiment, it is possible to prove clearly, by means of a short and conclusive argument, that a heavier body does not move more rapidly than a lighter one provided both bodies are of the same material and in short such as those mentioned by Aristotle. But tell me, William, whether you admit that each falling body acquires a definite speed fixed by nature, a velocity which cannot be increased or diminished except by the use of force or resistance.

William: There can be no doubt but that one and the same body moving in a single medium has a fixed velocity which is determined by nature and which cannot be increased except by the addition of momentum or diminished except by some resistance which retards it.

Jack: If then we take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter. Do you not agree with me in this opinion?

William: You are unquestionably right.

Jack: But if this is true, and if a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight; but the two stones when tied together make a stone larger than that which before moved with a speed of eight. Hence the heavier body moves with less speed than the lighter; an effect which is contrary to your supposition. Thus you see how, from your assumption that the heavier body moves more rapidly than the lighter one, I infer that the heavier body moves more slowly.

William: I am all at sea because it appears to me that the smaller stone when added to the larger increases its weight and by adding weight I do not see how it can fail to increase its speed or, at least, not to diminish it.

Jack: Here again you are in error, William, because it is not true that the smaller stone adds weight to the larger.

William: This is, indeed, quite beyond my comprehension.