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Examination of the Effects of Model-Based Inquiry on Students' Outcomes: Scientific Process Skills and Conceptual Knowledge

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Abstract

The current study suggests embedding of modelling in inquiry. Therefore, the purpose of this research was to empirically identify the effects of implementation of model-based inquiry on students' scientific process skills and conceptual knowledge. This study was framed theoretically by the Practice Framework which reflects model-based inquiry view of science. True-experimental design using quantitative research methods was carried out for the study. Participants of the research were pre-service physics teachers. Model-based inquiry was implemented in the experimental group while the control group worked in an inquiry-based environment. Therefore, guided inquiry was implemented in both groups but the control group did not build a model. The inquiry intervention lasted 10 weeks and was related to dynamics concepts. Data were collected by using the Integrated Process Skill Test and the Force Concept Inventory. The participants in both groups did not show any difference in their overall scores of scientific process skills and conceptual knowledge after the instruction However, when their scores of scientific process skills were compared in terms of the five dimensions in the test, it was found that while the control group increased their performances significantly in the dimensions of identifying variables and stating hypothesis, the experimental group improved their scores significantly in these two dimensions as well as in the dimensions of operational definitions and data and graph interpretations. This study adds to the limited research in the area of model-based inquiry by examining its effectiveness when used in a science classroom.

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Keywords: Model-based inquiry, physics, science process skills, conceptual knowledge;

1. Introduction

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In spite of the recommendations for using inquiry in science classrooms, research indicates some difficulties during inquiry process. Campbell, Zhang and Neilson (2011) reviewed the literature and documented the following problems that teachers identified when seeking to employ inquiry as an instructional strategy: (1) lack of clarity with respect to what constitutes inquiry, (2) lack of examples of how inquiry is facilitated as an instructional strategy in real classrooms, and (3) the lack of the explicit association of inquiry with science content.

Modelling is a core practice in science and a central part of scientific literacy (Schwarz et al., 2009). Therefore, the current study suggests embedding of modelling in inquiry that is model-based inquiry. Model-based inquiry (MBI) is a system of activity and discourse that engages learners more deeply with content and embodies five epistemic characteristics of scientific knowledge: that it is testable, revisable, explanatory, conjectural, and generative (Windschitl, Thomson & Braaten, 2008). According to Schwarz (2009), MBI is an instructional approach in which learners engage in scientific inquiry whose focus is on the creation, evaluation, and revision of scientific models that can be applied to understand and predict the natural world. Therefore, the purpose of this research was to empirically identify the effects of implementation of model-based inquiry on students' scientific process skills and conceptual knowledge.

2. Theoretical Framework

This study was framed theoretically by the Practice Framework (Passmore, Stewart & Cartier, 2009) which reflects model-based inquiry view of science. Passmore and her colleagues claim that the Practice Framework represents the products of inquiry (e.g., explanations and models) and allows us to emphasize that 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.

The Practice Framework is the only curricular framework that shows the relationships between and among models, explanations, and phenomena that make up discipline-specific practice (Passmore et al., 2009).

3. Methodology

3.1. Research Design and Participants

True-experimental design using quantitative research methods was carried out for the study. Participants of the research were pre-service physics teachers, who were in the fourth year of their five-year pre-service teacher education program in a state university. Their ages were around 23. The participants were used to cookbook-type lab experiments. They were randomly divided into two groups, one was the experimental group and the other one was the control group. There were 13 pre-service physics teachers in the experimental group.

3.2. Instructional Context

Model-based inquiry was implemented in the experimental group while the control group worked in an inquiry-based environment. Therefore, guided inquiry was implemented in both groups but the control group did not build a model. The inquiry intervention was implemented in a graduate elective course where the participants attended two hours a week. The intervention lasted 10 weeks and was related to dynamics concepts. Both groups defined research questions, made hypotheses, and designed and conducted experiments in order to solve the authentic problems. However, the experimental group began the practice with an initial model that is being tested. They had a modelling tool where they could express their acquired ideas in a model (Löhner, van Joolingen, Savelsbergh & van Hout-Wolters, 2005).

3.3. Role of the Researcher and Instructor Intervention

The instructor of both classes was the second author. She had two roles. One was as an instructor and the other one was as a researcher. However, she was only an instructor throughout the instruction. She did not analyse any data until the instruction was over. One of the roles of the instructor during the instruction was guidance. She observed the pre-service teachers, directed them to the next step, facilitated inquiry, started and led the discussion, and prevented irrelevant talk.

3.4. Data Collection and Analysis

Data were collected via the Integrated Process Skill Test (TIPS II) and the Force Concept Inventory. These inventories were administered in the pre- and post-test. TIPS II was developed by Burns, Okey and Wise (1985) to measure students' science process skills. The test includes 36 multiple-choice questions distributed under the following dimensions: identifying variables (12 questions), operationally defining (6 questions), stating hypothesis (9 questions), data and graph interpretation (6 questions), and designing experiment (3 questions). This inventory is designed for high school students. TIPS II was translated in Turkish and used by many researchers. For this research the Turkish translation of TIPS II's internal consistency computed by the Kuder Richardson formula (KR-20) was good, with reliability coefficients of 0.61 for the pre-test and 0.72 for the post-test.
The Force Concept Inventory (FCI) was developed by Hestenes, Wells and Swackhamer in 1992. There are 30 multiple-choice questions in the FCI. This inventory has been translated to many languages and used in much international research to measure learning of dynamics concepts (Savinainen & Scott, 2002). For this research, the Turkish translation of the FCI's internal consistency computed by the Kuder Richardson formula (KR-20) was good, with reliability coefficients of 0.75 for the pre-test and 0.79 for the post-test.
Non-parametric statistics was used to analyse the data due to the fact that the sample size was below 20 in each group. The Mann-Whitney U test was utilized to compare the experimental group and the control group. In addition, The Wilcoxon two-sample test helped to make comparison within the groups' pre-and post-tests.

4. Results and Discussion

4.1. Scientific Process Skills

The results of Mann-Whitney U test for the groups' TIPS II pre-test scores showed that there was no significant difference between the groups' scientific process skills before the instruction. The results also presented that the groups' scientific process skills were not different significantly from each other after the instruction. This means that model-based inquiry did not make any difference on the participants' overall scientific process skills. The pre-service teachers' final lab reports took important part in their grades. Their reports were evaluated in terms of forming a hypothesis, identification of variables, designing an experiment, drawing graphs, and interpretation of data. In addition to these criteria, the experimental group was required to explain their models in their lab reports. Consequently, both groups were evaluated with the same scientific process skills criteria. TIPS II did not include any questions related to model. These examination criteria might be the reason for this result.

Table 1. The results of Wilcoxon two-sample tests for the groups' TIPS II scores in the pre- and post-tests.

Group	N (Total)	Dimension	Change	N	Mean Rank	Sum of Ranks	z	p
Control	12	Identifying Variables	Positive	10	5.50	55.0	-2.85	0.004*
			Negative	0	.00	.00		
			Ties	2				

		Operationally Defining	Positive	6	4.92	29.50		
			Negative	3	5.17	15.50	-.85	0.4
			Ties	2				
		Stating Hypothesis	Positive	10	6.25	62.50		
			Negative	1	3.50	3.50	-2.68	0.01*
			Ties	1				
		Data and Graph Interpretation	Positive	8	4.81	38.50		
			Negative	1	6.50	6.50	-1.93	0.05
			Ties	3				
		Designing Experiment	Positive	3	2.00	6.00		
			Negative	0	.00	.00	-1.73	0.08
			Ties	9				
Experimental	13	Identifying Variables	Positive	9	7.72	69.5		
			Negative	3	2.83	8.50	-2.41	0.02*
			Ties	1				
		Operationally Defining	Positive	9	5.00	45.00		
			Negative	0	.00	.00	-2.7	0.01*
			Ties	4				
		Stating Hypothesis	Positive	12	6.50	78.00		
			Negative	0	.00	.00	-3.11	0.002*
			Ties	1				
		Data and Graph Interpretation	Positive	9	5.56	50.00		
			Negative	1	5.00	5.00	-2.45	0.01*
			Ties	3				
		Designing Experiment	Positive	6	5.00	30.00		
			Negative	3	5.00	15.00	-1.00	0.32
			Ties	4				

The results of Wilcoxon two-sample tests for the groups' TIPS II scores in the pre- and post-tests presented in Table 1. These tests were performed separately for the five dimensions in TIPS II. According to Table 1, the results of the tests for the control group in the identifying variables and stating hypothesis dimensions were in the expected direction ($z = -2.85$ and $z = -2.68$) and significant ($p<.05$). That is, the control group's post TIPS II scores were better than their pre TIPS II scores (mean rank of 5.50 and mean rank of 6.25) in the two dimensions. On the other hand, the experimental group showed significantly higher performance in the post TIPS II than they showed in the pre TIPS II for the dimensions of identifying variables, operationally defining, stating hypothesis, and data and graph interpretation (see Table 1). These findings indicate that while guided inquiry helped the pre-service physics teachers improve their skills in the dimensions of identifying variables and stating hypothesis, model-based inquiry enhanced the pre-service physics teachers' skills in two more dimensions at the end of the instruction. Thus, the pre-service physics teachers, who constructed, tested and revised their models, identified variables, stated hypothesis, made operational definitions, and interpreted data and graph better than they did before the instruction. The reason for this result might be that doing inquiry by basing their models helped the pre-service teachers focus on the content and inquiry process and prevented them to digress. This result is in line with the findings of Campbell et al. (2011), indicating that MBI was more effective at reducing science process differences that were initially found present.

4.2. Conceptual Knowledge

The results of Mann-Whitney U tests for the groups' FCI scores revealed that none of the groups showed significant difference in their conceptual knowledge after the instruction. The results of Wilcoxon two-sample tests comparing the pre-service teachers' FCI scores within the groups before and after the instruction demonstrated that there was no statistical difference. In other words, there was not any significant increase in the participants' conceptual knowledge of dynamics after involving with inquiry. These pre-service teachers completed the courses including the dynamics subject in previous years. They could not gain any knowledge by solving authentic problems in the inquiry process. This result is consistent with the result of Campbell et al. (2011). They worked with high school students and found no statistical differences between the traditional demonstration / lecture group and the model-based inquiry group in terms of the students' physics content knowledge after the instruction. However, the current result seems to be in contradiction with the results of Schwarz (2009). She reported that middle school students engaged in significant modelling-centred inquiry using technology and they improved their understanding of science content.

5. Conclusion and Suggestions

The following results can be drawn from the results: First, model-based inquiry improves students' scientific process skills. Second, model-based inquiry does not make any changes in students' conceptual knowledge if they already know the content.

This study adds to the limited research in the area of model-based inquiry by examining its effectiveness when used in a science classroom. Löner et al. (2005) stated that different modelling tools did induce significantly different reasoning activities. Further studies would investigate if type of the model that a student constructs during model-based inquiry has any effect on his/her learning.

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