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Exploration of Electromagnetic Waves with Investigative and Inquiry-Based Activities

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Abstract: Electromagnetic waves have been mathematically described by James Clerk Maxwell for the first time after many years of scientists' struggle to understand the world and the universe. Considering widespread use of technological devices emitting electromagnetic waves, their possible environmental and health effects, their role in rapidly advancing energy sector; electromagnetic waves have been a matter of curiosity amongst people. The reason of this curiosity is that electromagnetic waves do not fall directly into human observation range. The purpose of this study was using investigative and inquiry-based activities to make unobservable electromagnetic waves sensible and visible. In this context, 10 sequential demonstration activities were implemented to 46 teacher candidates continuing their education in third grade of science teacher education department. They were asked to note their predictions, observations and inferences down on the worksheets. Participants were surprised when a radio placed into a trashcan stopped playing music or a phone covered with aluminum foil did not receive calls since their observations contradicted with their common experiences. Bachelard defined this phenomenon as ''scientific discontinuity''. Even after weeks, participants tried to come up with explanations regarding their observations since their sense of curiosity was aroused and they had an irresistible desire for exploration. Classroom discussions were video recorded for detailed analysis. As intended; with the sequential activities, exploration of electromagnetic waves occurred at the end. In addition, with the light of inquiry, participants started thinking scientifically considering science as a part of their lives and a solution of problems. According to the results, it was determined that participants generally confused electromagnetic waves with sound waves, signal, power of attraction, frequency concepts. Recognition of some variables, comparisons between radio and microwaves by participants were observed. Interpretation of the data showed that participants generally had misconceptions and lack of knowledge regarding electromagnetic waves.

Keywords: Electromagnetic waves, Radio waves, Microwaves, science education, Electromagnetic wave theory

Introduction

Beginning from its existence, humankind tried to make sense of each phenomenon they encounter. Curiosity itself, is one of the main reasons of this effort to achieve the answers. Thinking, reasoning, asking, and searching are instinctive heritages of humankind that helps attaining knowledge.

Learning starts taking place when observations contradict with common experiences. Bachelard defined this phenomenon as ''scientific discontinuity''. In this study, with the use of sequential inquiry-based activities, participants encountered electromagnetic waves and their behaviors when confronting material environment that they may be heard about because of its increasing popularity among societies. Also, they were challenged when their common experiences or prior knowledge contradicted with that they saw, heard and felt during activities. With this regard, participants started to consider scientific thinking as a part of their lives and a solution of challenges.

After exploring electromagnetic waves and variables affecting their behavior on material environment, it is intended participants will go back their pre-existing ideas and modify them in such a way that they will be able

to make explanations based on evidences or secondary sources, which is one of the main aspects of inquiry-based learning as Harlen suggests (2014).

Electromagnetic waves have been mathematically described by James Clerk Maxwell for the first time after many years of scientists' struggle to understand the world and the universe. Considering widespread use of technological devices emitting electromagnetic waves, their possible environmental and health effects, their role in rapidly advancing energy sector; electromagnetic waves have been a matter of curiosity amongst people. The reason of this curiosity is that electromagnetic waves do not fall directly into human observation range. The main purpose of this study is using sequential inquiry-based activities about radio waves and microwaves as a purpose of exploring and comparing participants' scientific thinking and science process skill levels.

General Purposes and Sub- Purposes of the Study

The purpose of this study was using investigative and inquiry-based activities to make unobservable electromagnetic waves sensible and visible by participants. The reason of choosing electromagnetic waves as a topic is that electromagnetic waves concept that came into our lives just after 19^{th} century is novel to society. In a digitalized world, people are not aware of electromagnetic waves' possible, long term effects yet. The reason of using inquiry-based activities is believed to make participants start to think scientifically by guiding them to think based on data and evidence and raise questions just like scientists. The another reason of using inquiry-based activities that participants did not experienced inquiry-based sequential activities before. Structured inquiry which involves steps to be followed by participants were implemented because of this novelty.

Sub-Purposes of the Study

1-) Which levels of scientific thinking do pre-service teachers have before the inquiry-based activities?
2-) In which way the levels of scientific thinking of pre-service teachers change during inquiry-based activities?

Theoretical Framework

In accordance with the scope of the research, national and international review of literature is carried on. The authors paid much attention to inquiry-based approaches. Concept of electromagnetic risks itself and assessing of society's understanding and knowledge about the phenomena, recommending instructional practices to improve knowledge and awareness by stimulating understanding with the suggested activities was another issue that researchers interested in.

In the literature, societies' reactions, perceptions, awareness and attitudes towards electromagnetic waves are highly interested and investigated.

Sadık (2014) investigated perceptions of students in primary school towards environmental problems. Under the light of the data presented in interview forms, children are found to be aware of the connectedness of environmental problems however, their awareness of local and national environmental problems are found to be insufficient. Amongst all the elements of environmental problems, light pollution and magnetic pollution was the least perceived environmental problem. Yalçın and Okur (2014) investigated effect of electromagnetic field education on teachers' students' and academician's perceptions and awareness of electromagnetic fields. Results indicated that, participants' awareness was improved with the given education and they had tendency to be more careful using electrical devices in their daily lives. Similarly, Sarıgöz, Karakuş and İrak (2012) conducted their research on evaluations of vocational college students' opinions on electromagnetic wave risks. Researchers found out that students generally had enough knowledge about electromagnetic risks but they do not pay attention to precautions while using electrical devices.

As a newsworthy study, Plotz (2016) investigated students' perceptions of electromagnetic radiation dwelling on the fact that literature lacks studies investigating students' perceptions about electromagnetic radiation. Plotz emphasized that there are gaps in literature, for instance, there are no studies about investigation of students' conceptions regarding microwaves and radiofrequency waves. Instead, studies focus on microwave region of spectrum possibly because of the fact that most of the electronic devices we use today emits microwave radiation. Researcher indicates that there is limited information about students' conceptions fitting all kinds of

radiation as well. Plots also mentioned some misconceptions from literature that students hold such as thinking that UV radiation was violet or blue colored even though they know about the invisibility of UV. Plotz recommended the teaching of concepts such as wavelength, frequency and propagation velocity to reach better understanding of radiation by students.

Burger et al. (1997) investigated attitudes concerns of participants towards environmental wastes. Study conducted both science and non-science students and nonstudents older than the age of 35. Participants' ideas are recorded through survey. According to the findings, participants' perception of risks varied, most of the concern was about general environmental problems like deforestation, groundwater pollution, human-made trashes. Nuclear wastes were matter of concern for participants in moderate level. The least concerned issues were the use of fertilizers and pesticides, and electromagnetic waves.

Considering the findings of literature review on studies about individuals' awareness, attitudes and perceptions of electromagnetic waves, results generally showed that participants either lacked necessary knowledge or had insufficient knowledge with lots of misconceptions. Participants had low awareness and attitude levels towards electromagnetic wave risks. They also did not consider electromagnetic waves as a threat to the environment, through variety of environmental problems, electromagnetic waves were the last concept to come participants' minds. Studies showed that with appropriate instructional strategies and environmental education, participants' knowledge level may be improved and those strategies may help coping with misconceptions and low scores of awareness levels. Thus, we may infer that there is a consensus in literature in that with well-used instructional strategies, modern education approaches and with classroom activities may help improvement of electromagnetic wave comprehension.

Method

Research Design

In this research, survey design is used. The level of scientific thinking of pre-service science teachers is determined after the implementation of sequential inquiry-based activities are compared.

Sample Group

Sampling of this study comprises of 3rd grade elementary pre-service science teachers continuing their education in Muğla during 2018-2019 academic year. Convenience sampling method is used for selection of participants. It is intended to determine and compare thinking levels of pre-service teachers.

Data Collection

In this survey research intended to determine participants' level of scientific thinking and through use of sequential inquiry-based activities, data were collected in spring semester of 2018-2019 academic year. Data collection process took three months. Data were collected through various ways. Sequential worksheets prepared for inquiry-based activities were used as data collection tools. In these worksheets, there were sections provided for students to write down their predictions, observations, and possible explanations regarding the activities were demonstrated. Their level of scientific thinking and changes (or modifications of initial ideas) of their thinking has been analyzed. Pilot study also was carried on beforehand.

Data Collection Instruments

Sequential Worksheets

11 sequential worksheets were used as main data collection tools. It is designed in a framework of POE (predict, observe, explain) approach developed by White and Gunstone (1992), in such a way that participants are able to record their predictions, observations and explanations about the interaction of electromagnetic waves with the material environment. On 1th, 2th, 3th, 4th, and 5th worksheet, interaction of a music-playing radio with material environments of different properties; On the 6th, 7th, 8th, 9th, and 10th worksheets, the interaction of the smart mobile phone with the material environments of the different features were discussed. On the 11th

worksheet, a table is presented for participants to record the data, and it is expected to evaluate and deduce the data in a holistic way after the sequential demonstration experiments based on investigation and inquiry. The worksheets were used as a means of measuring level of scientific thinking of participants. In order to increase the reliability of the research model, the data collection tools were applied in multiple and sequential manner.

Analysis of Data

When analyzing the data, outputs of the class discussions, the explanations that the participants recorded on the worksheets was taken into consideration. SPSS (Statistical Package for Social Sciences) was used for the analyses in order to answer sub-purposes of current study.

In addition, activity sheets were analyzed whether there are changes between explanations through the activities, whether the predictions, observations, explanations and interpretations made are close to scientific thinking in the learning process of the participants. It is analyzed that whether participants considered variables, evidence and data, and whether they made explanations in objective and consistent way. Based on the qualities mentioned above, statements of participants were coded under three main headings. These headings are adapted and modified from works of Kember et al., 2000; Korthagen, 2001; Perschbach, 2006; Husu et al., 2008; as *'irrational thinking, intuitive thinking and scientific thinking'*.

Results and Discussion

In this study, research questions tried to be answered are as follows:

1-) Which levels of scientific thinking do pre-service teachers have before the inquiry-based activities?

For this research question, only first activity sheet is considered for the purpose of analyzing which way of thinking participants possess at the beginning. Results are not promising. Only 6.52 percent of the participants were closest to think scientifically when compared to total. While 43.47 percent of the participants held the intuitive way of thinking, 50.00 percent of the participants were thinking irrationally. These results indicate that 93.48 (N=46) percent of the participants which are teacher candidates could not think scientifically when they encounter a series of demonstrations regarding electromagnetic waves.

2-) In which way the levels of scientific thinking of pre-service teachers change during inquiry-based activities?
Participants' responding the sequential investigative and inquiry-based activities in different levels were one of the major findings in this study. Overall analysis of change in participants' ways of thinking were presented in figure 1.

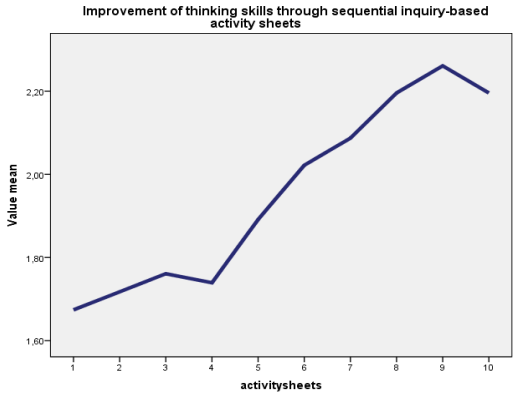


Figure 1 Overall change in participants' way of thinking

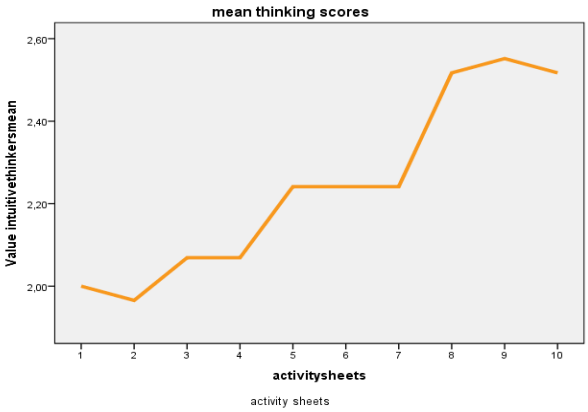
As shown in the figure, after encountering discrepant events and challenges (see activity sheet 3 and 4), participants improve their thinking skills through sequential inquiry-based activities.

Another considerable finding of the study was that participants improved their way of thinking, but in different levels. For instance, participants possessing intuitive thinking at the beginning, were more responsive to think

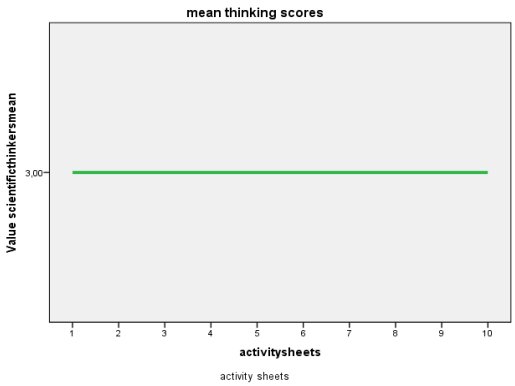
scientifically. They were much faster improving the statements when compared with irrational thinkers. They were most likely to keep the level of thinking they reach until the end of the activities without stepping back.

Comparison of different groups' (irrational thinkers, intuitive thinkers and scientific thinkers) improvement was presented below.

Irrational Thinkers



Intuitive Thinkers



Scientific Thinkers

Data analysis of the research shows that participants who held irrational thinking were generally resisted to change. Although they tried to improve their thinking and explanations, the thinking level could not get any further from intuitive thinking and sometimes they still went back into irrational thinking. However, intuitive thinkers showed more smooth improvement through the learning process.

This finding of the study supports findings of Capps and Crawford (2010, 2013). In their study, they also found that participants with readiness to inquiry processes, show more considerable gains.

Participants with explanations showing signs of scientific thinking were responsive to the activities as well. Although they already have scientific reasoning, they improved their explanations through the activities. They started to dwell on variables, evidence and data in mora scientific way. They also kept their scientific level of thinking until the end.

With the light of the data collected, it is also detected that participants held some pre-conceptions and misconceptions regarding electromagnetic waves which needs handling in a longer period of time. For instance, %58.7 of the participants confused electromagnetic waves with soundwaves. Especially in first 5 activities with radio, participants confused radio waves with soundwaves. In literature, similar findings have been reached. For instance, LoPresto and Murrell (2011) interested in misconceptions regarding astronomy and they found out that one of the most common misconception was thinking that radio waves propagate in speed of sound, therefore they are sound waves. Similar statements were recorded in current study's data collection tools, activity sheets.

Some of the participants explained the hiss noise of radio with soundwaves indicating they are mechanical waves that do not propagate without air presence which is also another findings of current study showing %17.4

of participants interpreted their observation with air presence. There was also detection of misuse of 'frequency' concept. % 67.7 of the participants used 'frequency' concept instead of electromagnetic waves. They indicated that 'frequency' is somehow disturbed, 'frequency' could not pass through material surface, and so on. (see table 1).

Table 1. Misconceptions about electromagnetic waves

Misconceptions	Percentage
Explanations based on soundwave concept	58.7
Explanations including misuse of frequency concept	67.7
Explanations based on air presence	17.4

Conclusion

One of the most important conclusion of data interpretation of this study was that sequential inquiry-based activities helped participants getting closer to think scientifically. When their common experiences contradicted with their observations, they paid attention harder and tried to come up with different explanations based on data and evidence which is one of the most important steps of inquiry. Challenging questions and discrepant events led the desire for knowing more and it was where their motivation started to increase. Participants also had opportunity to feel the presence of electromagnetic waves which are normally non-observable by human senses. With the use of 'sequential inquiry-based activities', different material surroundings and different kinds of electromagnetic wave sources were discussed and participants realized the importance of variables. They observed what happens or changes in electromagnetic wave behavior manipulating the variables and it led participants' approaching thinking with variables in the inquiry process.

The other significant conclusion we came up with was that participants with different levels of thinking skills showed improvement in different levels. This means that if an individual has a certain level of thinking skills, consistent with the findings of Capps and Crawford (2013), that individual is more likely to show consistent and considerable gains. However, participants with inadequate thinking skills needs more support and guidance from their teachers to get closer thinking scientifically.

Last but not least, with the inquiry-based activities, it is believed that importance of considering variables, collecting, recording and interpreting data and making explanations based on evidence are emphasized which are closely related to science process skills.

Future research

In future research, it is planned to compare different participant groups' level of thinking such as middle school students, teacher candidates and teachers. In this way, in addition to the pre-service teachers, middle school students' thinking levels that our pre-service teachers will appeal in future will be investigated. Teachers from different disciplines and from different working experiences also will be interested in.
In addition, after emphasizing the science process skills and inquiry skills with the current study, it is intended to compare participants' science process skills and scientific thinking skills.

Recommendations

Giving more importance especially on pre-service teacher education is important because those teacher candidates will have students in future to teach science concepts which may not be conceptualized without thinking scientifically. Therefore, similar activities that foster scientific thinking and inquiry skills may be implemented in universities.

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