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ORIGINAL ARTICLE

An Inquiry-Based Instruction on the Main Subatomic Particles: Enhancing High-School Students' Achievement and Motivation

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ABSTRACT

In this quasi-experimental research, the effect of the inquiry-based 5E instruction on students' learning of the topic of the main subatomic particles forming the atom as well as on their level of motivation was examined. The sample for the study comprised 45 ninth grade students enrolled in two randomly selected classes at a public high school located in a city center in the Aegean region, in the west of Turkey. The topic of main subatomic particles was taught to the experimental group students (n = 21) by inquiry-based 5E instruction, while the control group students (n = 24) were taught the topic using traditional instruction methods. The length of the study was 3 weeks. An academic achievement test which consisted of four open-ended questions and a chemistry motivation scale which was composed of 5-point Likert-type 30 items were administered to both groups as a pre-test and as a post-test. The data were analyzed using the independent-samples t-test and paired-samples t-test statistical analyses. The results showed that inquiry-based 5E instruction on the subatomic particles forming the atom has a significantly positive impact on academic achievement as compared to traditional instruction. Compared with traditional instruction, it was observed that using the inquiry-based 5E instruction did not produce a higher effect on student motivation. Based on the findings, this study provides suggestions that chemistry teachers, educators, and researchers can benefit from.

KEY WORDS: High-school chemistry; inquiry-based 5E instruction; atomic structure; achievement; motivation

INTRODUCTION

The subject of the atom is one of the fundamental concepts of chemistry and holds a distinct ground with regard to chemistry instruction and learning (Taber, 2001). However, the previous research has put forward that a number of students, from high school to tertiary level, encounter challenges in learning this topic. It has also been reported that many students lack an adequate understanding for the concepts in the topic. Learning difficulties have been reported in the context of the atom in science education and the difficulties have been described as related to the structure of the atom, its form, dimensions, and weight and also to animistic perceptions. It appears that the atom is a challenging and intangible subject for many students (Cokelez, 2012; Griffiths and Preston, 1992; Harrison and Treagust, 2000; Pekdağ and Azizoğlu, 2020; Ünlü, 2010).

There is no doubt that the topic of the atom has been and continues to be a problem from the aspects of both teaching and learning. We need to make an effort to better understand and teach the topic of the atom and there must be an effective approach to teaching for this to take place.

One of the biggest changes that have been initiated in science education today has been the widely adopted transition from traditional methods of teaching to inquiry-based instruction (National Research Council, 2000). The constructivist theory encompasses inquiry-based learning, setting forth that students are expected to experience the responsibility of their own learning that will help them structure their knowledge and improve their cognitive skills (Cobb, 1994). Presenting real-life problems to students in the learning setting and encouraging open-ended classroom discussions has an important effect on building cognitive competence. There is a body of literature (Balcı et al., 2006; Campbell, 2006; Duran and Duran, 2004; Liu et al., 2009; Salar and Turgut, 2021) which refers to one of the tools that facilitates this effect, that is the 5E instructional model.

Inquiry-Based Instruction

The approach of getting students interested in scientific processes and scientific activities (mostly referred to as scientific studies or inquiry-based instruction) is now considered to be an essential part of science teaching and education in general (National Research Council, 2000; Pedaste et al., 2015). Inquiry has been defined as the thought and interpretation methods which scientists use to analyze nature and the evidence that is the basis of scientific studies (Hofstein and Lunetta, 2004). Evidence on which scientific studies are based emphasize learner's abilities to analyze natural real-

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life phenomena, stress concepts, interpret evidence-based outcomes and offer scientists the opportunity to discuss their own statements in an attempt to capture the spirit of science. Expressed differently, students learn to inquire into the context of scientific content and they improve their inquiry skills related to the Nature of Science through the development of their epistemological understanding and scientific knowledge (Abd-El-Khalick et al., 2004). Inquiry activities encompass discussion around an open-ended question, phenomenon explanation, changing numerical parameters to understand a scientific model or solve a problem (Chen et al., 2018). Lim (2001) defines inquiry as the act of focusing on the research process rather than creating the product or solving a problem and says that it relates to improving high level thinking and researching skills. Scientific research is not limited to only designing experiments or conducting a process, using instruments, recording data or creating graphs. It has a much more complex structure (Ruiz-Primo et al., 2010). Bevins and Price (2016) have asserted that inquiry is now the best way students can reinforce their current knowledge and research abilities, absorb new knowledge and find answers to their questions. From these descriptions, it can be understood that inquiry-based instruction is not only an outcome-focused approach but also at the same time, it is a process of improving skills and attitudes as well as achievement.

A number of studies have been carried out to focus on the effects of inquiry-based instruction. These studies address students' academic achievement, their motivation, skills, attitudes and perceptions of learning environments. There are studies that report that inquiry-based instruction increases students' scholastic achievement (Abdi, 2014; Balım, 2009; Chiang et al., 2014; Kang and Keinonen, 2018; Köksal and Berberoğlu, 2014; Marshall et al., 2017). Hofstein et al. (2004) point out that inquiry-based laboratory activities in the chemistry course are effective in teaching high school students how to improve their skills related to inquiry and forming hypotheses, helping them at the same time to pose questions for their later research. Inquiry-based instruction is found as an effective method of teaching in terms of raising students' levels of self-confidence (Gormally et al., 2009; Hong et al., 2021) and to have an affirmative impact on students' attitudes toward their science lessons (Gibson and Chase, 2002; Sen and Oskay, 2017).

To ensure students' participation at the start of the learning process, there is a need for motivation and this need continues throughout the process, until learning is complete (Palmer, 2009). Environmental factors, the previous life experiences, the way students perceive themselves, and the physical setting are factors that have an impact on students (Barrett et al., 2005). Motivation in education is referred to as the disposition a student shows to find academic involvement purposeful and beneficial and the effort the student spends to gain such academic benefits (Brophy, 1983). Researchers have explored in many studies whether students' motivation impacts their learning in any way and it has been discovered that motivation does in fact have a major impact on students' learning (Lee and Brophy, 1996; Nolen, 2003; Palmer, 2009). It is reported that students' academic motivation is quite notably instrumental in their learning and for this reason this factor must never be overlooked (Watters and Ginns, 2000). Motivation is related to how students make use of learning strategies, the level of their knowledge, the content they are learning and other elements in the learning setting (Adler et al., 2018; Hynd et al., 2000, Minner et al., 2010). According to National Science Education Standards, increasing students' motivation is considered a major objective in ensuring their learning (National Research Council, 2000). The standards also emphasize the importance of supporting motivation as well as learning in inquiry-based instruction.

Purpose of the Study

The concept of the atom is among the concepts in chemistry that students find the challenging to learn. The results of many studies confirm that students have misconceptions about this topic (Cokelez, 2012; Griffiths and Preston, 1992; Papageorgiou et al., 2016). The most important factor that acts as a barrier to the meaningful understanding of the concept of the atom is, as with many other concepts in chemistry, the fact that the concept of the atom is an abstract concept (Adbo and Taber, 2009). In teacher-centered instruction based on lecturing, students are not given the opportunity to think about such abstract concepts, engage in an exchange of ideas, ask questions or investigate. Inquiry-based instruction, on the other hand, provides an opportunity for all of this and additionally allows students to improve their social and emotional learning skills. One of the inquiry-based learning models that can be effective in providing students with these positive learning outcomes is the 5E instructional model (Bybee et al., 2006). 5E instructional model encompasses stages that lead learners into exploration, an exchange of ideas and in-depth discussions and facilitate the implementation of inquiry-based learning activities.

In this study, 5E inquiry-based instruction was planned for the purpose of effectively teaching high school students the concept of the subatomic particles. The aim was to examine the effect of the planned inquiry-based instruction on students' learning of the topic of the main subatomic particles forming the atom as well as on their level of motivation. Toward this objective, answers were sought to the following questions:

1. How does inquiry-based instruction of the main subatomic particles that form the atom effect students' academic achievement?
2. How does inquiry-based instruction of the main subatomic particles that form the atom effect students' motivation?

METHODS

Research Design

The research followed the steps of the type of quasi experimental research design referred to as pre-test and post-test with a control group design. For the experimental study,

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an experimental group was formed as an addition to the control group. Groups were randomly assigned a type of treatment (inquiry-based teaching and conventional teaching). Details with regard to research design are shown in Table 1.

Sample

The sample for the study comprised 45 ninth grade students (students aged 14–15 years) enrolled in two different classes at a public high school located in Western Turkey. The experimental (n = 21) and control (n = 24) groups were randomly selected.

For ethical purposes, paperwork — a proposal including the purpose of the experimental study, the sample group of the study, the duration of the application, the scale, and the test to be used — was prepared and presented to the local directorate and then to the school administration. These procedures are regarded as sufficient to carry out experimental research in schools. The school administrative committee, consisting of the school principal and two vice principals, reviewed the proposal and allowed the research to be carried out in the school. After obtaining the permission, the participants (the students in two classes and the chemistry teacher) were informed about the procedure of the study to be conducted. The researchers clearly stated that the anonymity and confidentiality will be respected and the students will be free to discontinue participation at any time, in case they accepted to participate. The participants provided their verbal consent and stated their voluntariness.

Procedure

The same chemistry teacher, who had an instructional background of 19 years, instructed the topic of main particles making up the atom to both groups of students. Inquiry-based 5E instruction of the topic was employed with the experimental group. Correspondingly, the control group was exposed to the same subject using a traditional teacher-centered instruction that employed the usual 9th grade chemistry textbook (Güntut et al., 2017) and "talk-and-chalk" method of teaching. In the control group, the teacher often used the board and lectured the class, and the students listened to what the teacher is saying and/or wrote down in their notebooks. As for the post-test, after the instruction, both groups of students were administered an academic achievement test and the chemistry motivation scale (CMS). The timeline of the research's procedural steps is presented in Table 2.

Experimental and control groups were both taught the topic of the main particles making up the atom in the middle of October in the fall term of the 2017–2018 academic year. The time allotted to the teaching of the topic was 2 class hours (1 week). The instruction for both groups took place in the 2nd week of the study. The academic achievement test and the CMS were administered to both groups in week 1 as a pre-test, and in week 3 as a post-test.

Table 1: Research design used in the study

	Pre-test	Treatment	Post-test
Experimental group	T_1, T_2	X_1	T_1, T_2
Control group	T_1, T_2	X_2	T_1, T_2

T_1: Academic Achievement Test; T_2: Chemistry Motivation Scale; X_1: Inquiry-Based Instruction; X_2: Traditional Instruction

This research was carried out in 2017–2018 academic year. However, there were other research studies on which the authors were already working. These studies were prioritized. Hence, the writing of this paper was delayed.

The Instruction

Instruction for the topic of the main subatomic particles was planned and implemented in both the experimental and control groups as two class hours. The inquiry-based 5E instruction (Engage, Explore, Explain, Elaborate, and Evaluate) was applied to the students in the experimental group.

In the *Engage* step, the students were asked questions and given examples from everyday life. Afterwards, the students were provided with a short story taken from daily life. They were asked to think about the story and discuss it. In the *Explore* step, the students were shown interesting photographs and images (a photo of the popular Turkish butcher nicknamed Salt Bae, a photo of the chemical formula for salt, and an image of the lattice structure of salt). They were asked to think about these visual materials and discuss them. In the *Explain* step, the example of a "large football field and a football right in the middle" was given to guide the students into understanding the locations in the atom occupied by protons, neutrons and electrons. The concepts of atomic and mass numbers were explained with the help of a leading question. The students compared the number of proton and electron particles (e.g., p=e, p>e, p<e numbers) and discussed how charges changed. The example of salt was revisited, and the concepts of anions and cations were explained on the basis of Na^+ and Cl^- ions. Finally, the teacher provided explanations about which symbols in the visual materials that the researcher had prepared represented what (mass number, atomic number, neutron number, and number of electrons and ionic charge). In the *Elaborate* step, the students were asked to calculate the number of protons, electrons and neutrons in the X^{2-} ion with a mass number of 40 and an atomic number of 18. A student volunteered to attach the calculated values to the visual material that had been used in the explanation step. In another example provided, students were asked to calculate the atomic number, number of neutrons and ionic charge of the ion Y with a mass number of 19, 9 protons, and 10 electrons. A student volunteered to attach the calculated values to the visual material. The *Evaluate* step consisted of filling

Table 2: Procedure timeline of the study

Time	Procedure
Week 1	Administration of the academic achievement test and the chemistry motivation scale as a pre-test to both groups
Week 2	Instruction of the topic of "the main subatomic particles of the atom" in both groups
Week 3	Administration of the academic achievement test and the chemistry motivation scale as a post-test to both groups

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out, together with the students, the mass number, number of protons, neutrons and electrons on a table that had been drawn up by the researchers. Finally, the students were asked to fill out a concept map also prepared by the researchers. The teacher evaluated the entries of the students through discussions. An exemplary lesson is given in the Appendix.

Data Collection Instruments

Data for the study were obtained by administering a "Subatomic Particles Academic Achievement Test (SPAT)" and a "Chemistry Motivation Scale" (CMS) to the both groups of students.

SPAT

The SPAT consisted of four open-ended questions drawn up by the researchers. The student textbook (Güntut et al., 2017) and the ninth grade chemistry course curriculum (Ministry of National Education, 2013a) were taken into consideration in the preparation of SPAT. Care was taken to ensure that the SPAT was devised to measure the topic's learning objectives provided in the chemistry curriculum:

- Objective 9.2.2.a: To be able to make comparisons of electron, proton and neutron charges, masses and their locations in the atom.
- Objective 9.2.2.b: To be able to apply the knowledge of the concepts of atomic and mass number.

Question 1 in SPAT measures learning objective 9.2.2.a, while Questions 2, 3, and 4 in SPAT measure learning objective 9.2.2.b in the curriculum. Table 3 presents the questions on SPAT.

The test validity was reviewed by three chemistry education experts and one chemistry teacher, who provided feedback so that revisions could be made in the instrument. A pilot run was initiated before the actual implementation of the test to explore the reliability of the test. This pilot test was administered to another 9th grade class (n = 26) outside of the sample group. The comprehensibility of the questions, their levels and solution times were considered in the implementation of the test. Needed revisions were made based on the feedback and the test was given its final form.

Table 3: Questions on the SPAT

Subatomic Particles Academic Achievement Test	
Question 1	Explain the locations of electrons, protons and neutrons in the space of the atom and compare the volumes occupied by them.
Question2	Using the appropriate symbols, indicate on the Ne atom the mass number, the number of protons, number of electrons, number of neutrons, and the ionic charge.
Question 3	The charge of an X ion and its atomic number are known. How can we ascertain the number of which subatomic particles belong to the X ion? Please explain.
Question 4	The total number of particles in the Y^{3+}ion is 37. The number of neutrons of the Y atom is 1 more than the number of protons. On the basis of this, can we calculate the mass number of the Y atom? Please explain.

CMS

The other data collection instrument used in the research was the CMS. The CMS is a 5-point (never, rarely, sometimes, usually, and always) Likert-type scale composed of 30 statements. The scale was developed by Glynn et al. (2007). The Turkish adaptation was carried out by Güvendik (2010) and reliability coefficient of the CMS was calculated as 0.88 in accordance with Cronbach's Alpha. Some statements on the CMS are provided in Table 4 as examples.

Data Analysis

As stated, the SPAT comprises four open-ended questions. The written responses the students provided were evaluated on the basis of the following scores: Blank or wrong answers = 0, partially correct answers = 12.5, and correct answers = 25. The minimum possible score on SPAT is 0; and the maximum is 100.

The CMS is a 5-point Likert-type scale made up of 30 statements. Response scores have been coded on the following basis: Never = 1, rarely = 2, sometimes = 3, usually = 4, and always = 5. The minimum possible score on CMS is 30; the maximum is 150.

To reveal the effect of inquiry-based instruction on students' academic achievement (research question 1), the pre-test and post-test scores of the experimental and control groups on SPAT were compared with the independent samples *t*-test. To understand whether the experimental group exhibited a statistically significant change in their academic achievement scores, the mean scores of the experimental group on the pre-test and post-test of SPAT were compared with the paired-samples *t*-test.

To understand the effect of inquiry-based instruction on students' motivation (research question 2), the pre-test and post-test scores of the experimental and control groups on CMS were compared with the independent samples *t*-test. To discover whether the experimental group exhibited a statistically significant change in their motivation scores, the mean scores of the experimental group on the pre-test and post-test of CMS were compared using the paired-samples *t*-test.

The Statistical Package for the Social Sciences program version 17.0 was used in the data analysis. Significance

Table 4: Some statements on the CMS

Items	Statements
Item 1	I enjoy learning the chemistry
Item 2	The chemistry I learn relates to my personal goals
Item 7	Earning a good chemistry grade is important to me
Item 9	I use strategies that ensure I learn the chemistry well
Item 12	I expect to do as well as or better than other students in the chemistry course
Item 19	I think about how I will use the chemistry I learn
Item 21	I am confident I will do well on the chemistry labs and projects
Item 26	I prepare well for the chemistry tests and labs
Item 29	I believe I can earn a grade of "A" in the chemistry course

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levels for both SPAT and CMS were accepted as 0.05 and the results were evaluated on this basis. The assumptions for the parametric statistical analyses were checked for the sample through Kolmogorov-Smirnov test and the results showed that both the academic achievement scores [$z(45) = 0.835$, $\rho = 0.488$] and the motivation scores [$z(45) = 0.383$, $\rho = 0.999$] exhibited normal distribution.

Validity and Reliability of the Study

Control of validity and reliability in case of any threats from the factors was ensured under certain categories.

Selection

The two intact classes were randomly assigned as experimental and control groups that constituted the study sample. The scores on the High School Entrance Exam are taken into account when the students are placed in a high school. Students with equal or close scores to each other are to be placed at the same high school. Since the intact classes constituting the sample of the study were from the same school, a similarity regarding the students' prior knowledge was expected. Furthermore, said similarity was indicated by the outcome that there was no statistically significant difference between both groups' pre-test results.

History

This factor can be depicted as the incidents and occurrences taking place in the duration from the initial measurement to the subsequent one along with the experimental variable (Campbell and Stanley, 1966). Thus, over the study period, it was made sure that no time window was allowed for interaction between participants from two groups.

Confounding variable

Teaching of the subject of the subatomic particles to the groups was practiced by the same teacher. As noted, the study's teacher had had a 19-year-long chemistry instruction experience. What is more, the teacher possessed knowledge and experience on the inquiry-based instruction. Both groups received the same amount of lecture in terms of duration. The teacher followed two different lesson plans, for experimental and control groups separately, to avoid the mix of the instructions.

Instrumentation

The matter of instrumentation as a threat can be referred to as the shifts in adjustment concerning the instruments of measurement, or observer/scorer-related substitutions as they can alter the outcomes of the measurement (Campbell and Stanley, 1966). Thusly, certain precautions were taken to manage the threat: (1) SPAT content was developed with the consideration of teaching to which both groups were employed. Besides, the items of the SPAT were developed in line with the learning objectives of ninth grade chemistry course curriculum. (2) The data were collected through SPAT and CMS instruments which were previously confirmed in terms of validity and reliability. (3) Before administering the instruments, participants from both groups were given instructions about responding to the questions on SPAT and the statements on CMS. (4) Participants were given warnings regarding copying others' responses and the vitality of refraining from affecting others' answers. (5) Predetermining how the SPAT and CMS would be scored ensured the objectivity in the analyses of the data.

Design contamination

Equivalence and adequacy in time were ensured during the application of SPAT and CMS as pre-test and post-test for participants of both groups. Groups were independently administered both tests within a 40-min-long chemistry class period. Before the SPAT and the CMS tests, both groups' participants were individually given information about the importance of the study (student guidance). During the SPAT and the CMS tests, participants of both groups were accompanied by the chemistry teacher and a researcher from the study.

Testing effect

The design itself, the pre-test post-test with control group design, helped to kept under control the testing effect by exposing both groups to a pre-test (Campbell and Stanley, 1966).

Subject effects

The possible threat of characteristics of the subjects was eliminated by giving necessary information to the participants about the testing process, which includes the pre-test and post-test. In addition, it was stated to the experimental group that a theoretical content that was identical to the control group's content was used in teaching the topic. The study aimed to manage unexpected behavior from the participants through equal treatment of the groups with the exception of treatment administration, which enabled a non-disruptive flow in the classroom without the need to draw attention around the task. Thanks to this, subject attitude was no longer a matter of threat to validity and reliability.

Mortality

Data retrieved from participants having taken place in only one of the measurement phases were excluded from the analyses of the research.

FINDINGS

The results for the analyses of the research are presented in two sections. The former section describes the effect of inquiry-based 5E instruction in the subject of the main subatomic particles on students' academic achievement. The latter explains the effect of inquiry-based 5E instruction in the subject of the main subatomic particles on students' motivation.

The Effect of Inquiry-Based Instruction on Students' Achievement

The first research question sought the answer for the degree of impact of the inquiry-based 5E instruction over students' improvement level regarding learning main subatomic particles subject. That is why, the experimental and control groups received the SPAT as a pre-test and post-test. Through

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an independent samples *t*-test, potential occurrence of a statistically significant difference of the two tests (pre-test and post-test) was investigated. Related outcomes of the analysis are shown in Table 5.

According to the data shown in Table 5, no statistically significant difference was detected regarding pre-test mean scores of the groups, $t(43) = 1.08$, $\rho = 0.29$. Based on this, it can be suggested that background knowledge of students from both groups was of equivalence prior to instruction of the main subatomic particles subject. In the meantime, regarding the groups' post-test mean scores, the difference indicated statistical significance, $t(43) = 2.19$, $\rho < 0.05$. Based on this, experimental group scored ($M = 52.48$, $SD = 19.07$) gained higher scores from the SPAT than the participants of control group in the sense of significance ($M = 40.77$, $SD = 16.78$), which suggests that they understood the subject better. The Cohens'*d* indices of 0.65 generated a medium effect size, which indicated that there was a moderate relationship between instructional method and achievement of students. It was made clear by this value that variable of achievement was explained by the type of group a student was placed.

A paired samples *t*-test was run to analyze the experimental group students' difference in achievement scores with regard to statistical significance by taking their SPAT pre-test and post-test mean scores into consideration. The data concerning the procedure are presented as shown in Table 6.

As presented in Table 6, the post-test mean scores of SPAT ($M = 52.48$, $SD = 19.07$) are significantly higher than the pre-SPAT mean ($M = 3.55$, $SD = 4.96$) of the experimental group. The 95% confidence interval generated concerning mean difference of two ratings was 40.09–57.76. The result showed that the inquiry-based 5E instruction in the subject of the main subatomic particles significantly improves students' achievement, $t(20) = 11.55$, $\rho < 0.001$.

The Effect of Inquiry-Based Instruction on Motivation of Students

The second research question of the research aimed at determining the effectiveness of the inquiry-based 5E instruction on improving motivation of students. To serve this goal, the CMS was used in experimental and control groups as pre-test and post-test. Comparison of pre-test and post-test means of the groups concerning the CMS was made through screening the analysis of an independent samples *t*-test, which generated the results as presented in Table 7.

Table 7 indicates that no statistically significant difference was found regarding the pre-test mean scores of the groups, $t(43) = 0.51$, $\rho = 0.61$. Based on the results, groups had equivalent motivation levels before the teaching of main subatomic particles subject. Similarly, no statistically significant difference was detected between post-test mean scores of the groups, $t(43) = 0.11$, $\rho = 0.91$. The reason for this is that the means of scores of experimental group students ($M = 106.57$, $SD = 16.70$) and control group students ($M = 107.08$, $SD = 14.58$) are near to each other. This finding sets forth that compared with traditional instruction, the inquiry-based 5E instruction in the subject of the main subatomic particles is not more effective in improving students' motivation.

Significance of motivational increase based on scores was sought to be determined through comparison of experimental group's pre-test and post-test scores of the CMS by running a paired samples *t*-test. The analysis results are tabulated in Table 8.

As shown in Table 8, in the experimental group, the post-CMS mean ($M = 106.57$, $SD = 16.70$) is greater than the pre-CMS mean ($M = 100.05$, $SD = 21.08$). The 95% confidence interval for the mean difference between two ratings was –0.37 to –13.42. However, the change in the scores does not yield a statistically significant difference between the pre- and post-test mean scores of the experimental group, $t(20) = 1.97$, $\rho = 0.06$. Teaching the subject of the main subatomic particles with the inquiry-based 5E instruction did not increase significantly the students' motivation.

The results of teaching the subject of the main subatomic particles using two different instruction approaches are presented in Figure 1. The findings gathered from experimental and control groups were illustrated as comparison.

Table 5: Comparison of the pre-test and post-test mean scores of the groups on the SPAT

	Groups	*n*	*M*	*SD*	*df*	*t*	*ρ*
Pre-test	Experimental	21	3.55	4.96	43	-1.08	0.29
	Control	24	2.22	2.87			
Post-test	Experimental	21	52.48	19.07	43	-2.19	0.03
	Control	24	40.77	16.78			

Table 6: Comparison of the pre-test and post-test mean scores of the experimental group on the SPAT

Experimental group	*n*	*M*	*SD*	*df*	*t*	*ρ*
Pre-test	21	3.55	4.96	20	11.55	0.00
Post-test	21	52.48	19.07			

Table 7: Comparison of the pre-test and post-test mean scores of the groups on the CMS

	Groups	*n*	*M*	*SD*	*df*	*t*	*ρ*
Pre-test	Experimental	21	100.05	21.08	43	0.51	0.61
	Control	24	102.75	13.07			
Post-test	Experimental	21	106.57	16.70	43	0.11	0.91
	Control	24	107.08	14.58			

Table 8: Comparison of the pre-test and post-test mean scores of the experimental group on the CMS

Experimental Group	*n*	*M*	*SD*	*df*	*t*	*ρ*
Pre-test	21	100.05	21.08	20	1.97	0.06
Post-test	21	106.57	16.70			

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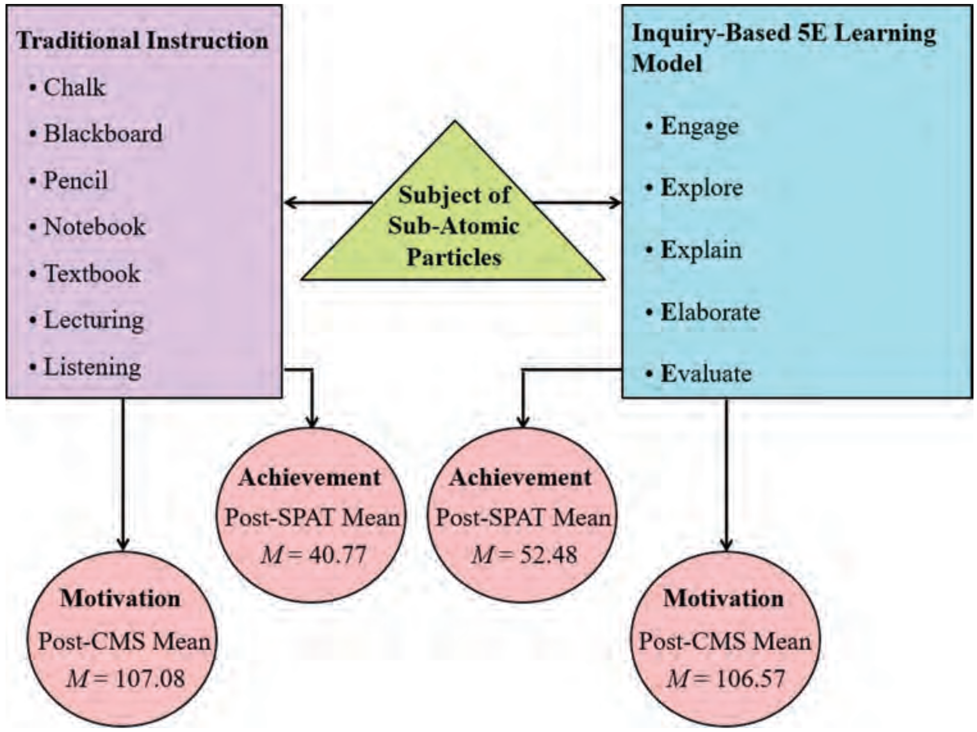

Figure 1: The comparison of the findings obtained from both groups of students. Adapted from "History-based instruction enriched with various sources of situational interest on the topic of the atom: The effect on students' achievement and interest." by B. Pekdağ and N. Azizoğlu, 2020, *Research in Science Education, 50*(3), p.1205.Copyright (2018) by the Springer Nature and Copyright Clearance Center. Adapted with permission.

As shown from Figure 1, while the inquiry-based 5E instruction seems more effective than traditional teaching in the sense of students' academic achievement, it did not show the same superiority in terms of the motivation.

RESULTS AND DISCUSSION

To successfully ensure that students grasp the learning objectives of the instruction, scientific content must be presented to the class in an interesting and meaningful manner (Feng and Tuan, 2005). It was based on this notion that the topic of the main particles of the atom was treated using the inquiry-based 5E instruction in an effort to increase high-school students' academic achievement and motivation.

The present study, therefore, was conducted to understand the effect of the inquiry-based 5E instruction on student academic achievement through a comparison with traditional instruction. It was found before the instruction that the pre-test mean scores of both the experimental and control groups were low on SPAT with respect to the topic of main subatomic particles. The topic of the atom is taught in the middle school science course curriculum, and it is in science class that students become acquainted with the concept of the atom. This acquaintance, however, is confined to only learning about the structure of the atom, realizing that it is made up of protons, neutrons, and electrons (Ministry of National Education, 2013b). The high school level teaching program, designed in the form and in-depth content appropriate for this level, is first introduced to students in the ninth grade. It was because of this that the students SPAT pre-tests yielded low mean scores.

After the teaching of the topic, both student groups exhibited increases in their post-test mean scores on SPAT. However, this increase in academic achievement was greater in the students who had been exposed to the inquiry-based 5E instruction compared to the students in the traditional instruction group. Furthermore, inquiry-based instruction was seen to have a significantly positive impact on academic achievement as compared to traditional instruction. In other words, the inquiry-based 5E model was more successful in teaching the topic of main subatomic particles compared to traditional instruction. This study also offers results that support previously performed research (Abdi, 2014; Campbell, 2006; Chiang et al., 2014; Liu et al., 2009; Pandey et al., 2011).

Another variable that was examined in the present study was motivation. While the pre-test mean scores of the experimental and control groups on the CMS showed no significant difference before the instruction on the topic of the main subatomic particles, following the instruction, both student groups displayed a slight increase in their post-test mean scores on CMS. This increase, however, did not reveal a statistically significant difference between the post-test mean scores of the experimental and control groups. Ultimately, when compared with traditional instruction, it was observed that the topic of the main subatomic particles forming the atom taught using the inquiry-based 5E instruction did not produce a greater effect on student motivation. Similar result was reported in Çalışkan's (2004) and Tuan et al.'s (2005) studies. Contrary

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to this conclusion, there have been results reported that show that instruction using the 5E learning model has been effective in increasing student motivation (Boddy et al., 2003; Kuo et al., 2020).

Among the factors that may explain the differences in levels of motivation is the duration of the process. To impact levels of motivation, teachers need to set up the learning environment with activities that are appropriate to the specific characteristics of the students in the class (Abdi, 2014). Besides, the theory of self-determination - which is one of the theories that deal with human motivation and personality-emphasizes that learners are motivated to learn when their needs for competence, autonomy, and relatedness are satisfied. In other words, when students engage in an activity willingly (autonomy), perceive that they are able to achieve the task (competence), and desire to feel part of a discussion group (relatedness), we can say that they are motivated (Deci and Ryan, 2000). In the present study, considering the non-significant changes in the motivation levels, we can conclude that the duration of the inquiry-based instruction has not been long enough to meet these needs of the learners.

Another factor may be associated with whether or not all of the requirements of the learning model have been met. For example, whether or not the inquiry-based 5E instruction has been appropriately implemented can be deduced from the teacher's skills in being an effective listener during class discussions, providing more frequent feedback, and asking the students more questions so that they are encouraged to respond. The demonstration of such skills and the teacher's ability to elicit a reaction from the students toward this stimulation are interactive elements that increase student motivation (Gross Davis, 2009). On the other hand, considering that the instruction is limited to a two-hour lesson, the expectation of a significant increase in motivation can be criticized, no matter how intense interaction has taken place in such a short time.

To sum up, the results of this study show that in terms of academic achievement, the inquiry-based 5E instruction is an effective teaching approach for chemistry education. However, it appears that the time allocated for teaching should be long enough for the desired affective effect.

Implications

The current research provides novel and meaningful knowledge about the use of the inquiry-based 5E instruction in teaching the topic of the main subatomic particles that form the atom. When the positive effect of the inquiry-based 5E instruction on achievement is considered, it can be said that this method can provide benefit in trying to eliminate the difficulties students have with learning the topic of the atomic structure.

From the perspective of motivation, the success of the inquiry-based 5E instruction in raising student motivation to the same degree as conventional teaching should not be underestimated. In conclusion, a positive impact on motivation was observed. In the light of the fact that there was an increase observed in motivation as well as a positive and significant increase in achievement, the inquiry-based 5E instruction may be made a preference in science education, particularly in teaching chemistry.

There is a need for curriculum designers, teachers, and textbook authors to develop a perspective on inquiry-based instruction and become more knowledgeable about this method. Teacher training programs should contain theoretical and practical lessons on the inquiry-based 5E instruction. It is this way that teachers can gather the knowledge and experience about this method and consequently adopt a positive attitude toward its use in teaching environments.

The inquiry-based 5E instruction is considered an effective approach to teaching in the area of chemistry education. The results of this study may facilitate teachers to utilize such a teaching approach in their classes. At the same time, the application of inquiry-based learning in this study may serve as a useful example for teachers and for teachers' education. It can, therefore, be said that the inquiry-based approach to teaching in this study will be beneficial in terms of the cognitive and affective aspects of learning.

Limitations

This study depended on quantitative data to demonstrate the effects of the inquiry-based 5E instruction on academic achievement and motivation. These effects can also be explored on a qualitative basis. Another limitation of the study was the use of a short-term procedure, which may imply that a longer study of inquiry-based instruction may bring out different effects of the method on achievement and motivation. Indeed, a long-term application (e.g., for a full academic year) of the inquiry-based instruction may lead to higher levels of student achievement and motivation. Investigating this matter will be beneficial for science education. Another limitation is the subject itself. The reasons the topic of the atom was chosen for the study were: (i) That the atom is a central concept in chemistry and (ii) Teaching the atom is a difficult and abstract concept to both learn and teach.

Still another limitation was that the study results cannot be generalized. Although there were enough participants in the study sample for quasi-experimental research of pre-test-post-test control group design, generalization of the findings is limited to only two classes of the ninth grade in a public high school.

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APPENDIX

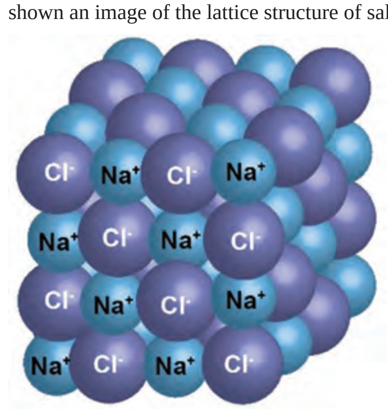
Lesson Example for Instruction of the Main Subatomic Particles Topic through the Inquiry-Based 5E Instruction Model

Step	Instruction
Engage	The students were first asked the question, "*What is the fundamental unit of matter*?" at the beginning of the lesson. They were provided with examples taken from the building they were in and their own desks. Then, the following story was related: "Melisa and her friends decided to go to an amusement park close to their home after school. Melisa's favorite ride was the Ferris wheel. She and her best friend Lara got on the Ferris wheel, which then started to turn. Melisa observed that the passenger car they were in turned around a central point, moving at a certain level and with the distance of the car from the center never changing." The students were asked to think about the story and discuss it.
Explore	The students were shown interesting photographs and images (a photo of the popular Turkish butcher nicknamed Salt Bae, a photo of the chemical formula for salt, an image of the lattice structure of salt).

The students were shown a photograph of Nusret, the popular Turkish butcher nicknamed Salt Bae). They were asked what Nusret was famous for. This way, the students were led into thinking about salt.

Then they were shown a photograph of the chemical formula for salt.

They were asked for their ideas about the structure of salt. They were guided into thinking about how salt is a compound, made up of the elements Na and Cl. The students were then shown an image of the lattice structure of salt.



They were asked to discuss this lattice structure

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Explain The students were then asked about how many protons and electrons the Na and Cl atoms had. The results were written on the board. Emphasis was given to the exchange of electrons in the Na and Cl atoms. The students were asked to explain what they knew about electrons, protons and neutrons. They were told to imagine a big soccer field with a ball right in the center of the field. Through trying to imagine that ball and the expanse of the field, they were guided through the discussions into thinking about the center/nucleus of the atom and the spaces the protons, neutrons, and electrons occupied, forming associations between these two concepts. The teacher then asked a few of the students their school ID numbers and what these numbers were used for. The example of the Turkish Citizenship Number was given. *"Which subatomic particle can take on the identifying role of the atom? Why? Let's discuss it."* With the help of this question that led into discussions, the teacher called the students' attention to the proton particle. Finally, the concept of the atomic number was explained. The teacher thus explained that the atom's mass collected in its nucleus and by talking of the main particles in the nucleus (protons and neutrons), the concept of mass number was elucidated. The word "nucleus" was clarified and the concept of nucleon was defined

The students compared the number of proton and electron particles and discussed how charges changed (e.g., p=e, p>e, and p<e numbers). Going back to the example of salt, the concepts of anion and cation were explained in terms of Na+ and Cl^-. Finally, stickers were distributed to the students containing mass number, neutron number, number of electrons and ionic charge. The students were asked to attach each of these stickers on the appropriate place in the visual material seen below.

Each student was asked to come to the board to place the sticker and share his/her thoughts with the rest of the class while doing this.

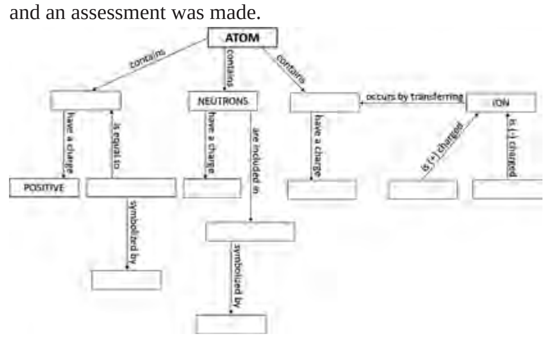
The teacher explained what the symbols on the visual material represented.

Elaborate The students were asked to calculate the proton number, number of electrons, and neutrons of the ion X with a mass number of 40, an atomic number of 18 and a charge of –2. A student volunteered to attach the given and calculated values to the visual material that had been used in the explanation step. Then another example was discussions. The students were asked to calculate the atomic number, neutron number and ionic charge of the Y ion whose mass number is 19, proton number is 9, and number of electrons is 10. A student volunteered to attach the given and calculated values to the visual material.

Evaluate The students filled out the table below and then checked it for accuracy together with the teacher.

Substance	Number of Protons	Number of Neutrons	Mass Number	Number of Electrons
H	1		1	1
Li	3	2		
Na^+	11	12		
K^+		20	39	
Mg	12		24	
Ca^{2+}	20	20		
Al	13	14		
C	6		12	
Si		14		14
N^{3-}			14	10
P	15		31	
O	8		16	
F^-	9		19	
Cl^-	17	18		
He	2	2		
Ne	10	10		
Ar	18		36	

In the next activity, the students were asked to complete the partially filled out concept map seen below. After the concept map was filled out, the teacher provided feedback by explaining whether the students' answers were right or wrong and an assessment was made.



The students were expected to fill out the concept map as seen below.