Article

The Impact of Innovative Teaching Approaches on Biotechnology Knowledge and Laboratory Experiences of Science Teachers

Tugce Yagmur Orhan [1] and Nurettin Sahin [2,*]

[1] Graduate School of Educational Sciences, Muğla Sıtkı Koçman University, 48000 Mugla, Turkey; tugceyagmurorhan@posta.mu.edu.tr

[2] Faculty of Education, Science Education Department, Muğla Sıtkı Koçman University, 48000 Mugla, Turkey

* Correspondence: nsahin@mu.edu.tr; Tel.: +90-252-211-1826

check for updates

Abstract: The current study presents an evaluation of the laboratory instructional tasks prepared based on innovative teaching approaches (research-inquiry, problem solving, project, argumentation and web-based interdisciplinary learning approaches) designed to enhance science teachers' biotechnology knowledge, awareness and laboratory experiences. The laboratory instructional tasks developed by the researchers aim to improve the laboratory experiences, as well as support the teaching of biotechnology through innovative teaching approaches. For this purpose, in-service training course titled Biotechnology Education Practices was conducted with the voluntary participation of science teachers (*n* = 17). The current study employed the embedded design. The quantitative part of the embedded design is designed as the single group pretest-posttest model and the qualitative part of it is designed as the case study. The data of the current study were collected through the Biotechnology Awareness Questionnaire, Biotechnology Evaluation Questions, The Laboratory Self-Evaluation form and worksheets. The results obtained from the analyses revealed that the instructional tasks conducted within the context of the Biotechnology Education Practices resulted in significant effects on the science teachers' biotechnology knowledge and awareness and that the innovative teaching approaches were effective in developing the science teachers' laboratory experiences. It would be useful to use laboratory instructional tasks enriched with innovative teaching approaches in teaching biotechnology subjects.

Keywords: biotechnology; innovative teaching approaches; laboratory experience; science teacher; science education

1. Introduction

Technological developments in fields such as medicine, agriculture, industry, etc. shape the future educational approaches and the curricula are updated accordingly. As stated in the science curriculum of the Turkish Ministry of National Education (MoNE) [1] and U.S National Research Council (NRC) [2] the comprehensive goal of science curricula is science literacy. Genetics and biotechnology in science education are an integral part of science literacy. For this reason, curricula are important in individuals' decision-making situations related to biotechnological processes [3]. Although biotechnology is an important and rapidly advancing field, it has not been a common subject of teaching in science education, particularly in public schools [4]. Due to some reasons such as teachers' inadequate academic skills, limited time and funding for experimental activities, science teachers avoid teaching biotechnology subjects [5]. In addition, the fact that teachers or school administrators have personal opinions about the applications of biotechnology reduces the possibility of focusing on these subjects in their classrooms, because teachers have no positive perceptions due to the lack of

resources available to teachers [6]. To solve these problems, it is necessary to design applied activities related to biotechnology and to provide appropriate teaching environments [7]. The use of innovative teaching approaches is an effective way to provide new science education standards. Innovative teaching positively affects students' performance [8]. Moreover, it has been reported that innovative learning-teaching methods increase students' interest and improve classroom environments [9]. It has been reported that teachers have positive attitudes towards the application of innovative learning approaches [10] and a positive relationship between teachers' innovative learning performances and educational qualifications [11].

In this respect, there is a need for innovative biotechnology education environments for science teachers.

1.1. Teaching of Genetics and Biotechnology Topics

Biotechnology is the use of an organism, components of an organism, or biological systems to create a product or a process. Nowadays, scientific developments in the field of biotechnology make biotechnology education important. Biotechnology is addressed directly as technology literacy in USA [12]. In the National Science Course Curriculum, the subject of biotechnology is addressed within the unite "DNA and Genetic Code" with three learning outcomes from the 8th grade of elementary education onwards [1]. Through these learning outcomes, it is intended to make students discuss the relationship between biotechnology and genetic engineering, useful and harmful aspects of biotechnology applications and future applications of biotechnology.

Concepts related to genetics and biotechnology (DNA fingerprint, DNA analysis, genome project etc.) are difficult to learn [13]. A study has found that university students have inadequate knowledge in the fields of biotechnology and environmental education and their awareness in these fields change depending on their academic achievement [14]. In addition, it has been noted that while pre-service teachers were aware of biotechnological applications, they could not answer the questions about genetic information and biotechnological processes correctly [15]. A study has reported that pre-service biology teachers had low levels of knowledge of gene technologies [16]. Similar results have been reported in other studies, indicating that pre-service teachers have various misconceptions about biotechnology and gene engineering [17,18].

Studies show that individuals have limitations on genetic and biotechnology issues. There are also studies on the use of classroom environments or laboratories for the teaching of these subjects. For example, in a study conducted with pre-service science teachers, it was reported that the use of animation and models related to the concept of DNA led to more permanent learning than mere lecturing [19]. As a result of the use of laboratory applications in teaching basic biotechnology subjects, some increase was achieved in the knowledge and opinions of teachers and pre-service teachers about biotechnology [20]. Orhan [21] found that as a result of a study on pre-service science teachers, laboratory activities related to DNA technologies enhanced the pre-service teachers' perceptions of DNA technologies and applications and positively affected their attitudes towards technology. Key to success in biotechnology classes is the integration of theory with practice. Biotechnology laboratory teaching will be more effective when students can play an active role in laboratory design and procedures [22].

1.2. Laboratory-Based Learning

Laboratory experiences are direct interactions with the physical world in which scientific tools and research skills are used together with various tools and materials in the development and interpretation of scientific knowledge [23]. Various approaches are used in laboratories to facilitate learning. These are inductive, discovery, scientific process skills, technical skills and deductive approaches [24] (p. 49). The hypothesis-driven laboratory approach, which has become popular recently, helps students to develop their research skills [25]. Hypothesis-driven laboratory activities develop the skills of using the scientific method and laboratory technical skills as well as content knowledge [26]. The technical skills development approach is required to conduct the experiments or tasks to improve technical skills

related to the installation and use of some special tools or experimental setups such as microscopes. Technical skills are not limited to the introduction, operation and correct use of the equipment' to be used in the experimental process, but in some cases, they can include the maintenance and repair of this kind of equipment and their repair even though limited [27] (pp. 210–211). In the study conducted with biology teachers, it was reported that there is a direct correlation between the conception of laboratory technique and asking research questions [28]. It is observed that laboratory activities are effective in developing problem solving skills [29]. Jarette, et al. [30], in their study, provided the opportunity for undergraduate students to learn basic concepts and to experience with biotechnological tools by using inquiry and problem-solving approaches in order to teach basic principles and concepts about sickle cell anemia. In spite of the benefits of laboratory practices, there may be difficulties such as not being economical, requiring time for implementation, teachers' lack of adequate knowledge and skills, and unsuitable course schedule [24] (pp. 48–49). Researchers use different methods to overcome these difficulties. For example, Bowling, Zimmer and Pyatt [31] pointed out that next-generation sequencing technologies are difficult to deliver in the laboratory due to the high cost involved though they have yielded significant developments in the field of medicine and genome research. Therefore, interactive laboratory environments have been developed to teach biotechnological processes.

1.3. Innovative Teaching Approaches

Innovation in education can be seen as a new pedagogical theory, methodological approach, instructional technique, teaching tool, or as a theoretical structure that creates a significant change in teaching and learning and that leads to better learning on the part of the students when applied [32]. It is observed that the methods and techniques currently adopted for innovation in science education are integrated into teaching environments with an interdisciplinary approach such as integration of technology in science education, science-technology-engineering-mathematics (STEM), etc. In some studies, game-based learning environments are considered as an innovative teaching approach. It has been stated that game-based teaching will help students to develop technological awareness and to overcome difficulties in their professional development [33]. Lin and Tsai [34] stated that using technology to enhance learning in science education has become an important trend and found that virtual reality, mobile learning, ubiquitous learning, augmented learning and game-based learning approaches are generally used as innovative technologies in science teaching. Similarly, Istance and Kools [35] pointed to the relationship between innovation and technology in education. In another study, the event-based learning approach has been used as a tool for collecting data, evaluating data, proposing innovative ideas and writing to promote students' innovative thinking and entrepreneurship. Through such innovative approaches, innovative thinking and achievement are claimed to be promoted [36]. Fiksl, Flogie and Abersek [9], stated that the innovative didactic model based on the problem-based and research-based teaching approaches that they had developed proved to be an innovative approach in Science, Engineering and Technology education. Kavacık, Yanpar Yelken and Sürmeli [37] stated that innovative project studies is one of the methods that can provide innovation in modern science education. Martins and Martel [38] compared the traditional laboratory techniques with innovative laboratory research projects including scientific thinking, scientific writing and speaking and presentation of outcomes as posters. As a result of the study, it was reported that the students' conducting experimental data analysis and scientific discussions and working in cooperation with each other can make positive contributions to their achievement. Oyelekan, Igbokwe and Olorundare [39], reported that the majority of science teachers see laboratory and model use as an innovative strategy in science education.

1.4. Problem Statement

In recent years, it has been emphasized that science education that only teaches the nature of science is not sufficient and that scientific knowledge should be open to revision in the light of new findings provided by new generation disciplines [40]. Although many science curricula include

scientific process skills such as interpretation of data, problem solving, experimental design, scientific writing, verbal communication, collaboration, science teacher training programs in universities are limited to the transfer of these skills to undergraduate students [41]. Biotechnology is an interdisciplinary field of science and addressed in science courses from primary education to tertiary education [1,12,42]. However, studies on biotechnology education show that there are several deficiencies. The main reason for these deficiencies is inadequate incorporation of the subject of biotechnology into curricula and teachers' lack of biotechnology-related competences [5]. It is thought that teachers with limited knowledge and skills cannot contribute to the spread of science culture in society. Moreover, when the literature is reviewed, it is seen that studies focusing on attitudes [14,15,43], knowledge [16,30,44], opinions [45] about biotechnology applications in science education are available but studies related to biotechnology laboratory activities with innovative approaches are limited. The teaching of the multi-disciplinary subject of biotechnology with a single approach restricts its teaching ability. It is thought that the activities developed with the integration of more than one teaching approach will be effective in eliminating the problems experienced in biotechnology education. Therefore, the development of biotechnology instructional tasks prepared based on innovative teaching approaches for science teachers is the main aim of the study.

For the training of teachers with developmental levels specified in international standards, their research experiences should be supported and encouraged through university-school cooperation for their professional, scientific and technological development. In this context, it is aimed to interactively inculcate necessary knowledge and skills in science teachers by means of innovative approaches, strategies, methods and techniques so that they can arouse their students' interest and curiosity, they can develop positive attitudes in their students and they can increase their students' motivation towards biotechnology subjects.

The research question of the current study can be expressed as follows: "What is the effect of instructional tasks prepared based on innovative instructional approaches on science teachers' biotechnology knowledge and laboratory experiences?"

Sub-questions:

1.　What is the science teachers' biotechnology knowledge and awareness?
2.　What are the science teachers' laboratory experiences and technical skills?

On the basis of the research problems, the following hypotheses were developed.

Hypothesis 1. (H1): *The science teachers' biotechnology knowledge and awareness vary significantly after the implementation of the biotechnology instructional tasks prepared based on innovative approaches.*

Hypothesis 2. (H2): *The science teachers' laboratory experiences and technical skills vary significantly after the implementation of the biotechnology instructional tasks prepared based on innovative approaches.*

1.5. Significance of the Study

The quality of science education in schools should be improved to ensure success in science education. When the studies carried out to increase the quality of science education are examined, it is seen that each teaching approach has pros and cons. What is important here is that the specific approach to the topic to be taught should be chosen correctly.

Considering the interdisciplinary nature of biotechnology, the current study adopts and changes innovative teaching approaches in such a way as to meet the needs of biotechnology education. Experimental design principles are used by focusing on real world problems related to biotechnology.

Activities emphasize cooperative teamwork by focusing on advanced science and technology content related to biotechnology. These activities guide teachers in preparing them for complex situations they will inevitably face at school or in their daily lives. Our aim is not to tell individuals

what to think, but to provide the information they will need to make their own decisions. In addition, this study will serve as an example of innovative laboratory instructional tasks related to biotechnology applications in thus science education, can make great contributions.

2. Materials and Methods

2.1. Research Design

The current study employed the embedded design, one of the mixed research methods. The embedded design is used in cases where a single data set is not enough and different research questions require different data sets (qualitative and quantitative data) [46] (pp. 98–103). In the collection of the quantitative data, a single group pretest-posttest quasi-experimental design was used. In this method, a group is given the pretest and then the experimental process is conducted and then the same group is given the posttest. The change between the pretest and posttest is examined [47] (p. 96). The qualitative part of the current study was designed as a case study. In a case study, elements concerning the case (individuals, setting, events, processes, etc.) are investigated through a holistic approach and the main emphasis is on how they affect the related case [48] (p. 83).

The embedded design was qualitative weighted in this study. In this embedded design, the intervention that is the basic design of both the qualitative and quantitative data—Biotechnology Education Practices—is embedded into the main design. The quantitative data were used to test the theory that predicts that the instructional tasks will have some effects on the dependent variable for the science teachers. The qualitative data are embedded into this broad case intervention trial during and after the instructional tasks so as to collect in-depth information.

2.2. Study Group

Because this research is qualitative weighted and an intervention research was used, the study group was taken instead of sample selection. While selecting the study group, the purposive sampling method [49] (p. 230) was used. The size of the study group depends on the purpose of the study, usefulness, credibility, availability time and resources [49] (p. 244). Therefore, the study group comprised of science teachers ($n = 17$) working in state schools. In addition, during the development of instructional tasks, a pilot study was conducted with voluntary science teachers ($n = 18$) outside the study group.

The teachers' identities were kept confidential so that they would not face any material, spiritual or psychological losses and they are named as "participants". While presenting the opinions of the science teachers, abbreviations such as P1 (Participant 1), P2, P3, etc. are used. The demographics of the participants are presented in Table 1.

Table 1. Demographic data of participants.

Education Status	Gender	Professional Experience				
		5 Years and Below	6–10 Years	11–20 Years	21 Years and Above	Total
Graduate	Female	2	3	2	1	8
	Male	-	2	3	1	6
Postgraduate	Female	-	1	-	-	1
	Male	-	-	2	-	2
Total		2	6	7	2	17

2.3. Data Collection Tools

In the current study, the quantitative data were collected through "The Biotechnology Awareness Questionnaire" and "Biotechnology Evaluation Questions" and the qualitative data were collected by

using "The Laboratory Self-Evaluation Form". In addition to these, the worksheets developed to offer guidance to the participants during the activities were also used as the data source.

2.3.1. Biotechnology Awareness Questionnaire

The questionnaire was developed to determine the science teachers' opinions about the principles, applications, etc. of biotechnology. First the literature related to the theoretical structure of the questionnaire was reviewed; science curricula were analyzed and the item section of the questionnaire was constructed considering the objectives of the activities. Then the item pool was submitted to the review of a field expert, two measurement and evaluation experts and a science teacher and on the basis of their suggestions, some corrections were made. The draft questionnaire was administered to a group of 150 teachers and pre-service teachers. On the collected data, factor (Kaiser-Meyer-Olkin (KMO) = 0.832 and Bartlett Test χ^2 = 1588.38, $p < 0.001$) and reliability (Cronbach's Alpha = 0.908) analyses were conducted and then the final form of the questionnaire was given. The questionnaire was comprised of five open-ended questions and 16 Likert-type items. The participations responded to each Likert-type items on a five-point Likert scale ranging from "Strongly Agree", "Agree", "Undecided", "Disagree" to "Strongly Disagree". The reliability coefficient for the study group was found to be 0.908.

2.3.2. Biotechnology Evaluation Questions

These questions were prepared to measure science teachers' knowledge about the developed biotechnology instructional tasks. For the determination of the theoretical structure and content of the evaluation questions, the literature related to the objectives of the instructional tasks and to the subject of biotechnology were reviewed, and thus, the items were constructed. These items were submitted to the review of two field experts and a science teacher and then content validity studies were carried out by establishing the question-objective table of specifications. Subsequently they were administered to 46 pre-service teachers. On the basis of the collected data, some changes were made and thus a test consisting of a total of 12 open-ended questions was developed. In the evaluation of the responses to the questions, a rubric developed by the researcher was used. The responses to these questions were also scored by a rater (science teacher) aside from the researcher. The inter-rater agreement [50] (p. 278) was found to be 84%. The participants were given 20–25 min to complete the test (Appendix A).

2.3.3. The Laboratory Self-Evaluation Form

In this form, there were nine multiple-choice items and four open-ended questions to evaluate attitudes and behaviors towards instructional tasks. The multiple-choice items were evaluated on a scale ranging from never (1), rarely (2), sometimes (3), frequently (4) and always (5). As the examples given in the National science curriculum were taken for the preparation of the form, expert opinion was considered to be enough for reliability and validity. In the pilot study, the Cronbach's Alpha reliability coefficient of the multiple-choice items was found to be 0.898. The form was individually administered to the participants after each instructional task.

2.3.4. Worksheets

While developing biotechnology instructional tasks, a literature review was conducted about individuals' deficiencies in the subjects of biotechnology, the knowledge and skills to be possessed by them and the levels of knowledge and skills and science curricula [1,42] and teacher competences [51] were examined. A total of 18 learning outcomes were determined for five instructional tasks. Seven of these 18 learning outcomes were related to the subject content derived from the National curricula [1,42] and eleven of them were developed by the researchers. By structuring the content to be imparted to the learner through the tables of qualification matrix, by organizing the methods, techniques and skills to be used during learning-teaching activities and by seeking the opinions of field experts ($n = 3$), content validity of the instructional tasks was established. Piloting of the instructional tasks was performed with the participation of voluntary science teachers ($n = 18$) working in middle schools affiliated to

Mugla provincial Directorate of National Education in the 2017–2018 school year. In light of the data obtained from the piloting, some corrections were made on the instructional tasks and their final forms were given.

2.4. Data Collection

Implementation of the Instructional Tasks

An in-service training entitled Biotechnology Education Practice was conducted with the science teachers. Details of the training program are given in Table 2. Within the context of the Biotechnology Education Practice, the instructional tasks called "Introduction to the Biotechnology Laboratory", "Genomic DNA isolation", "Polymerase Chain Reaction", "Who is the guilty?", and "Bioinformatics: Phylogenetic prediction" were carried out (Table 2). In the developed biotechnology instructional tasks, up-to-date approaches were combined with the laboratory approach, leading to an innovative synergy. While the theoretical framework of the tasks was made up of the laboratory approach, techniques and learning approaches considered to be innovative for each task were used. As biotechnology is a multidisciplinary science, it was thought that the effectiveness of the instruction would be enhanced through the synthesis of multiple approaches. Detailed information about the instructional tasks is given in the Appendix B.

Table 2. Biotechnology Education Practice schedule.

	Class Hours	Course Content	Teaching Approach Used	Experimental Phase	Subject to be Processed
First Day	1	What is biotechnology?			Pre-test, the place in daily life and application areas of biotechnology
	1	Introduction to the biotechnology laboratory	Research-inquiry based teaching	Micropipette exercises	Laboratory safety and equipment presentation
	1			Agarose gel electrophoresis	Electrophoretic analysis of DNA
	1			Microorganisms in our environment	Microorganisms culture technique from various environmental samples
	1	Genomic DNA isolation	Project-based teaching		Obtaining DNA from fruits with simple materials
Second Day	1	Polymerases Chain Reaction (PCR)	Problem-based teaching		Informing about Polymerases Chain Reaction (PCR) Technique
	2			PCR laboratory	DNA amplification throught PCR
	2	Who is the guilty?	Argument-based teaching		Forensic biotechnology practices of gel electrophoresis technique
Third Day	2	Bioinformatics: Phylogenetic prediction	Web-based teaching and interdisciplinary teaching		Basic concepts of bioinformatics, DNA-protein databases, BLAST: Sequence comparison method
	1	Evaluation			Post-test and evaluation of the in-service training

2.5. Data Analysis

The qualitative data collected in the current study were subjected to content analysis and evaluated through rubrics. The quantitative data were analyzed by using SPSS program package. The size of the study group is smaller than the sampling size which is considered to be acceptable for parametric tests [52] (p. 268). Thus, the distribution of the data was tested with normality (Shapiro-Wilk; $n < 50$) and homogeneity (Levene) tests. Moreover, Skewness and Kurtosis values were also calculated. As a result of the analyses conducted, it was decided to use non-parametric test analyses (Wilcoxon) for the Biotechnology Awareness Questionnaire (Shapiro Wilk $p < 0.05$, Levene $p < 0.05$) and Biotechnology Evaluation Questions (Shapiro Wilk $p < 0.05$, Levene $p > 0.05$). Moreover, Cohen's d effect size was also calculated. Cohen's d value shows the power of the relationships or their significance in practice. Cohen's d was calculated through an online program (see https://www.uccs.edu/lbecker/) on the basis of the means of the compared groups and standard deviation values. If the effect size value calculated is $d < 0.20$ then it means that there is weak effect; if it is 0.21–0.50 then it means that the effect size is small; if it is 0.51–1.00 then it means that the effect size is medium and if it is >1.01 then it means that the effect size is large [53] (p. 521).

For the analysis of the data collected through the Biotechnology Evaluation Questions, a rubric was developed by the researcher. Then in order to evaluate the participants' responses, an evaluation approach similar to the one used by Abraham et al. [54] was used. According to this approach, the participants' responses to each question were individually subjected to content analysis. Then these responses were gathered and scored under four groups which were the correct answer (3 points), partially correct answer (2 points), an answer including misconceptions (1 point), unrelated answer (0 point).

A similar approach was adopted for the evaluation of the task worksheets. First, specific themes were determined by reviewing the literature about the levels of the cognitive and psychomotor skills to be possessed to be successful in doing the instructional tasks. Then the worksheets were subjected to content analysis and described under these determined themes. An analytical rubric was developed to evaluate the laboratory experience intended to be gained for each instructional task. In this rubric, laboratory experiences are scored as advanced (4 points), adequate (3 points), partially adequate (2 points) and inadequate (1 point). Each instructional tasks was separately evaluated and categories from common experiences were constructed and frequencies (%) were calculated. In the analysis of the other qualitative data in the current study, content analysis and descriptive analysis were used.

3. Findings

3.1. The First Sub-Problem of the Study Seeks an Answer to the Question "What is the Science Teachers' Biotechnology Knowledge and Awareness?"

When the participants' responses given prior to the implementation of the instructional task to the Biotechnology Awareness Questionnaire were examined, it is seen that the responses given to the Question 1 and Question 2 show diversity (Tables 3 and 4).

Table 3. Biotechnology Awareness Questionnaire first question pre-post application themes.

Question 1: What Do You Understand When the Biotechnology Is Called?					
Pre-Test			**Post-Test**		
Themes	*f*	**Sample Answers**	**Themes**	*f*	**Sample Answers**
Technology	5	Technological practices in the world of living things (P8) The connection of conditions related to living things, as well as genetic conditions with technology (P11)	Technology	3	Biotechnology: putting out products by using technology according to the needs (P12) Comparing the materials in the nature with technology (P1)
Bioengineering applications	6	By using living things such as human, animal etc., the studies on them (P3) Biotechnology: creating new cells in an intended way, eliminating the unwanted genes by changing the genes in the cells of animals, plants, and microorganisms (P6)	Bioengineering applications	6	Creating a new organism by using the whole or a part of plants, animals or microorganisms (P3) Bringing the wanted features, removing the unwanted features by examining DNA structure of living things (P8)
Productions	3	Production by working on plant and animal cultures (P5) It can be said that it is the process of production on living organisms by using technological materials (P17)	Productions	5	Producing new products by using living things (P9) Biotechnology is the situation of products adapted to technology- industry in order to increase people's growing needs or quality of life (P13)
Genetic information	1	Pharmacology-gene-DNA (P1)	Treatment	3	Treatment of disease thanks to genetic engineering (P16) New types of vaccine, studies on plants, production of medicine etc. (P17)

Table 4. Biotechnology Awareness Questionnaire second question pre-post application themes.

Questions 2: What Are The Applications of Biotechnology that You Know?					
Pre-Test			**Post-Test**		
Themes	**ƒ**	**Sample Answers**	**Themes**	**ƒ**	**Sample Answers**
Agricultural applications	12	Creating more resistant fertile plants (P10) Works about DNA, GMO food products (P8)	Agricultural applications	6	In agricultural field- GMO (P6)
Medical applications	15	Treatment of diseases thanks to genetic engineering (P4) Treatment and diagnosis methods of some diseases (P12)	Medical applications	11	Diagnosis and treatment of diseases, in health sector, in production of medicine (P7)
Industry applications	4	Production of waterproof clothes (P12)	Industry applications	1	In industrial branches which has economical return- yogurt with fruits (P2)
			Forensic applications	9	DNA fingerprint, paternity test (P13)
Classical biotechnology	2	Beer making, yoghurt making (P15)	Animal application	2	In animal field, production of insulin (P5)
			Environmental application	2	Aquatic- by using underwater creatures (P3)
Forensic applications	1	Fingerprint, DNA match (P3)	Classical biotechnology	3	Making yoghurt, fermentation products like cheese, wine (P12)
			DNA technology	8	Gene mapping, cloning, DNA fingerprint, genome project (P11)

When the majority of the participants defined biotechnology, they emphasized the themes of "technology" (*n* = 5) and "bioengineering applications" (*n* = 6). Moreover, as they emphasized the theme of "productions", it can be said that they see biotechnology as a process of product development. When the responses given to Question 2 are examined, it is seen that the participants are most knowledgeable about "medical applications" (*n* = 15) and "agricultural applications" (*n* = 12) of biotechnology. All the participating science teachers stated that they found DNA fingerprint more reliable (Question 3. In a forensic event, is DNA fingerprint less reliable than the testimony of an eye-witness? Explain it). But, their reasons for this were found to be different. A large majority of the participants (*n* = 11) stated that DNA is more reliable as it is specific to a person. They were of the opinion that as the scope of biotechnology is remarkably broad (*n* = 6) and it is a developing discipline (*n* = 7), it can create new job opportunities (Question 4. Can biotechnology create new job opportunities? Explain it). Moreover, all the participating science teachers stated that the public is not informed about biotechnological applications in question 5 (Do you think people are well-informed about biotechnological applications?). When the mean scores (M) for the multiple-choice questions in the Biotechnology Awareness Questionnaire were examined, it was seen that they have a medium level of awareness of biotechnology (*n* = 17, M = 4.22). The participants got the highest mean score for the item "One of the forensic biotechnology applications is DNA fingerprint" (*n* = 17, M = 4.88) while the lowest mean score (*n* = 17, M = 3.65) was for the item "Bioinformatics is an interdisciplinary field in which information technologies are used to analyze biological processes." (see Appendix C).

When the results obtained from the participants' responses to the Biotechnology Evaluation Questions prior to the implementation of the instructional task were examined, it was seen that the participants' biotechnology methodological and technical knowledge was weak (*n* = 17, M = 0.75). When the questions were examined individually, it was seen that their level of knowledge about the question "What are the steps of DNA isolation? Please explain." was low (*n* = 17, M = 0.35) while the highest number of correct answers was given to the question "Please write the types and functions of biotechnology." (*n* = 17, M = 1.47).

When the responses given after the completion of the tasks to the open-ended questions in the Biotechnology Awareness Questionnaire were evaluated, it was seen that the themes emphasized by the participants was more diversified. While the numbers of the themes emerging before and after the execution of tasks were found to have not changed, the themes were found to have changed (Tables 3 and 4). The theme most emphasized by the participants before and after the instructional tasks was found to be the theme of "bioengineering applications" (*n* = 6) (Question 1). When the responses to the Question 2 were examined, it was seen that the participants' responses related to the applications of biotechnology are collected under five themes before the implementation of the tasks, the number of themes increased to eight after the implementation tasks. Three new themes, "animal applications, environmental applications and DNA technology" were added to the five themes having emerged before the implementation of the tasks (Table 4). All of the participants were of the opinion that forensic biotechnology is more reliable than the testimony of a witness before and after the tasks. Moreover, from this sentence " . . . *Because it includes certain evidence . . . (P11)"*, it was understood that they put emphasis on the reliability of science. While the participants were of the opinion that biotechnology can create new job opportunities as it was "interdisciplinary" and "emerging science" before the implementation of the tasks, after the implementation of the tasks besides these characteristics of biotechnology, they also emphasized another characteristic of "creating new products". After the the implementation of the tasks, they were again thinking that the public is not informed well about biotechnological applications due to the same reasons. According to the results of the Biotechnology Awareness Questionnaire, it was concluded that the instructional tasks led to a significant difference in the teachers' awareness of biotechnology (*p* < 0.05). Moreover, Cohen's *d* (0.68) value showed that the effect size between the means was medium (0.51–1.00) (Table 5).

Table 5. Wilcoxon signed rank test result of Biotechnology Awareness Questionnaire.

Pretest-Posttest	*N*	Mean Rank	Sum of Rank	*z*	*p*
Negative ranks	-	-	-	3.627 *	0.000
Positive ranks	17	9	153		
ties	-	-	-		

* Based on negative ranks. *p* < 0.05 there is a significant difference.

The results of science teachers' responses to the Biotechnology Evaluation Questions before and after the implementation of the instructional tasks are shown in Figure 1.
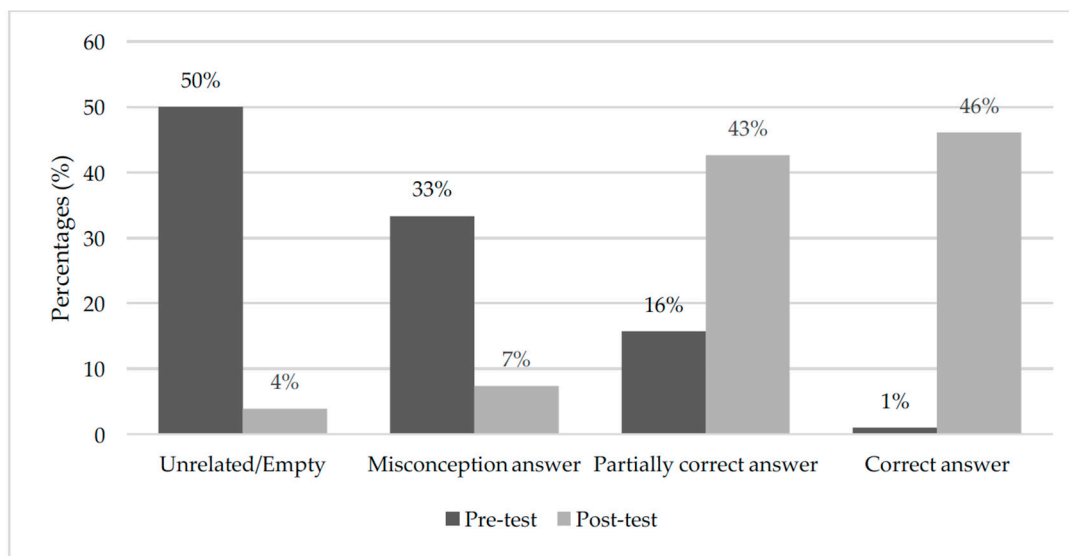
Figure 1. Result of Biotechnology Evaluation Questions.

While 50% of the teachers provided "Unrelated/Empty" answers before the implementation of the tasks, the rate of "Correct answers" after the implementation of the tasks was found to be 46% (Figure 1). Furthermore, as a result of the comparison of the pretest and posttest results obtained from the scoring of the categories determined with the rubric, a statistically significant difference was found. The effect size calculated as Cohen's *d* (0.91) showed that the effect size between the means was high (>1.01) (Table 6). Therefore, Hypothesis 1 is accepted.

Table 6. Wilcoxon signed rank test result of Biotechnology Evaluation Questions.

Pretest-Posttest	*N*	Mean Rank	Sum of Rank	*z*	*p*
Negative ranks	-	-	-	3.626 *	0.000
Positive ranks	17	9	153		
Ties	-	-	-		

* Based on negative ranks. *p* <0.05 there is a significant difference.

3.2. The Second Sub-Problem of the Study Seeks an Answer to the Question "What are the Science Teachers' Laboratory Experiences and Technical Skills?"

The instructional tasks designed to enhance the participants' biotechnology laboratory experiences included more than one instructional approach. The instructional approaches involved in the instructional tasks conducted in the current study and the categories formed for evaluation are shown in Table 7.

Table 7. Teaching approaches used in instructional tasks and categories.

Teaching Approach Used in Tasks/Categories	Readiness	Research Design	Practices	Evaluation
Research-inquiry based learning	Pre-inquiry (wondering)	Hypothesis, Identifying variables	Experiment design	Organizing the data, Result and evaluation
Project based learning	Motivation (wondering/connecting)	Design and planning, Organizing according to standards	Activities/creating a generic framework on experiment	Evaluation and presenting
Problem based learning	Identifying the problem	Planning for the solution, Developing solution	Experimental process	Evaluation
Argumentation based learning	Claim	Data/reason, Supporting and corrupting evidence	Experimental process	Result
Web based-interdisciplinary learning	Problem/explanation	Variables and mathematical calculation	Experimental process	Usage of images Biology and computer science

The rubrics developed to evaluate the worksheets include different objectives. As a result of the content analysis, these objectives were gathered under four categories depending on their effects on laboratory experiences as readiness, research design, laboratory practices and evaluation. The frequency distribution of the scores taken by the participants from the laboratory experiences within the context of all the activities is given in Figure 2.
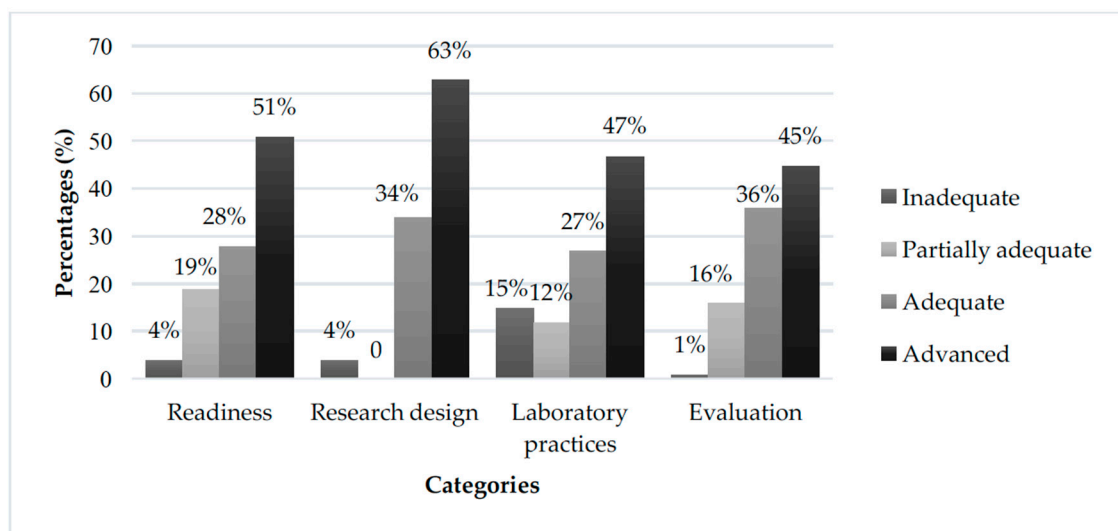

Figure 2. The quality of laboratory experience in the worksheet of science teachers (*n* = 17).

Of the participating teachers, 51% obtained four points for the category of readiness and 63% obtained four points for the category of research design, which showed that they were successful at the advanced level in these categories. The highest ratio of participants (15%) obtained one point for the category of laboratory practices. When the mean scores were examined across the instructional tasks, the lowest mean score (M = 1.3) was obtained for the "Introduction to the Biotechnology Laboratory"

and the highest mean score (M = 3.6) was obtained for the "Bioinformatics: Phylogenetic prediction" in the category of laboratory practices. Of the participants, 45% obtained four points for the category of evaluation. This is relatively lower when compared to the mean scores taken from the other categories (Figure 2).

When the laboratory self-evaluation forms filled by the participants after the completion of each instructional task were examined, it was found that they had not encountered any difficulty during the implementation in general. The participants' statements about the situations in which they were successful and they experienced problems are given below.

Some participants expressed the problems they experienced as they encountered some materials for the first time during the "Introduction to the Biotechnology Laboratory" task as follows: *"I have seen some equipment for the first time. I have learned their names and understood their functions during the process (P8).", "I didn't know how to use some materials (e.g., micropipette) (P4)."* They expressed their successes as follows; *"In establishing the culture environment in medium and performing loading on the well during the electrophoresis (P5)."; "Inoculation the samples on the culture medium (P12)".*

Within the context of the "Genomic DNA isolation", experienced problems in preparing the DNA isolation solution due to carelessness: *"When I forgot the kiwi-detergent mixture on fire, some kind of decay occurred (P3)."* The majority of the teachers stated that they were successful in DNA isolation. While they expressed the problems, they experienced during the "Polymerase chain reaction" as follows: *"I was unfamiliar with some terms (P11)."; "It took longer due to a leaking problem in the microcentrifuge tube (P3)."* They also mentioned their successes as follows: *"I improved the use of micropipette. I performed the stages of the application (P17)."*

In relation to the "Who is the guilty?", they expressed their opinions as follows: *"We accurately placed into small wells by using the micropipette (P4)."; "I did not encounter any problems during the experiences of the first day. I easily placed the isolated DNA into small wells by using the micropipette (P9)."; "We were successful in placing into electrophoresis tanks with the micropipette and in the hypothesis, we established (P12)".* They also made the following explanations regarding this task: *"Through this activity, I learned that not only the DNAs of humans but also those of the other living creatures around should be examined while solving crimes (P13)."; "I learned the importance of using DNA fingerprint in judicial cases (P14)."*

Within the context of the "Bioinformatics: Phylogenetic prediction", the science teachers stated that they enjoyed the instructional tasks but they experienced some difficulties as the web sites used were in English: *"I experienced problems while doing research in web sites prepared in a foreign language (P2).";* *"I experienced some difficulties as I had never used these web sites before (P11)."* They wrote the following expressions in the "what I have learned" section in the self-evaluation form: *"We formed the genealogy of genetic diseases. We capitalized on the study field and database of bioinformatics (P7)."; "We prepared the gene maps of diseases by using the information provided in OMIM, NCBI web sites (P14)"; "We developed genealogies (P12)."*

The laboratory experiences of the participants were evaluated by examining the worksheets according to the teaching approaches used in the instructional tasks. Accordingly, it was determined that the participants had the highest score (M = 3.5) for the category of "identifying variables" in the research-inquiry based instructional task (Introduction to Biotechnology Laboratory). In the project-based instructional task (Genomic DNA isolation), they obtained the highest score (M = 3.6) for the category of "activities/creating a generic framework on experiment". In the problem- based instructional tasks (Polymerase Chain Reaction) found that participants were sufficient all category and they obtained the highest score (M = 3.6) for the category "experimental process". In the argumentation instructional task (Who is the guilty?) they obtained the highest score (M = 3.5) for the category "supporting and corrupting evidence" in process of to test claim. Finally, in the interdisciplinary-web-based instructional task (Bioinformatics: Phylogenetic prediction), it was found that participants obtained the highest score for categories "problem/ explanation" (M = 3.9) and "biology and computer science" (M = 3.9).

The mean scores taken by the participants from the instructional tasks were examined and they were given in ascending order as follows: 2.8 (partially adequate), 3.2 (adequate), 3.4 (adequate), 3.3 (adequate), 3.7 (adequate), indicating that during the training the science teachers were adequate in general in terms of their laboratory experiences and technical skills and the scores tended to increase towards to the final instructional task. Thus, Hypothesis 2 was also supported.

4. Discussion

The aim of the current study was to enhance the knowledge and laboratory skills of science teachers regarding biotechnology, through the use of laboratory instructional tasks developed on the basis of innovative teaching approaches (research-inquiry, problem solving, project, argumentation and web-based interdisciplinary learning approaches). In this context, the effect of the laboratory tasks developed on the basis of the innovative teaching approaches on science teachers' biotechnology knowledge, awareness and laboratory experiences was investigated.

When the findings were examined, it was observed that the participants defined biotechnology as "technology, bioengineering applications and creating new products". As the applications of biotechnology, they seem to be aware of the "agricultural, medical, industrial, and forensic applications of biotechnology and classic biotechnology". Similarly, Acarlı [55] found that while pre-service biology teachers describe the concept of biotechnology, they emphasized the themes of "technology, techniques, innovation, development and treatment" and that in relation to the applications of biotechnology, they are aware of the applications of biotechnology in the fields of agriculture, medicine and industry such as genetically modified organisms (GMO), treatment of diseases, making cheese and yoghurt etc. According to the Biotechnology Awareness Questionnaire, the participants have a moderate amount awareness of biotechnology before the implementation of the instructional tasks. This leads to the creation of an expectation that the participant science teachers should have information about biotechnological processes and applications. However, the findings of the Biotechnology Evaluation Questions show that the participants have low knowledge of basic biotechnological processes and applications. Their poor knowledge of biotechnology results in their having misconceptions about methods and techniques used in biotechnology (DNA isolation, PCR, gel electrophoresis and bioinformatics). Some participants described biotechnology as *"Pharmacology and biochemistry (P2)"* and DNA isolation as *"DNA fragmentation (P11)"* and the stages of DNA isolation as *"Prophase, metaphase, anaphase, telophase (P16)"* is an example of misconceptions.. Similarly, Öztürk-Akar [56] conducted on university students, it was reported that they have a certain view of the application fields of biotechnology but inadequate knowledge about them. Jiménez-Salas et al. [57], found that elementary school teachers' ($n = 362$) who participated in the study, had low levels of knowledge about general biotechnology issues (GMO, cloning, etc.). They stated that this may be due to inadequate education, lack of interest or lack of continuing education for teachers working in state institutions. Similarly, Yılmaz and Öğretmen [16], reported that the pre-service biology teachers have low levels of knowledge about gene technologies, which may be because they have not taken enough courses about gene technologies.

An increase was observed in the participants' biotechnology knowledge and awareness after the completion of the in-service training course titled Biotechnology Education Practices in the current study (Tables 5 and 6). In a similar manner, Çimen [20] reported an increase in biotechnology knowledge of teachers in different branches (science, classroom and biology teachers) after they had participated in laboratory experiments conducted about the subjects of biotechnology.

In the current study, it was determined that teaching of biotechnology subjects through innovative teaching approaches also enhanced laboratory experiences and technical skills as well as knowledge and awareness of the participants. Quantitative and qualitative data obtained from the questionnaire, evaluation questions and worksheets support each other. When the worksheets were examined, the participants were successful at the advanced level in eliciting their prior knowledge in the readiness category, detecting the problem and constructing the research design with problem-oriented variables

(Figure 2). Yet, the quality and clearness of their explanations are weak. Even though 47% of the participants were able to carry out the experimental operations related to the design of the research in the category of laboratory practices in cooperation with their peers, they experienced some difficulties in the laboratory techniques section. This is reflected in the laboratory self-evaluation form with the following statements: *"I have seen some equipment for the first time. I have learned their names and understood their functions during the practices (P8)"*; *"As I had not much encountered the names of the laboratory materials before, it was difficult to learn them (P13)."* Similarly, Lounsbury [58] reported that during DNA isolation and PCR experiments, it was observed that students and teachers experienced difficulties in the quick use of equipment and in the preparation of the necessary solutions.

The success of teachers in laboratory practices depends on their laboratory technical knowledge and skills to a great extent. On the basis of the participants' statements, it can be argued that they lack knowledge and practice. Of the participants, 45% were able to effectively interpret the result they obtained in the evaluation section. Similar results have been obtained in the studies related to the applied teaching of biotechnology subjects in the literature. It was stated that the discovery-based laboratory course using the DNA analysis methods and recombinant DNA cloning techniques enabled the students to gain detailed information about the laboratory techniques used [59]. Studies on the use of DNA technologies (PCR, electrophoresis, etc.) covering biotechnology topics have been reported to improve technical skills as well as knowledge of the subject [60]. Yisau, et al. [61], reported that the combination of theoretical courses with applied laboratory sessions significantly increased the knowledge and skills of participants in molecular biology in a five-day intensive molecular biology training workshop.

Present study also indicated that innovative teaching approaches (research-inquiry, problem solving, project, argumentation and web-based interdisciplinary learning approaches) were found to have positive effects on the participants' laboratory experiences (Table 7). With the task "Introduction to biotechnology laboratory" designed based on research-inquiry, the participants have reached a sufficient level of skills such as creating hypotheses, identifying variables, conducting experiments, editing data and interpreting results. It has been reported that activities designed with a similar teaching approach increased the students' conceptual knowledge [62], and improved their skills of questioning, problem solving, and making conclusions [63]. It was observed that the science teachers' technical knowledge of DNA isolation and awareness of the use of this technique in biotechnology improved as a result of their constructing mini projects related real life problems with their group members within the context of the "Genomic DNA Isolation". It has been shown that project-based activities, including real-life biotechnology practices, increase the perceptions of biotechnology and positively contribute to the skills of developing and implementing an action plan according to the needs of a community [64]. With the "Polymerase Chain Reaction" task, the participants developed solutions to a problem situation and implemented these solutions. Similarly, Casla and Zubiaga [65] reported that the problem-based activity designed on the topic of paternity testing, an application of biotechnology, strengthened teaching by using both individual and group work and combining in-class activities with out-of-class activities. Tatner and Tierney [29] reported that problem-based laboratory activities related to biotechnology issues developed problem solving and laboratory technical skills. The use of the argumentation approach in the "Who is the guilty?" task enabled the participants to learn about the functioning of this process in real life. They have learned to interpret the data they obtained by using forensic biotechnology techniques in the process of testing their claims. Similarly, university students involved in forensic medicine-based laboratory applications built on forensic biotechnology applications have learned to interpret the possible evidence through the data they have obtained [66]. With the web-based "Bioinformatics: Phylogenetic Prediction" task, the teachers have raised their biotechnology awareness and learned how to interpret biological data by using computer science. Langheinrich and Bogner [67] reported that computer-supported gene technology module increased the students' conceptual understanding of the structure of DNA. It has been reported that the web-based bioinformatics module not only provides bioinformatics information, but also develops

specific knowledge (informatics, biological sequence analysis, and structural bioinformatics) and skills [68]. In this study, virtual laboratory (Polymerase Chain Reaction) and web-based teaching (Bioinformatics: Phylogenetic Prediction) were used in biotechnology teaching within the scope of innovative teaching approaches. It has been found useful with regard to meaningful learning of subjects and concepts to use interactive environments in situations including such abstract concepts and requiring expensive tools. Similarly, Bowling, Zimmer ve Pyatt [31] reported that interactive laboratory activity on next-generation sequencing technologies helped students understand the molecular biology behind these technologies.

5. Conclusions

As a result, the biotechnology instructional tasks prepared on the basis of innovative teaching approaches were found to be effective in enhancing the science teachers' biotechnology knowledge, awareness and laboratory experiences. This study is limited to the developed laboratory tasks and the study group.

In light of the findings of the current study, the following suggestions can be made:

- Both theoretical and experimental information should be given to science teachers about the teaching of issues related biotechnology and while planning how to this, innovative teaching approaches should be taken into consideration.
- It is suggested that science teachers be supported by in-service training, seminars, etc. related to biotechnology subjects and to increase the laboratory practices of science teachers and students.
- The current science teacher training course is limited to the teaching of biotechnology subjects. It is suggested that instructional tasks which allow integration of the laboratory-based and innovative learning approaches are included in the science teacher training programs and included in the science curricula.
- Aside from the instructional tasks used in the current study, activities related to different contemporary issues of biotechnology and based on different innovative teaching approaches can be designed and their contribution to teacher training can be investigated.

Appendix A

Biotechnology Evaluation Questions

1. Please write the types and functions of biotechnology.
2. What are the methods and techniques of genetic engineering used in biotechnology?
3. Please explain the concepts of micropipette, agarose gel and bacterial inoculation.
4. What are the steps of DNA isolation? Please explain.
5. What is meant by Polymerase Chain Reaction (PCR)?
6. What are the components needed to synthesize a new DNA by PCR? Please explain.
7. What are the usage areas of PCR in biotechnology?
8. What is gel electrophoresis? What is its working principle?
9. What does the movement of the DNA molecules during electrophoresis depend on?

10. What is bioinformatics?
11. What are the applications of bioinformatics?
12. What can be the applications of biotechnology and genetic engineering in the future?

Appendix B

> **Task 1:** Introduction to the Biotechnology Laboratory
> **The purpose of the activity:** Informing the participants about the place and use of biotechnology in daily life. Introduction and usage protocols of equipment and devices used in biotechnology laboratory.
> **Learning outcomes:**

(a) Relate genetic engineering and biotechnology (learning outcome number F.8.2.5.1 [1]).
(b) Explain the concepts of genetic engineering and biotechnology (learning outcome number 12.1.2.2 [42]).
(c) Predict what the laboratory techniques and device-equipment required by biotechnology applications can be.
(d) Discover the basic techniques and equipment used in molecular biology.
(e) Design experiments using basic molecular biology techniques.

> **Procedure:** This activity constitutes the introduction stage of Biotechnology Education Practice. The aim of this activity is to test participants' readiness for biotechnology. In order to be suitable for this purpose, this activity was designed according to the inquiry based learning approach. Scientific process skills and technical skills were used in the laboratory approach. Participants were divided into groups of two or three and the activity worksheets were distributed to them. The activity began with the implementation of the K-W-L. (what do you **K**now?, what do you **W**ant to know, and what did you **L**earn) chart. K-W-L charts are typically used before a lesson or unit of study to assess the knowledge that students know about a topic [69]. Participants noted down what they know and want to know about genetic engineering and biotechnology. Asking the participants questions like "What is biotechnology?", "What are types of biotechnology?", "Where is biotechnology used?" etc., their discussions were provided in class. Then a computer-based visual presentation about biotechnology was carried out. After the topic was taught, participants were asked to note what they had learned about biotechnology. After the pre-inquiry part of the activity was completed with the K-W-L chart, experimental phase of the task started. Respectively, there were three different practices: "Micropipetting", "Agarose gel preparation" and "Microorganisms in our environment". Participants completed the experimental procedures with the help of an instructor.

> **Task 2:** Genomic DNA isolation
> **The purpose of the activity:** Informing the participants about the physical and chemical structure of DNA. DNA isolation from the cell.
> **Learning outcomes:**

(a) Predict which future genetic engineering and biotechnology practices might be (learning outcome number F.8.2.5.3 [1]).
(b) Show genomic DNA in the cell by doing experiment.
(c) Set up the experimental using the solutions and tools required for genomic DNA isolation.

> **Procedure:** Modern biotechnology studies have been made possible by the processing of DNA. For any changes on DNA, first, the DNA must be separated from the cell. In this activity, it is aimed to inform the participants about the physical and chemical structure of DNA by performing DNA isolation from the cell. This activity is designed according to the project-based learning approach. The laboratory approach is a scientific process skills approach. This activity begins with a problem question. Participants tested their hypotheses and recorded their result in groups of 4–5 people.

While they were answering the questions given in the worksheets, they made a division of labor within the group. Finally, they had to design a mini-project in order to adapt what they learned to new situations. At this stage, they were asked to write the original mini-projects that they designed together with their group members in the project template in the worksheet.

Task 3: Polymerase Chain Reaction (PCR)

The purpose of the activity: Informing the participants about DNA self-matching and the principle of PCR, they to examine more closely each of the components of PCR reactions and technology.

Learning outcomes:

(a)   Expresses how DNA matches itself (learning outcome number F.8.2.1.3 [1]).
(b)   Explain genetic engineering and its practices (learning outcome number 12.1.2.3 [42]).
(c)   Explain the essential elements of DNA replication in the laboratory.
(d)   Set up the PCR mechanism.

Procedure: Polymerase Chain Reaction is one of the techniques used effectively in biotechnology since 1993. This technique is at the center of the completion of the Human Genome Project and the solution of important forensic events. In this activity, it is aimed to inform the participants about DNA self-matching and the principle of PCR, to examine more closely each of the components of PCR reactions and technology. For this purpose, in this activity, problem-based learning and web-based learning approaches were used together. The laboratory approach is the validation (deduction) approach. This activity begins with a problem situation. Participants were asked to note what they knew about the problem and what they needed to solve the problem. By synthesizing and organizing their existing knowledge, participants formed hypotheses about the problem statement and they determined the variables. In order to provide pre-information about the operation of PCR, a web-based virtual laboratory application (http://learn.genetics.utah.edu/content/labs/pcr/) was carried out with the question "What should I do to solve the problem?". After having knowledge about the PCR, they prepared their PCR reactions in the laboratory and performed the experimental procedure. After completing the procedures for solving the problem situation, the activity was terminated with the results and evaluation section.

Task 4: Who is the guilty?

The purpose of the activity: Order to solve the event given in the vital example, the participants were intended to validate or falsify their arguments using the electrophoresis technique from biotechnological methods.

Learning outcomes:

(a)   Relate genetic engineering and biotechnology (learning outcome number F.8.2.5.1 [1]).
(b)   Predict which future genetic engineering and biotechnology practices might be (learning outcome number F.8.2.5.3 [1]).
(c)   Evaluate the effect of genetic engineering and its practices on human life (learning outcome number 12.1.2.4 [42]).
(d)   Set up the gel electrophoresis.
(e)   Compare and interpret the traces formed by DNA on gel.

Procedure: In this activity, it is aimed that participants get information about forensic biotechnology and methods used in biotechnology. For this purpose, the activity is designed according to the argumentation-based learning approach. The laboratory approach is the inductive approach. In the beginning, the participants were introduced to the scenario "Who is the Guilty?". After the class discussion on possible situations in the given scenario, the participants established their claim about who the offender would be, they identified data from within the scenario to support their claims and the rationale for how the data supported the alleged claim and individually recorded the relevant sections in the worksheet. Then, they designed an experiment to support or refute their claims.

Participants were given the materials to be used during the experiment and electrophoresis technique was mentioned. Participants performed the experiment with the instructor and interpreted the results of the experiment.

Task 5: Bioinformatics: Phylogenetic Prediction

The purpose of the activity: Use of bioinformatics in biotechnology, phylogenetic tree formation with differences in gene sequences of different organisms and use of BLAST algorithm.

Learning outcomes:

(a) Relate genetic engineering and biotechnology (learning outcome number F.8.2.5.1 [1].

(b) Predict which future genetic engineering and biotechnology practices might be (learning outcome number F.8.2.5.3 [1]).

(c) Explain the importance of classification in understanding diversity of living things (learning outcome number 9.3.1.1 [42]).

(d) Analyze and evaluate biological data using various databases.

Procedure: Phylogenetic is the investigation of the evolutionary relationship between various organism groups (species and communities). Genes change over time, differentiate or disappear. These processes can be shown as a phylogenetic tree. Comparative analysis of phylogenetic trees can be performed using bioinformatics. Bioinformatics is the examination and processing of biological information with the help of a computer. In this activity, it is aimed to raise awareness about the use of bioinformatics in biotechnology, create phylogenetic trees with differences in gene sequences of different organisms, introduction and use of the BLAST (Basic Local Alignment Search Tool) algorithm and OMIM (Online Mendelian Inheritance in Man), NCBI (National Center of Biotechnology Information) databases. For this purpose, the activity was designed using web-based learning and interdisciplinary learning approaches. The laboratory approach used is a research-based approach. The activity begins with an updated news topic related to evolutionary biotechnology. The participants formed their own hypotheses based on this news. To test their hypotheses, they used online databases (OMIM, NCBI) and the BLAST algorithm. As a result, they confirmed or falsified the hypotheses they developed by supporting the data they acquired with visual models.

Appendix C

Table A1. Biotechnology Awareness Questionnaire multiple choice items.

Item	N	Pre-Test		Post-Test	
		M	SD	M	SD
1. By altering the genetics of microorganisms such as bacteria and yeasts, the production and processing of many foods can be facilitated.	17	4	1.12	4.76	0.75
2. Plants are used in molecular pharmacy as a source of pharmacological products.	17	4.59	0.51	4.82	0.39
3. Genetically modified microorganisms can be designed to clean industrial wastes more effectively.	17	4.41	0.87	4.88	0.33
4. One of the forensic biotechnology applications is DNA fingerprint.	17	4.88	0.33	-	-
5. By plant biotechnology can be produced plant which produces bio-products such as plant vaccines and biofuels.	17	4.65	0.49	-	-
6. Biotechnology makes it possible to produce a high proportion of gene products that are medically important.	17	4.41	0.51	4.94	0.24
7. In evolutional biotechnology, differences genetic of species with DNA sequence analysis are being used in creating a family-tree.	17	4.18	0.81	4.88	0.33
8. Insect resistant plants can be produced with biotechnology.	17	4.47	0.87	4.76	0.44

Table A1. *Cont.*

Item	N	Pre-Test		Post-Test	
		M	**SD**	**M**	**SD**
9. The goal of the Human Genome Project is to determine all the genes in DNA and their location on chromosomes.	17	3.82	1.01	4.94	0.24
10. The cell culture contains the solid and liquid nutrients necessary for the development of the cells.	17	3.94	0.97	4.88	0.33
11. With gene therapy, genetic diseases are treated by transferring normal genes to patient's genome or changing the gene which causes the disease.	17	4.24	0.75	4.82	0.39
12. By improvements in nanobiotechnology, it is aimed to produce small particles which will transport medicines to target cells.	17	4.29	0.69	4.82	0.39
13. Production of disease-resistant oysters is a practice of aquatic environment biotechnology.	17	3.94	0.75	4.82	0.39
14. Regenerative medicine is called the self-renewal of cells, tissues or organ with stem cells.	17	4.24	0.90	4.71	0.47
15. Bioinformatics is an interdisciplinary field in which information technologies are used to analyze biological processes.	17	3.65	0.70	4.82	0.39
16. The analysis of ancient DNAs in the bone and other tissues from fossil samples is "Stone Age" genomics which is known as paleogenomics.	17	3.82	0.81	4.53	0.62

References

1. Ministry of National Education (MoNE). *The Science Teaching Curriculum (3rd, 4th, 5th, 6th, 7th, and 8th grades)*; Turkish Ministry of National Education (MoNE) Press: Ankara, Turkey, 2018. Available online: http://mufredat.meb.gov.tr/Programlar.aspx (accessed on 30 October 2018).
2. National Research Council (NRC). *Next Generation Science Standards: For. States, By States*; The National Academic Press: Washington, DC, USA, 2013.
3. Dawson, V.; Schibeci, R. Western Australian high school students' attitudes towards biotechnology processes. *J. Biol. Educ.* **2003**, *38*, 7–12. [CrossRef]
4. Borgerding, L.A.; Sadler, T.D.; Koroly, M.J. Teachers' concerns about biotechnology education. *J. Sci. Educ. Technol.* **2013**, *22*, 133–147. [CrossRef]
5. Gelamdin, R.B.; Alias, N.; Attaran, M. Students' and teachers' perspectives on biotechnology education: A review on publications in selected journals. *Life Sci. J.* **2013**, *10*, 1210–1221.
6. Fonseca, M.J.; Costa, P.; Lencastre, L.; Tavares, F. Disclosing biology teachers' beliefs about biotechnology and biotechnology education. *Teach. Teach. Educ.* **2012**, *28*, 368–381. [CrossRef]
7. Lazaros, E.; Embree, C.A. Case for teaching biotechnology. *Technol. Eng. Tech.* **2016**, *75*, 8–11.
8. Naz, F.; Murad, H.S. Innovative teaching has a positive impact on the performance of diverse students. *SAGE Open* **2017**, *7*. [CrossRef]
9. Fiksl, M.; Flogie, A.; Aberšek, B. Innotive teaching/learning methods to improve science, technology and engineering classroom climate and interest. *J. Balt. Sci. Educ.* **2017**, *16*, 1009–1019. Available online: http://oaji.net/articles/2017/987-1513971461.pdf (accessed on 30 October 2018).
10. Hung, C.L.; Li, F.C. Teacher perceptions of professional role and innovative teaching at elementary schools in Taiwan. *Educ. Res. Rev.* **2017**, *12*, 1036–1045. [CrossRef]
11. Zhu, C.; Wang, D.; Cai, Y.; Engels, N. What core competencies are related to teachers' innovative teaching? *Asia Pac. J. Teach. Educ.* **2013**, *41*, 9–27. [CrossRef]
12. International Technology Education Association/International Technology and Engineering Educators Association (ITEA/ITEEA). *Standards for Technological Literacy: Content for the Study of Technology*, 3rd ed.; ITEEA: Reston, VA, USA, 2007.
13. Sıcaker, A.; Öz Aydın, S. Assessment of secondary biotechnology and gene engineering concepts by students. *OMU J. Fac. Educ.* **2015**, *34*, 54–62. [CrossRef]

14. AbuQamar, S.; Alshannag, Q.; Sartawi, A.; Iratni, R. Educational awareness of biotechnology issues among undergraduate students at the united arab emirates university. *Biochem. Mol. Biol. Educ.* **2015**, *43*, 283–293. [CrossRef] [PubMed]

15. Casanoves, M.; González, Á.; Salvadó, Z.; Haro, J.; Novo, M. Knowledge and attitudes towards biotechnology of elementary education preservice teachers: The first Spanish experience. *Int. J. Sci. Educ.* **2015**, *37*, 2923–2941. [CrossRef]

16. Yılmaz, M.; Öğretmen, T. The level of knowledge of prospective biology teachers on gene technology and their source of information. *Pegem Egitim ve Ogretim Dergisi* **2014**, *4*, 59–76. [CrossRef]

17. Gürkan, G. The Comparison for Several Variables of Knowledge Levels of Science Teachers and Prospective Science Teachers about Biotechnology and Genetic Engineering. Master's Thesis, İnönü University, Malatya, Turkey, 2013.

18. Sürmeli, H.; Şahin, F. Examination of university students' attitudes towards biotechnological studies in terms of faculty and gender variables. *Procedia Soc. Behav. Sci.* **2010**, *2*, 3999–4005. [CrossRef]

19. Yurdatapan, M.; Şahin, F. The effect of animation and model usage regarding DNA conception on the learning of science teaching students. *Electron. Turk. Stud.* **2013**, *8*, 2303–2313. [CrossRef]

20. Çimen, S.Y. The Effect of Applied Biotechnology Education for Teachers and Pre-Service Teachers on Their Biotechnological Perception. Master's Thesis, Fatih University, İstanbul, Turkey, 2015.

21. Orhan, T.Y. Investigation the Effects of Laboratory Activities on Student Science Teachers' Attitudes on Technology and Perceptions about DNA Technologies Concept and Applications. Master's Thesis, Mugla Sıtkı Koçman University, Muğla, Turkey, 2014.

22. Geng, F.; Alani, F. Biotechnology labs reinvented through experiential learning: Enhancing student outcomes through the "flipped lab". In Proceedings of the Canadian Engineering Education Association (CEEA), Hamilton, ON, Canada, 31 May–3 June 2015.

23. Prabha, S. Laboratory experiences for prospective science teachers: A meta-analytic review of issues and concerns. *Eur. Sci. J.* **2016**, *12*, 235–250. [CrossRef]

24. Taşkın, Ö. (Ed.) *New Approaches in Science and Technology Teaching*, 1st ed.; Pegem Academy: Ankara, Turkey, 2008; pp. 48–49.

25. Steury, M.D.; Poteracki, J.M.; Kelly, K.L.; Rennhack, J.; Wehrwein, E.A. Hypothesis-driven laboratories: an innovative way to foster learning in physiology laboratory courses. *Adv. Physiol. Educ.* **2016**, *40*, 129–133. [CrossRef]

26. Sato, B.K. Attack of the killer fungus: a hypothesis-driven lab module. *J. Microbiol. Biol. Educ.* **2013**, *2*, 230–237. [CrossRef]

27. Ayas, A.; Çepni, S.; Akdeniz, A.R.; Özmen, H.; Yiğit, N.; Ayvacı, H.Ş. *Science and Technology Teaching from Theory to Practice*, 6th ed.; Pegem, A. Publication: Ankara, Turkey, 2007; pp. 201–211.

28. Hasson, E.; Yarden, A. Separating the research question from the laboratory techniques: Advancing high-School biology teachers' ability to ask research questions. *J. Res. Sci. Teach.* **2012**, *49*, 1296–1320. [CrossRef]

29. Tatner, M.; Tierney, A. An extended, problem-based learning laboratory exercise on the diagnosis of infectious diseases suitable for large level 1 undergraduate biology classes. *J. Biol. Educ.* **2016**, *50*, 54–60. [CrossRef]

30. Jarrett, K.; Williams, M.; Horn, S.; Radford, D.; Wyss, J.M. Sickle cell anemia: tracking down a mutation: an interactive learning laboratory that communicates basic principles of genetics and cellular biology. *Adv. Physiol. Educ.* **2016**, *40*, 110–115. [CrossRef] [PubMed]

31. Bowling, B.; Zimmer, E.; Pyatt, R.E. Bringing next-generation sequencing into the classroom through a comparison of molecular biology techniques. *Am. Biol. Teach.* **2014**, *76*, 396–401. [CrossRef]

32. Serdyukov, P. Innovation in education: what works, what doesn't, and what to do about it? *J. Res. Innov. Teach. Learn.* **2017**, *10*, 4–33. [CrossRef]

33. Sadler, T.D.; Romine, W.L.; Menon, D.; Ferdig, R.E.; Annetta, L. Learning biology through innovative curricula: A comparison of game- and nongame-based approaches. *Sci. Educ.* **2015**, *99*, 696–720. [CrossRef]

34. Lin, T.-C.; Tsai, C.-C. Innovative technology-assisted science learning in Taiwan. In *Science Education Research and Practices in Taiwan: Challenges and Opportunities*; Chiu, M.-H., Ed.; Springer: Singapore, 2016; pp. 189–209.

35. Istance, D.; Kools, M. OECD Work on technology and education: innovative learning environments as an integrating framework. *Eur. J. Educ.* **2013**, *48*, 43–57. [CrossRef]

36. Winterman, B.; Malacinski, G.M. Teaching evidence-based innovation (EBI) as a transdisciplinary professional skill in an undergraduate biology writing workshop. *Int. J. Arts Sci.* **2015**, *8*, 423–439.

37. Kavacık, L.; Yanpar Yelken, T.; Sürmeli, H. Innovation practices in elementary school science and technology course and their effect on students. *Educ. Sci.* **2015**, *40*, 247–263. [CrossRef]

38. Martins, M.J.; Martel, F. An innovative laboratory research practice supporting an introduction to research methodology in the medical undergraduate curriculum: the students' perspective. *J. Contemp. Med. Educ.* **2013**, *1*, 3–8. [CrossRef]

39. Oyelekan, O.S.; Igbokwe, E.F.; Olorundare, A.S. Science teachers' utilization of innovative strategies for teaching senior school science in Ilorin, Nigeria. *Malays. Online J. Educ. Sci.* **2017**, *5*, 49–65.

40. Lederman, N.G.; Lederman, J.S. Is nature of science going, going, going, gone? *J. Sci. Teach. Educ.* **2014**, *25*, 235–238. [CrossRef]

41. Coil, D.; Wenderoth, M.P.; Cunningham, M.; Dirks, C. Teaching the process of science: Faculty perceptions and an effective methodology. *CBE-Life Sci. Educ.* **2010**, *9*, 524–535. [CrossRef] [PubMed]

42. Ministry of National Education (MoNE). *The Biology Teaching Curriculum (9th, 10th, 11th ve 12th Grades)*; Turkish Ministry of National Education (MoNE) Press: Ankara, Turkey, 2018. Available online: http://mufredat.meb.gov.tr/Programlar.aspx (accessed on 30 October 2018).

43. Turan, M.; Koç, I. Preservice science teachers' attitudes toward biotechnology application. *Trakya Univ. J. Educ.* **2012**, *2*, 74–83.

44. Mueller, A.L.; Knobloch, N.A.; Orvis, K.S. Exploring the effects of active learning on high school students' outcomes and teachers' perceptions of biotechnology and genetics instruction. *J. Agric. Educ.* **2015**, *56*, 138–152. [CrossRef]

45. Van Lieshout, E.; Dawson, V. Knowledge of, and attitudes towards health-related biotechnology applications amongst Australian year 10 high school students. *J. Biol. Educ.* **2016**, *50*, 329–344. [CrossRef]

46. Creswell, J.W.; Plano Clark, V.L. *Designing and Conducting Mixed Method Research*, 2nd ed.; SAGE Publications: Los Angeles CA, USA, 2011; pp. 98–103.

47. Karasar, N. *Scientific Research Method*, 28th ed.; Nobel Publication: Ankara, Turkey, 2013; p. 96.

48. Yıldırım, A.; Şimşek, H. *Qualitative Research Methods in the Social Sciences*, 9th ed.; Seçkin Publication: Ankara, Turkey, 2013; p. 83.

49. Patton, M.Q. *Qualitative Research & Evaluation Methods*, 3th ed.; SAGE Publications: Los Angeles, CA, USA, 2002; p. 230.

50. Miles, M.B.; Huberman, A.M. *Qualitative Data Analysis: An. Expanded Sourcebook*, 2nd ed.; SAGE Publications: Los Angeles, CA, USA, 1994; p. 278.

51. Ministry of National Education (MoNE). The Science and Technology Teachers of Special Area Competence. 2017. Available online: http://oygm.meb.gov.tr/www/ilkogretim-ozel-alan-yeterlikleri/icerik/257 (accessed on 30 October 2018).

52. Sönmez, V.; Alacapınar, F.G. *Illustrated Scientific Research Methods*, 5th ed.; Anı Publication: Ankara, Turkey, 2017; p. 268.

53. Cohen, L.; Manion, L.; ve Morrison, K. *Research Methods in Education*, 6th ed.; Routledge: New York, NY, USA, 2007.

54. Abraham, M.R.; Grzybowski, E.B.; Renner, J.W.; Marek, E.A. Understandings and misunderstandings of eighth graders of five chemistry concepts found in textbooks. *J. Res. Sci. Teach.* **1992**, *29*, 105–120. [CrossRef]

55. Acarlı, D.S. Determining prospective biology teachers' cognitive structure in terms of "Biotechnology". *J. Balt. Sci. Educ.* **2016**, *15*, 494–505.

56. Öztürk-Akar, E. Turkish university students' knowledge of biotechnology and attitudes toward biotechnological applications. *Biochem. Mol. Biol. Educ.* **2017**, *45*, 115–125. [CrossRef]

57. Jiménez-Salas, Z.; Campos-Góngora, E.; González-Martínez, B.E.; Tijerina-Sáenz, A.; Escamilla-Méndez, A.D.; Ramírez-López, E. Basic-education Mexican teachers' knowledge of biotechnology and attitudes about the consumption of genetically modified foods. *Biochem. Mol. Biol. Educ.* **2017**, *45*, 396–402. [CrossRef]

58. Lounsbury, K.M. Crime scene investigation: An exercise in generating and analyzing DNA evidence. *Biochem. Mol. Biol. Educ.* **2003**, *31*, 37–41. [CrossRef]

59. de Lencastre, A.; Thomas Torello, A.; Keller, L.C. An investigative graduate laboratory course for teaching modern DNA techniques. *Biochem. Mol. Biol. Educ.* **2017**, *45*, 351–359. [CrossRef]

60. Fernando, J.; Carlson, B.; LeBard, T.; McCarthy, M.; Umali, F.; Ashton, B.; Rose, F.F. A laboratory exercise for genotyping two human single nucleotide polymorphisms. *J. Biol. Educ.* **2016**, *50*, 73–85. [CrossRef]

61. Yisau, J.I.; Adagbada, A.O.; Bamidele, T.; Fowora, M.; Brai, B.I.C.; Adebesin, O.; Bamidele, M.; Fesobit, T.; Nwaokorie, F.O.; Ajayi, A.; et al. Assessment of knowledge of participants on basic molecular biology techniques after 5-day intensive molecular biology training workshops in Nigeria. *Biochem. Mol. Biol. Educ.* **2017**, *45*, 313–317. [CrossRef] [PubMed]

62. Treadway, M.N. Inquiry-Based Biotechnology Education for Kent Intermediate School District Early College Program. Master's Thesis, Grand Valley State University, Allendale, MI, USA, 2016.

63. Ketpichainarong, W.; Panijpan, B.; Ruenwongsa, P. Enhanced learning of biotechnology students by an inquiry-based cellulose laboratory. *Int. J. Environ. Sci. Educ.* **2010**, *5*, 169–187.

64. Nguyen, P.D.; Siegel, M.A. Community action projects: Applying biotechnology in the real world. *Am. Biol Teach.* **2015**, *77*, 241–247. [CrossRef]

65. Casla, A.V.; Zubiaga, I.S. Paternity testing in a PBL environment. *Biochem. Mol. Biol. Educ.* **2010**, *38*, 37–42. [CrossRef] [PubMed]

66. Smit, J.; Heath, D.D.; Walter, R.P. A molecular genetic lab to generate inclusive and exclusive forensic evidence: Two suspects, a victim, and a bloodstained t-shirt. *Biochem. Mol. Biol. Educ.* **2014**, *42*, 230–236. [CrossRef]

67. Langheinrich, J.; Bogner, F.X. Student conceptions about the DNA structure within a hierarchical organizational level: Improvement by experiment-and computer-based outreach learning. *Biochem. Mol. Biol. Educ.* **2015**, *43*, 393–402. [CrossRef]

68. Vincent, A.T.; Bourbonnais, Y.; Brouard, J.-S.; Deveau, H.; Droit, A.; Gagné, S.M.; Guertin, M.; Lemieux, C.; Rathier, L.; Charette, S.J.; Lagüe, P. Implementing a web-based introductory bioinformatics course for non-bioinformaticians that incorporates practical exercises. *Biochem. Mol. Biol. Educ.* **2018**, *46*, 31–38. [CrossRef]

69. Cherner, T.S.; Fegely, A. Educational apps in the blended learning classroom: Bringing inquiry-based learning into the mix. *Curr. Issues Emerg. eLearn.* **2017**, *4*, 1.