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Assessing elementary understanding of electromagnetic radiation and its implementation in wireless technologies among pre-service teachers

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ABSTRACT

The research on the knowledge and perceptions of electromagnetic radiation among teachers who will teach these topics in primary and secondary education is relatively limited. According to existing literature, electromagnetic radiation is a challenging and complex concept for students to comprehend. Despite the widespread use of radiation-emitting devices like cell phones and wireless networks, the misuse of the term "radiation" has resulted in various misconceptions. This study aimed to examine the elementary understanding of electromagnetic radiation and its application in wireless technologies among prospective primary and secondary education teachers from different specialties. 427 pre-service teachers participated in the survey, and the data was gathered through a closed questionnaire. The study's overall conclusion was that teachers' knowledge regarding electromagnetic radiation was insufficient. The curricula of their departments, their interests in high school courses, and their gender significantly affect their understanding of electromagnetic radiation and its application to wireless technologies.

Keywords: electromagnetic radiation, knowledge, teachers, cell phones, wireless technology, specialty, track, gender

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INTRODUCTION

Didactics of Physics

The field of physics is concerned with the investigation of all physical phenomena. The principles of physics are widely regarded as challenging to comprehend due to the fact that while physics is concerned with everyday phenomena and interactions, the knowledge that is generated is not always congruent with human sensory experiences or direct observations (Andreou & Kotsis, 2005). During the process of learning, knowledge is not simply transmitted from one person to another, but rather is constructed based on pre-existing knowledge and shaped by socio-cultural factors. This process leads to the formation of mental models, which are then utilized to address the challenges encountered in everyday life by individuals and society as a whole (Piaget, 1983; Vygotsky, 1978). If the mental models constructed by an individual do not align with accepted scientific knowledge, they are often referred to as misconceptions or alternative ideas (Gilbert & Watts, 1983).

In the realm of natural sciences education, significant attention is given to the exploration and documentation of the ideas, perspectives, and alternative concepts held by both students and teachers (Beijaard et al., 2004; Kotulakova, 2019; Pajares, 1992; Penuel et al., 2009; Valcke et al., 2010), as they are the individuals responsible for imparting scientific knowledge and promoting changes in understanding. The process of facilitating such changes involves guiding learners from holding misconceptions towards embracing scientifically-accepted concepts (Heddy et al., 2017; Kotsis, 2011).

After conducting a review of relevant literature, it was discovered that numerous studies have explored and documented the knowledge, perceptions, and alternative ideas of both students and teachers concerning various Physics concepts such as force and motion (Christonasis & Kotsis, 2022; Kotsis & Stylos, 2023; Liu & Fang, 2016; Lopez, 2003; Rowlands et al., 2005; Stylos et al., 2008; Temiz & Yavuz, 2014), gravity (Gonen, 2008; Kikas, 2004; Sneider & Ohadi, 1998), energy (Lee, 2016; Kotsis & Panagou, 2023; Kotsis et al., 2023; Stylos & Kotsis, 2021; Stylos et al., 2017; Yeh et al., 2017), electricity (Metioui, 2022; Moodley & Gaigher, 2019; Widodo et al., 2018), and environment (Gontas et al., 2020, 2021; Goulgouti et al., 2019; Gavrilakis et al., 2017; Papanikolaou et al., 2020, 2021). In contrast to engineering, which deals with tangible and concrete objects (Yalvac et al., 2007), electromagnetic fields, waves, and radiation are abstract and intangible concepts (Griffiths, 2017) that are challenging to comprehend through direct observation or sensory experiences (Papoulis, 1977).

Even though these concepts are regarded as some of the most challenging and abstract ones to grasp (Siersma et al., 2021; Ye et al., 2010), the quantity of research devoted to them is noticeably lower compared to the aforementioned concepts in physics (Morales López & Tuzón Marco, 2022; Plotz, 2016).

Research for Electromagnetic Radiation

Electromagnetic radiation, which can originate from either natural or man-made sources, is present throughout the environment. In recent years, the amount of exposure that humans have had to artificial electromagnetic radiation has increased sharply. This is largely due to the rising need for electricity (Guzman et al., 2006; Horak et al., 2022), the prevalence and advancements of wireless technology, and changes in social behavior (Gavrilas et al., 2022a; World Energy Council, 2016).

The origins of radiation research can be traced back to the late 1800s when scientists started examining the properties of radiation. In 1895, a German physicist named Wilhelm Conrad Roentgen discovered X-rays, a type of electromagnetic radiation that can penetrate solid objects and create images of the human body (Tubiana, 1996). After this breakthrough, researchers continued to study radiation and its effects on living organisms. In the 1920s and 1930s, scientists started investigating radiation therapy as a treatment for cancer, and by the 1950s, it had become a widely used method for treating many types of cancer (Connell & Hellman, 2009).

In modern times, radiation research remains significant across various fields, including biology, medicine, physics, and engineering. Scientists are still exploring radiation's properties, and potential applications, as well as its hazards and risks of exposure (Cho et al., 2019). Several misconceptions about radiation have been researched recently, and this has helped to create greater public awareness about radiation's benefits and risks, leading to more informed decision-making regarding radiation-related issues (Lips et al., 2021; Neumann, 2014a, 2014b).

These research mainly focused on the difference between radiation and contamination (Boyes & Stanisstreet, 1993; Eijkelhof et al., 1990; Millar, 1994). As time progressed, research shifted to identifying misconceptions about ionizing radiation, which could stem from natural or artificial sources (Henriksen & Jorde, 2001). More recently, studies have explored the knowledge of medical students regarding different forms of radiation, with a particular focus on nuclear radiation (Mubeen et al., 2008).

Other studies have examined students' perceptions of different types of radiation and the difference between ionizing and non-ionizing radiation, as well as their beliefs about electromagnetic radiation from electronic devices. Results from these studies indicate that the majority of students' perceptions of radiation differ significantly from scientifically accepted knowledge (Hori et al., 2019; Neumann & Hopf, 2012; Rego & Peralta, 2006).

Furthermore, research has indicated that the term "radiation" is often viewed as something detrimental, regardless of its source or category (Neumann & Hopf, 2012). Another survey, which was part of a more comprehensive study of students' scientific knowledge, demonstrated that their understanding was largely centered around the hazards of radiation, rather than its potential applications (Romine et al., 2014). Moreover, a recent survey among prospective teachers of various disciplines also revealed a pessimistic attitude toward electromagnetic radiation (Gavrilas et al., 2022a).

Significance of Understanding Electromagnetic Radiation

In recent times, the proliferation of electronic devices and wireless communication technologies has raised concerns about electromagnetic radiation, which is also referred to as electromagnetic fields or electromagnetic pollution. The primary cause of these concerns is the emission of electromagnetic waves in the radio frequency range. These waves are a form of non-ionizing radiation and are emitted by various electronic devices, such as microwave ovens, power lines, Wi-Fi routers, and cell phones (Du & Swamy, 2010; Subha, 2017).

Research has indicated that high levels of electromagnetic radiation can be harmful to health and may raise the risk of cancer, neurological disorders, and reproductive issues. Furthermore, individuals may experience symptoms such as headaches, tiredness, and disrupted sleep patterns after prolonged exposure to electromagnetic radiation (Chu et al., 2011; Farashi et al., 2022; Gavrilas & Kotsis, 2023; Jacob, 2020). Electromagnetic radiation has been categorized as a potential carcinogen by World Health Organization, prompting many nations to develop rules and standards to limit exposure to it. Moreover, young children and adolescents nowadays begin using wireless technologies and cell phones at earlier ages than adults, whose bodies are still in development. (International Agency for Research on Cancer, 2011; Magiera & Solecka, 2020; Pendse & Zagade, 2014; World Health Organization, 1946). However, the rapid proliferation of electronic devices and wireless technologies has made it difficult to control exposure to electromagnetic radiation, and some experts have raised concerns about the long-term health effects of chronic exposure to low levels of electromagnetic radiation (Davis et al., 2013; Moulder et al., 2005).

Ongoing research into the effects of Electromagnetic radiation on human health reveals that there is still much that is not fully understood about the benefits and risks of these technologies (International Agency for Research on Cancer, 2002; World Health Organization, 2014). Thus, individuals must stay informed about the potential risks of electromagnetic radiation and take measures to reduce their exposure, such as using wired connections instead of Wi-Fi, using a headset or speakerphone when making calls on a cell phone, and limiting the use of electronic devices in the bedroom (American Academy of Pediatrics, 2019; Federal Communications Commission, 2020; Government Advice, 2022; U.S. Food and Drug Administration, 2020).

The aforementioned points indicate the significance of possessing adequate scientific knowledge about electromagnetic radiation, and the ability to implement this knowledge in our everyday lives. Common misunderstandings related to electromagnetic radiation are due to the use of the term "radiation" in everyday language, which differs from the scientific definition, and also to false information from unreliable sources in the media (Gavrilas et al., 2018; Neumann, 2014a). Given the internet's prominent role as the main information source for many people today, the development of critical thinking skills is crucial in assessing information found online. The vast amount of information available online makes it challenging to differentiate between reliable and unreliable sources. Critical thinking abilities can assist in evaluating the credibility of sources, detecting biases, and evaluating arguments (Abrami et al., 2015; Lawrence & Giles, 1998; Sahin et al., 2010).

To improve teaching methods and promote scientific understanding and critical thinking about electromagnetic radiation, it is necessary to conduct further research into the knowledge of future primary and secondary teachers (Gavrilas et al., 2022a). As educators, teachers have a crucial role in shaping young people's understanding of science and technology, and their level of knowledge can greatly impact students' learning outcomes (Darling-Hammond, 2017). To create efficient teaching techniques, it is essential to evaluate the existing knowledge of primary and secondary school teachers concerning electromagnetic radiation. This evaluation enables the development of customized professional development programs and classroom strategies that cater to the needs and knowledge levels of teachers. The ultimate goal is to encourage critical thinking and scientific inquiry among students (National Research Council, 2012).

The endeavors aimed at equipping upcoming generations with the required knowledge, abilities, and resources to effectively handle the intricate technological environment of contemporary society are of significant importance. Teachers need to possess fundamental knowledge about scientific facts concerning electromagnetic radiation generated by everyday devices and be equipped with the ability to impart a comprehensive understanding of the related concepts to their pupils. This can be accomplished by conducting research studies, providing appropriate resources, and offering professional development programs to educators (Kaliampos et al., 2023); National Research Council, 2012; Wahyudi et al., 2019).

Research Questions

The responsibility of teaching science topics to students falls upon teachers across all grade levels. However, the topic of electromagnetic radiation has been identified as particularly challenging for students to grasp. Moreover, given the increasing use of electromagnetic radiation in various modern electronic devices, the potential risks associated with it have become a topic of controversy. These factors prompted us to develop the following research questions:

1. What is the level of understanding among primary and secondary education teachers regarding the fundamentals of electromagnetic radiation and its application in contemporary electronic devices?
2. Which group of prospective teachers possesses the most comprehensive understanding of electromagnetic radiation and its application?
3. What factors are linked to the level of understanding among teachers regarding this subject matter?

METHODOLOGY

Participants

A total of 427 pre-service teachers, 146 (34.2%) men and 281 (65.8%) women participated in the research. 112 (26.2%) were primary school teachers, 102 (23.9%) were pre-school teachers, 105 (24.6%) were computer science teachers, and 108 (25.3%) were science teachers. In addition, the participants during their high school studies in terms of track, 94 (22.0%) followed science track, 152 (35.6%) technology track, and 181 (42.4%) art & letters track.

Research Tool

A close-ended questionnaire was utilized to collect quantitative data for this research. The research tool was developed after considering the unique characteristics of the respondents and conducting a literature review related to the topic. This questionnaire was previously used in a larger study on electromagnetic radiation and pollution generated by cell phones and wireless networks (Gavrilas, 2017). The questionnaire was designed to explore four main areas, including knowledge, attitudes, behaviors, and symptom statements. A pilot study was conducted on thirty university students of different genders to ensure the feasibility and validation of the questionnaire. Furthermore, three subject matter experts were consulted to confirm the face validity and content validity of the research tool (Gavrilas et al., 2022a, 2022c).

Cronbach's alpha coefficient was used to assess the internal consistency of the questionnaire. The coefficient value for the entire factor of the questionnaire was .704. Cronbach's alpha coefficient values range from 0 to 1, with 0 indicating no reliability and 1 indicating that the research instrument is entirely reliable. Generally, a coefficient value between .60-.70 is considered acceptable, while a value of .80 or higher is considered very good. This is a commonly accepted standard (Ursachi et al., 2015).

Data Collection

The researchers distributed the questionnaires in paper form to collect research data. They had consulted with the professor beforehand to ensure they had the required time. The researchers provided introductory information to the participants about the research purpose, data usage, questionnaire anonymity, and instructions for completing the questionnaire before distributing them. Once the allotted time had elapsed, the questionnaires were collected and digitized for data analysis (Gavrilas & Kotsis, 2023; Gavrilas et al., 2022a, 2022b).

Data Analysis

The data analysis was performed using the statistical software SPSS (statistical package for social sciences) version 21. Descriptive statistics were employed to summarize the data, and the results were presented using appropriate tables and graphs created with Microsoft Excel. The statistical test χ^2 (Pearson Chi-square) was used to examine the relationship between the respondents' answers and their department, track, and gender, with a significance level of α=.05.

To investigate the relationship between the respondents' grades and their department and track, the statistical test ANOVA (analysis of variance) was used at a significance level of α=.05. The statistical test t-test was utilized with a significance level of α=.05 to investigate the relationship between the respondents' grades and their gender (Shih & Fay, 2017).

RESULTS

Correlations Between Questions and Specialty, Track, and Gender of Pre-Service Teachers

Table 1 displays the questionnaire questions and the corresponding percentages of correct and incorrect answers. The results show that the majority of questions have high rates of incorrect answers. For instance, 68.9% of teachers lack knowledge about the causes of electromagnetic pollution, and 62.1% do not know which type of radiation is more hazardous. However, in terms of knowledge about specific absorption rate (SAR), teachers performed relatively better, with 47.8% answering correctly. Interestingly, 80.8% of respondents believe that cell phones emit radioactivity, while 71% believe that wireless networks also emit radioactivity.

Table 1. Participant's answers & Chi-square tests results

Question	Answer	Percentage	χ^2 test p-value specialty	χ^2 test p-value track	χ^2 test p-value gender
1. What is source of electromagnetic pollution?	Correct	31.1%	.003*	.001*	.000*
	Wrong	68.9%			
2. Is ionizing radiation more dangerous than non-ionizing radiation?	Correct	37.9%	.000*	.006*	.238
	Wrong	62.1%			
3. What does SAR of a cell phone mean?	Correct	47.8%	.000*	.000*	.002*
	Wrong	52.2%			
4. Do cell phones emit radioactivity?	Correct	19.2%	.000*	.000*	.000*
	Wrong	80.8%			
5. Are there limits to SAR of a cell phone?	Correct	57.6%	.002*	.000*	.004*
	Wrong	42.4%			
6. Do all cell phones have same SAR?	Correct	72.6%	.000*	.000*	.001*
	Wrong	27.4%			
7. Does your cell phone's emitted radiation remain constant?	Correct	32.1%	.007*	.019*	.001*
	Wrong	67.9%			
8. Do Wi-Fi networks emit radioactivity?	Correct	29.0%	.000*	.000*	.017*
	Wrong	71.0%			
9. Does Wi-Fi network stop emitting radiation when no device is connected?	Correct	64.9%	.000*	.000*	.001*
	Wrong	35.1%			
10. Do you think TV aerials on rooftops emit radiation?	Correct	19.9%	.000*	.000*	.000*
	Wrong	80.1%			

Note. Pearson Chi-square; *Correlation is significant at 0.05 level; Sig. (2-tailed); & p<.05

After controlling for correlations between the answers to the questionnaire and variables such as subject specialty, high school track, and gender, a correlation was found in almost all cases, as determined by the χ^2 test. The only exception was the question regarding the danger of ionizing or non-ionizing radiation, for which no correlation was found with the teacher's gender ($X^2[1, 427]=1.381$, p=.238), as shown in **Table 1**.

Performance Distribution of Pre-Service Teachers

The survey consists of 10 questions that test students' knowledge, and they are asked to provide the correct answer if they know it. Each correct answer is worth +1 point, while incorrect or unknown answers do not receive any marks. To determine a student's performance percentage on the subject of electromagnetic radiation, the sum of their scores is multiplied by 100 and divided by the total number of knowledge questions, which is 10 in this case. The resulting percentage score can range from 0% if no questions are answered correctly to 100% if all questions are answered correctly.

Table 2 presents some descriptive statistics on the performance of the 427 participants in the knowledge questions. The average performance score of the students is 41.22 (mean [M]), and some participants did not answer any questions correctly (minimum=.0), while others answered all questions correctly (maximum=100.0). The range of values (range) is 100.0%, and the median (median) performance score of the students is 40.0%.

Table 2. Statistics for pre-service teacher's performance

n	**Valid**	**427**
	Missing	**0**
Mean		41.21
Standard error of mean		1.16
Median		40.00
Mode		40.00
Standard deviation		24.01
Variance		576.91
Range		100.00
Minimum		.00
Maximum		100.00

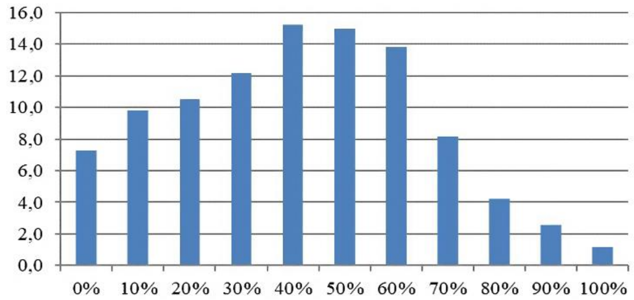

Figure 1. Performance distribution of pre-service teachers (Source: Authors)

The data presented in **Figure 1** shows that a majority of the participants, 70.0% of them, scored below 50% on the knowledge questions. Specifically, 65 participants, or 15.2% of all participants scored 40%, while the next largest percentage, i.e., 15.0% of them scored 50%. A small number of participants, 7.3%, failed to answer any of the questions correctly, and 9.8% of them answered only one question correctly. In contrast, only 1.2% of the participants answered all the knowledge questions correctly.

Performance of Pre-Service Teachers According to Their Specialty

Figure 2 displays the performance of pre-service teachers on the knowledge questions, categorized by their specialty. The results show that 22% of primary teachers obtained a score of 10%, while 12% of pre-school teachers scored .0%. Moreover, 18% of computer science teachers scored 40%. These findings indicate a significant variation in the performance of teachers depending on their specialty.

It can be seen that there is a noteworthy variance in the mean performance of teachers among their specialties. Specifically, primary education teachers achieved an average of 31.78% while pre-school teachers achieved an average of 30.88% on the knowledge questions. Science teachers attained the highest average at 53.24% (as presented in **Table 3**). To compare the impact of followed track on performance in

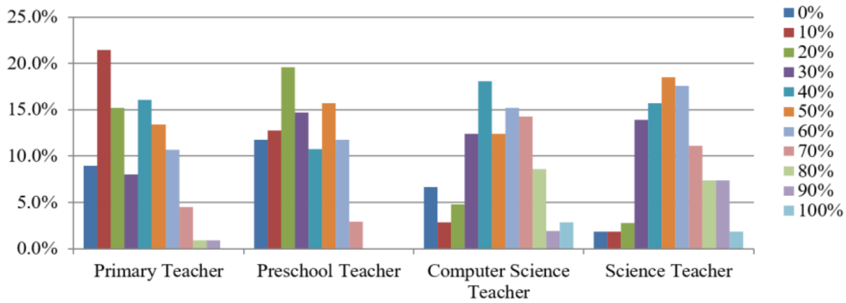

Figure 2. Performance of pre-service teachers according to their specialty (Source: Authors)

Table 3. Statistics for pre-service teacher's performance by their specialty

Specialty	n	Mean	Standard deviation	Standard error	95% confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
Primary education	112	31.7857	21.77751	2.05778	27.7081	35.8633	.00	90.00
Preschool education	102	30.8824	20.15303	1.99545	26.9239	34.8408	.00	70.00
Computer science	105	48.9524	24.05618	2.34764	44.2969	53.6078	.00	100.00
Science education	108	53.2407	21.43579	2.06266	49.1518	57.3297	.00	100.00
Total	427	41.2178	24.01910	1.16237	38.9331	43.5025	.00	100.00

Table 4. Statistics for pre-service teacher's performance

	Sum of squares	df	Mean square	F	Sig.
Between groups	42,752.797	3	14,250.932	29.693	.000
Within groups	203,013.948	423	479.938		
Total	245,766.745	426			

knowledge questions, a one-way ANOVA was conducted (as demonstrated in **Table 4**).

A statistical analysis known as one-way ANOVA was conducted to examine the differences in performance between groups. The results showed that there was a significant difference in performance between at least two groups (F[3, 423]=29.693, p=.000). Using Tukey's HSD test for multiple comparisons, it was found that primary and science teachers had significantly different mean performance values (p=.000, 95% CI=[-29.0755, -13.8346]), as did primary and computer science teachers (p=.000, 95% CI=[-24.8423,-9.4910]).

Similarly, pre-school and science teachers had significantly different mean performance values (p=.000, 95% CI=[-30.1601, -14.5567]), as did pre-school and computer science teachers (p=.000, 95% CI=[-25.9256, -10.2144]). However, there was no significant difference between science and computer science teachers (p=.482), nor between primary and pre-school teachers (p=.990) (**Table 4**).

Performance of Pre-Service Teachers According to Their Track in High School

Performance of pre-service teachers on knowledge questions is shown in **Figure 3**, grouped by track they followed in high school. Majority of teachers who followed arts & letters track scored only 10% on the knowledge questions, representing 18% of the total participants. Those who followed technology track had the highest percentage of

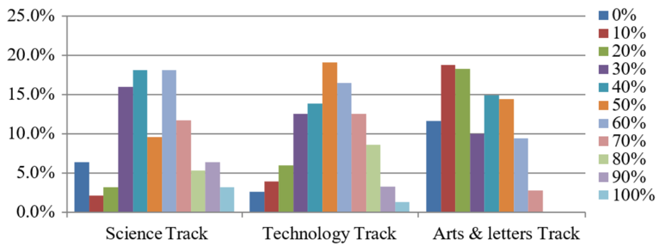

Figure 3. Performance of pre-service teachers according to their track (Source: Authors)

50% performance, accounting for 18.5% of participants. In contrast, only 3% of those who followed science track achieved a perfect score of 100%. Results suggest that there is a significant difference in teacher performance on high school track they followed. It can be seen that there is a notable disparity in the mean performance of teachers based on the track they followed. Specifically, those who pursued the science track had an average score of 49.89%, while those in the technology track had a slightly higher average score of 50.13%. Conversely, teachers who followed the arts & letters track had the lowest average score of 29.22% in knowledge questions. These results are presented in **Table 5**.

To further investigate this relationship, a one-way ANOVA was conducted to assess the impact of the track followed on performance in knowledge questions, as shown in **Table 6**.

Table 5. Statistics for pre-service teacher's performance by their track

Track	n	Mean	Standard deviation	Standard error	95% confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
Science	94	49.8936	24.60416	2.53773	44.8542	54.9330	.00	100.00
Technology	152	50.1316	21.86614	1.77358	46.6273	53.6358	.00	100.00
Arts & letters	181	29.2265	20.01273	1.48753	26.2913	32.1618	.00	70.00
Total	427	41.2178	24.01910	1.16237	38.9331	43.5025	.00	100.00

Table 6. One-way ANOVA for pre-service teacher's performance & track

	Sum of squares	df	Mean square	F	Sig.
Between groups	45,178.727	2	22,589.364	47.749	.000
Within groups	200,588.017	424	473.085		
Total	245,766.745	426			

The results of a one-way ANOVA analysis showed a significant difference in performance between at least two groups (F[2, 427]=47.749, p=.000). Further analysis using Tukey's HSD test revealed that the mean performance score was significantly different between the science track and arts & letters track (p=.000, 95% CI=[14.1633, 27.1709]), as well as between the technology track and arts & letters track (p=.000, 95% CI=[15.2769, 26.5332]). However, there was no statistically significant difference between science and technology tracks (p=.996) (**Table 6**).

Performance of Pre-Service Teachers According to Their Gender

As seen in **Figure 4**, there are differences in the performance of male and female teachers regarding their knowledge of electromagnetic radiation of information and communication technologies. Women tend to score lower than men in this area, indicating a significant gender difference in performance.

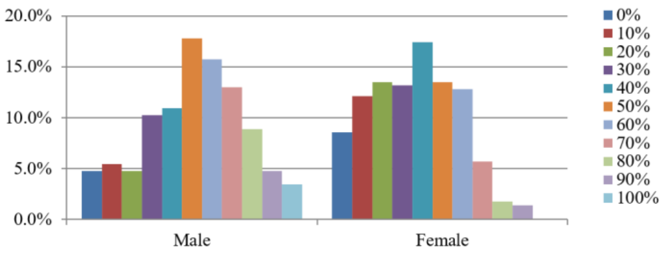

Figure 4. Performance of pre-service teachers according to their gender (Source: Authors)

There is a noticeable discrepancy in the mean performance of male and female teachers. Specifically, male teachers achieved an average score of 51.30%, whereas female teachers achieved an average score of 35.97% on the knowledge questions (**Table 7**). The t-test (**Table 8**) supports this finding.

,The researchers conducted a two-sample t-test to evaluate the difference in knowledge question performance between genders. The analysis found a significant difference in the mean scores of men (M=51.30, standard deviation [SD]=24.81) and women (M=35.97, SD=21.87); t(425)=6.554, p=.000 (**Table 8**).

DISCUSSION

Several studies (Morales López & Tuzón Marco, 2022; Nakiboglu & Tekin, 2006; Wadana & Maison, 2019) indicate that electromagnetic radiation is a complex and challenging phenomenon for students to comprehend. Although educational programs cover topics related to electromagnetic radiation throughout all years of education, research has shown that teachers have limited knowledge in this area, as evidenced by their low scores on basic questions. Even science teachers, who extensively study the subject matter related to electromagnetic radiation in their academic departments, have been found to have misconceptions (Gavrilas et al., 2018).

The educational programs offered by the academic departments attended by the respondents have a significant impact on their knowledge about electromagnetic radiation emitted from wireless technologies, according to research. Specifically, science and computer science teachers tend to have more knowledge than primary and pre-school teachers. In addition, science teachers tend to score the highest percentages of correct answers on questions related to scientific knowledge or critical thinking. The curricula of these departments cover topics such as the different types of radiation, their potential dangers, and their applications. On questions related to SAR, computer science teachers had higher percentages of correct answers. The reasons for this differentiation may be attributed to university courses related to these technologies, as well as the more frequent use of these technologies in their academic environment (Gavrilas et al., 2018).

Science literacy refers to a person's comprehension of scientific knowledge and their ability to apply it in identifying scientific issues, acquiring new knowledge, providing scientific explanations for phenomena, and drawing conclusions based on scientific evidence about science and technology (Organization for Economic Cooperation and Development, 2010). However, the research on issues related to electromagnetic radiation suggests that these goals have not been met. A significant percentage of participants lack knowledge of the causes of electromagnetic pollution and are unable to differentiate it from other types of pollution.

The majority of participants were found to be unaware of which type of radiation is more hazardous. Previous research has shown that students perceive anything associated with the term "radiation" as harmful (Neumann & Hopf, 2012). The high frequency of incorrect responses regarding whether cell phones and wireless networks emit

Table 7. Statistics for pre-service teacher's performance by gender

	Gender	n	Mean	Standard deviation	Standard error mean
Marking	Male	146	51.3014	24.81000	2.05329
	Female	281	35.9786	21.87267	1.30481

Table 8. Independent samples test of pre-service teachers' performance with gender

	Levene's test for equality of variances		t-test for equality of means						
	F	Sig.	t	df	Sig. (2-tailed)	M difference	SE difference	95% CI difference Lower	95% CI difference Upper
Equal variances assumed	1.173	.279	6.554	425	.000	15.32272	2.33800	10.72723	19.91821
Equal variances not assumed			6.298	263.503	.000	15.32272	2.43281	10.53251	20.11293

radiation is particularly noteworthy. Respondents often confuse radiation with radioactivity, a phenomenon also observed in studies conducted by Burcin and Ince (2010) and Neumann and Hopf (2012).

The responses of the participants were influenced by their mental frameworks, which were either intuitive or based on their practical experiences with cell phones and wireless networks, as well as scientific knowledge they acquired from school education (Andreou & Kotsis, 2005; Gavrilas et al., 2021, 2022c; Kotsis, 2011). The variations in study programs at the high school level had a significant impact, as respondents from the arts % letters track exhibited considerably lower levels of knowledge. In contrast, teachers who had a science background displayed more knowledge, particularly in theoretical areas, compared to those from a technological background. Conversely, respondents who had pursued a technological track exhibited greater knowledge, especially in the application of electromagnetic radiation in wireless technologies.

Regarding the research questions, it was found that women who participated in the study had less knowledge compared to men, which is consistent with the findings of previous research on science education (Gavrilas et al., 2020a, 2022b; Gontas et al., 2020). According to Engeström (1991) and Plakitsi (2013), learning occurs when an individual strives to achieve a significant goal, developing and expanding their range of actions. Often, the goals set by men and women differ, resulting in men having more opportunities to act and therefore acquiring significantly more experiences, especially with objects and tools related to sciences, such as electromagnetic radiation. In many cases, the content of science courses fails to capture the interests of girls (Jewett, 1996). Girls tend to be more interested in areas such as cooking, care, and the arts, which aligns with the societal stereotypes they have been exposed to for many years (Tindall & Hamil, 2004). Additionally, the social environment and its expectations for women's performance in natural sciences are very low (Zohar & Bronshtein, 2005), which directs them to other scientific fields, such as theoretical sciences.

The gender gap in academic performance could also be attributed to school textbooks that are written according to male standards (Joanne et al., 2002; Rupley et al., 1981). Students interpret the information they read in their textbooks based on their existing knowledge and schemas, which can vary between genders, leading to different interpretations of the same material. As a result, students may misunderstand the author's intended meaning, whether they are reading a textbook or an article online (Gavrilas et al., 2018).

Based on the results of multiple studies, it has been observed that differences in the interests of genders lead to the varying acceptance and utilization of new technology (Goswami & Dutta, 2016; Sainz & López-Sáez, 2010), thereby resulting in distinct experiences and knowledge related to electromagnetic radiation emitted from these devices. This aspect explains the inconsistent responses among the participants regarding SAR, which is not necessarily a subject taught in detail in the curricula. However, respondents could have answered such questions using their critical thinking and personal experiences with the use of wireless technologies.

The attainment of critical thinking skills is one of the primary objectives of education (Abrami et al., 2008; Gavrilas et al.,2022a, Marin & Halpern, 2011) and is an essential attribute for an active member of modern society (Behar-Horenstein & Niu, 2011). Nevertheless, the study findings suggest that this objective has not been accomplished. Despite having been provided with information about the hazards of radioactivity and the detrimental impacts of nuclear incidents and nuclear weapons on humans, respondents did not understand that electronic devices like cell phones or wireless networks do not emit radioactivity. Consequently, it would have been reasonable for them to exercise critical thinking and avoid the use of these devices due to their harmful effects. This finding is a striking example of the extent of the misconceptions concerning electromagnetic radiation from wireless networks and cell phones and the participants' failure to think critically.

CONCLUSIONS

The review of relevant literature indicates a significant lack of research on electromagnetic radiation and electromagnetic theory in general. It is necessary to conduct further investigations and document the knowledge and alternative ideas held by both students and teachers to enhance the educational process. As artificial sources of electromagnetic radiation, such as wireless networks and cell phones, have become a part of people's daily lives (Kumar et al., 2011; Piper et al., 2019; Salehan & Negahban, 2013), education should provide individuals with the requisite knowledge and encourage critical thinking so they can make informed decisions about their safety (International Commission on Non-Ionizing Radiation Protection, 2009). Researchers have raised serious concerns about the potential impact of prolonged exposure to electromagnetic radiation on living organisms (Baste et al., 2008; Carlberg & Hardell, 2012; Hepworth et al., 2006; Levitt & Lai, 2010; Lonn et al., 2005; Yan et al., 2009). It is thus important to prioritize development of critical thinking skills among individuals through education, as demonstrated by numerous studies.

To address the gender disparities in scientific knowledge, it is crucial to develop teaching practices that promote girls' interest in these fields from an early age, as well as to design curricula and textbooks that eliminate racial disparities. In addition, training teachers in areas such as electromagnetic radiation, where there is insufficient knowledge, and implementing interdisciplinary STEM education can help improve the educational process for students (Gavrilas et al., 2020b; Mater et al., 2022; Parno et al., 2021).

Future Directions

After considering the discussion and conclusions, several areas for further research on the issue of cell phone electromagnetic radiation are suggested. These include:

- Conducting further research to document the knowledge and alternative ideas about electromagnetic radiation among students and teachers from all disciplines.
- Designing teaching practices aimed at addressing alternative ideas about radiation.
- Creating environmental education programs focused on informing people about the risks of electromagnetic pollution.
- Investigating the possible biological effects of radiation from information and communication technologies, especially on young children and pregnant women.
- Developing health education programs to encourage students to develop a critical attitude towards the use of devices that emit electromagnetic radiation.

Limitations

The generalizability of research findings can be limited when the sample is not representative of the population of interest. In this case, the sample was drawn from a single area and the same educational level, which means that the findings may not apply to other populations with different backgrounds and characteristics. To improve the generalizability of research findings, future studies could aim to include a more diverse sample of participants from different regions and educational backgrounds, and employ methods to collect more objective data, such as observations.

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