International Journal of Education and Teaching Zone
Volume 5, Issue 2, 2026, pp. 290-306

https://doi.org/10.57092/ijetz.v5i2.794
p-ISSN: 2963-7899 | e-ISSN: 2830-7925

Original Article

Teachers' Conceptions of Electromagnetic Radiation in Mobile and Wireless Technologies: The Role of Teaching Specialization and Gender

Leonidas Gavrilas[1*], Marianna–Sotiria Papanikolaou[1], Konstantinos T. Kotsis[1]

Abstract: Electromagnetic radiation is a fundamental scientific concept encountered daily through mobile phones, wireless networks, and other technologies. However, it is often mistakenly associated with radioactivity and health risks, leading to widespread misconceptions. This study investigated Greek teachers' conceptions of electromagnetic radiation in mobile and wireless technologies, examining differences by teaching specialization and gender. A quantitative survey of 455 teachers from four specialization groups used ten dichotomously scored items to assess understanding of electromagnetic radiation, radioactivity, emissions from everyday technologies, and the specific absorption rate (SAR). The total score showed acceptable internal consistency for exploratory use (Cronbach's $\alpha = .713$). The mean correctness score was 40.99% (SD = 24.24), indicating substantial variability across items. In the bivariate analysis, men scored higher than women, $t(453) = 5.72$, $p < .001$. However, in the unbalanced two-way ANOVA model, the gender effect was not statistically detectable when teaching specialization and the gender-by-specialization structure of the sample were included, $F(1, 447) = 0.14$, $p = .708$, whereas specialization remained significant, $F(3, 447) = 18.57$, $p < .001$. Computer Science and Physics teachers outperformed those in Primary and Preschool Education. The findings underscore the need for teacher education to strengthen understanding of the distinctions between electromagnetic radiation and radioactivity, emissions from mobile and wireless technologies, and the specific absorption rate (SAR).

Keywords: Teacher conceptions; Teaching specialization; Mobile and wireless technologies; Electromagnetic misconceptions

Author Affiliation:
[1]Department of Primary Education, University of Ioannina, Ioannina, Greece

***Corresponding author(s):**
Leonidas Gavrilas, Department of Primary Education, University of Ioannina, Ioannina, Greece
email l.gavrilas@uoi.gr

Article History:
Received 21 March 2026; Revised 26 May 2026; Accepted 6 June 2026
Available online 30 June 2026

INTRODUCTION

Electromagnetic radiation (EMR) is a foundational concept in physics and a recurring feature of contemporary life. Learners encounter EMR not only in school science but also through everyday technologies such as mobile phones, wireless networks, broadcast antennas, base stations, smart meters, and medical devices (Alhassan et al., 2025;

Quarshie et al., 2026). Although visible light is one part of the electromagnetic spectrum, many technologically relevant forms of EMR, including radio waves and microwaves, are not directly visible. This makes EMR educationally important but also conceptually demanding, because the term *radiation* is often used in public discourse without distinguishing between electromagnetic radiation, ionizing radiation, and radioactivity. As a result, EMR becomes both a scientific concept and a topic through which learners interpret technology, health, and risk (Henriksen & Jorde, 2001; Plotz, 2017).

Research in science education has consistently shown that radiation-related ideas are vulnerable to misconception, a pattern also linked to how these concepts are represented in instructional materials such as textbooks (Boyes & Stanisstreet, 1994; Economides et al., 2021; Millar, 1994; Neumann, 2014; Neumann & Hopf, 2012). From a science-education perspective, such misconceptions are not simply isolated factual errors. They may function as alternative conceptions that help learners interpret new information but can also obstruct the development of scientifically valid understanding (Gilbert & Watts, 1983). In the specific case of EMR, important conceptual obstacles include distinguishing electromagnetic radiation from radioactivity, recognizing the difference between ionizing and non-ionizing radiation, and understanding that technological emissions such as Wi-Fi or mobile-phone signals do not automatically imply radioactive contamination or nuclear risk. These obstacles may be reinforced by everyday language, media narratives, and fragmented online information, where terms such as "radiation," "signal," "exposure," and "danger" are often used imprecisely (Osborne & Pimentel, 2023).

The issue becomes especially relevant when EMR is considered in relation to everyday technologies (Hanum, 2026; Hartati, 2026; Mustafidah, 2026). Smartphones, Wi-Fi routers, and other communication systems are embedded in daily life, yet they are often discussed through vague or scientifically inaccurate language, for example when radiation is treated as synonymous with radioactivity or when signal exposure is interpreted as contamination. Such framings may encourage learners to connect electromagnetic radiation with health threat without clearly considering frequency, energy, ionization, or regulatory limits. This is a matter of scientific literacy as well as conceptual knowledge, since learners must be able not only to recall scientific ideas but also to interpret and evaluate scientific information in everyday contexts (Tsoumanis et al., 2024). Recent discussions of scientific literacy emphasize the evaluation of claims, evidence, and source credibility in public contexts, including among pre-service teachers (Chinn et al., 2023; Osborne & Allchin, 2024; Stylos et al., 2023). In this respect, EMR is not only a physics topic but also a context in which scientific concepts interact with public concern, technological familiarity, and risk interpretation (Firmansyah & Sukma, 2025; Nuha & Rahman, 2025; Saputra et al., 2025). Related work with university students has also shown that knowledge about radiation-emitting technologies may coexist with negative attitudes and protective behaviors that are not always scientifically well grounded, suggesting that EMR-related understanding remains educationally challenging beyond school settings (Gavrilas et al., 2022; Gavrilas & Kotsis, 2024).

Teachers form a particularly important group in this context. Their conceptual understanding matters for their own scientific literacy and may influence how EMR-related ideas are selected, explained, and connected to everyday examples in classroom settings. Teachers' beliefs and subject-matter understanding shape how science is framed and communicated in school practice (Pajares, 1992). However, the present study does not assume a direct causal link between teachers' responses and classroom instruction. Rather, it starts from the premise that teachers' conceptions are educationally important because they form part of the knowledge base through which scientific topics are interpreted for learners (Basham & Editor, 2010; Clough & Bagley, 2012; Wan et al., 2020). Existing research suggests that teachers and pre-service teachers often experience difficulties with radiation-related concepts, particularly when these concepts require distinctions between electromagnetic radiation, radioactivity, ionizing and non-ionizing radiation, and technological exposure. Such difficulties have been reported in studies focusing on teachers' or pre-service teachers' interpretations of radiation and related scientific concepts (Gavrilas & Kotsis, 2023a; Kotsis & Gavrilas, 2025; Pahrudin et al., 2019; Ramaligela, 2021; Bezen et al., 2021).

Despite this body of work, further investigation is needed into how teachers respond to EMR-related items situated in familiar technological contexts and how these responses vary across teacher backgrounds. In particular, teaching specialization may be relevant because teachers in Physics, Computer Science, Primary Education, and Preschool Education are likely to differ in their formal exposure to scientific and technological content (Deerinck, 2011; Kuzmickaja et al., 2015; Weinberg & Sample McMeeking, 2017). Gender has also been examined in science and technology education, but in teacher samples it may be strongly entangled with specialization because men and women are often unevenly distributed across subject areas. For this reason, gender-related patterns should not be interpreted independently of teaching specialization. The present study therefore examines teachers' responses to items targeting selected EMR concepts and incorrect responses consistent with common misconceptions in everyday technological contexts. More specifically, it addresses three research questions: (a) What level of understanding do teachers demonstrate on selected EMR concepts related to everyday technologies? (b) How does performance differ across teaching specialization groups? and (c) how are gender-related differences in performance affected when teaching specialization and the gender-by-specialization structure of the sample are taken into account?

METHOD

This study employed a quantitative survey design to examine teachers' responses concerning electromagnetic radiation and everyday technologies, with attention to patterns associated with gender and teaching specialization. The analysis was based on 455 teachers, including 159 men (34.9%) and 296 women (65.1%). Participants came from four teaching specialization groups: Primary Education (n = 117, 25.7%), Preschool Education (n = 106, 23.3%), Computer Science (n = 115, 25.3%), and Physics (n = 117, 25.7%). Teaching specialization was operationalized according to participants' reported professional specialization group and was therefore treated as an indicator of teaching background rather than as a direct measure of the amount, quality, or recency of prior physics coursework.

Data were collected through a closed-ended questionnaire. For the purposes of the present study, 10 dichotomously scored items were selected from a broader questionnaire on electromagnetic radiation and related issues. The items were retained because they represented conceptual areas central to the research questions and preserved coverage of three related domains: distinctions between ionizing and non-ionizing radiation and radioactivity; understanding of specific absorption rate; and recognition of electromagnetic radiation in everyday technological sources such as mobile phones and wireless networks. Their selection was theory-driven and based on recurring areas of misunderstanding identified in prior literature (Boyes & Stanisstreet, 1994; Gavrilas & Kotsis, 2024; Millar, 1994; Neumann & Hopf, 2012; Plotz, 2017).

The scientific rationale for the scoring key followed established distinctions in physics and radiation science, particularly the difference between ionizing and non-ionizing radiation, the non-radioactive nature of mobile phones and wireless networks, and the technical meaning of specific absorption rate. Because the instrument did not include interviews or open-ended explanations, incorrect responses are interpreted as responses consistent with common misconceptions or limited factual understanding, not as direct evidence of stable or fully articulated alternative conceptions.

The questionnaire was pilot tested before the main data collection phase, and three experts reviewed the instrument to support face and content validity. The expert panel included specialists in physics education, science education, and radiation-related physics content. The review focused on scientific accuracy, relevance to EMR-related misconceptions, clarity of item wording, and alignment with the conceptual distinctions assessed in the study. The response options were balanced across items, and no "don't know" option was included. At the level of construct representation, validity in the present study rests primarily on content-based evidence rather than on factor-analytic or item-response modelling. Accordingly, the total score is used as an exploratory summary index of performance across selected EMR-related items, not as evidence of a single latent construct. Administration took place in paper-and-pencil format. Participants were informed about the purpose of the study, assured that participation was anonymous, and given approximately 15 minutes to complete the questionnaire.

Each item was coded dichotomously (0 = incorrect response, 1 = correct response). An overall correctness score was calculated in percentage form (0–100). Internal consistency of the 10-item score was assessed with Cronbach's alpha, which is equivalent to KR-20 for dichotomously scored items, and was interpreted cautiously given the small number of items and their coverage of related but not identical conceptual domains ($\alpha = .713$). Descriptive statistics were used to summarize sample characteristics and response distributions. The overall score was treated as the primary outcome, while item-level analyses were exploratory. Independent-samples *t* tests examined bivariate gender-related differences in the overall score. Differences across teaching specialization groups were examined with one-way analysis of variance followed by Tukey and Games-Howell post hoc comparisons. Item-level associations between gender or specialization and each scored response were examined using chi-square tests and Cramer's V. Because 10 separate item-level tests were conducted, a Bonferroni-adjusted threshold of .005 (.05/10) was used as a conservative reference point when evaluating the robustness of item-level findings.

Finally, a two-way analysis of variance was conducted with gender, teaching specialization, and their interaction as fixed effects. Because the factorial design was unbalanced, Type III sums of squares were used. Assumption checks included homogeneity of variance and inspection of residual distributions. The model was used to examine whether bivariate gender-related differences remained detectable when teaching specialization was included. However, because gender was unevenly distributed across specialization groups, particularly in Preschool and Primary Education, the model cannot fully disentangle gender from specialization. Therefore, gender-related findings are interpreted cautiously, and emphasis is placed on specialization-group patterns rather than on claims about an independent gender effect.

RESULT

The final analytic sample consisted of 455 participants, including 159 men (34.9%) and 296 women (65.1%). In terms of teaching specialization, 117 participants (25.7%) specialized in Primary Education, 106 (23.3%) in Preschool Education, 115 (25.3%) in Computer Science, and 117 (25.7%) in Physics (Table 1). The gender distribution differed markedly across specialization groups: women represented 95.3% of Preschool Education and 81.2% of Primary Education, whereas men represented 63.5% of Computer Science and 50.4% of Physics. This uneven distribution is important for interpreting gender-related analyses, because gender and teaching specialization were not evenly crossed in the sample.

Table 1. Sample characteristics and gender-by-specialization distribution

Variable	**Category**	**n**	**%**
Gender	Men	159	34.9
	Women	296	65.1
Teaching specialization	Primary Education	117	25.7
	Preschool Education	106	23.3
	Computer Science	115	25.3
	Physics	117	25.7
Teaching specialization	**Men n (%)**	**Women n (%)**	**Total**
Primary Education	22 (18.8)	95 (81.2)	117
Preschool Education	5 (4.7)	101 (95.3)	106
Computer Science	73 (63.5)	42 (36.5)	115
Physics	59 (50.4)	58 (49.6)	117

***Note.** The distribution of gender across teaching specializations was highly uneven, especially in Preschool Education and Primary Education. The extreme gender-by-specialization imbalance prevents independent estimation of gender effects; therefore, gender-related results are reported descriptively and should not be interpreted as evidence of an independent gender effect.

The descriptive results for the 10 scored items are presented in Table 2. Correct-response rates varied substantially across items, ranging from 19.1% to 72.5%. The lowest percentages of correct responses were observed for items related to distinguishing EMR from radioactivity and identifying EMR sources: *Do smartphones emit radioactivity?* (19.1%), *Do rooftop television antennas emit electromagnetic radiation?* (20.0%), and *Do* *wireless networks emit radioactivity?* (28.4%). Items related to specific absorption rate showed a more mixed pattern, with 48.1% correct responses for the meaning of specific absorption rate, 57.6% for maximum permissible specific absorption rate limits, and 72.5% for whether all mobile phones have the same specific absorption rate value. Across the 10 scored items, the average correctness score was 40.99% (SD = 24.24), indicating substantial variation in performance across the selected EMR-related items.

Table 2. Correct and incorrect responses across the 10 scored items

Conceptual area	Item	Incorrect n (%)	Correct n (%)
EMR and radioactivity	Do smartphones emit radioactivity?	368 (80.9)	87 (19.1)
EMR and radioactivity	Do wireless networks emit radioactivity?	326 (71.6)	129 (28.4)
Ionizing radiation	Meaning of ionizing radiation	280 (61.5)	175 (38.5)
SAR-related knowledge	Meaning of specific absorption rate in a mobile phone / smartphone	236 (51.9)	219 (48.1)
SAR-related knowledge	Are there maximum permissible specific absorption rate limits?	193 (42.4)	262 (57.6)
SAR-related knowledge	Do all mobile phones / smartphones have the same specific absorption rate value?	125 (27.5)	330 (72.5)
Technology-related EMR	Radiation emitted by one's mobile phone / smartphone	314 (69.0)	141 (31.0)
Technology-related EMR	Does Wi-Fi stop emitting when no device is connected?	162 (35.6)	293 (64.4)
Technology-related EMR	Do rooftop television antennas emit electromagnetic radiation?	364 (80.0)	91 (20.0)
Electromagnetic pollution	Causes of electromagnetic pollution	317 (69.7)	138 (30.3)

Gender-related patterns in performance

In the bivariate analysis, men obtained a higher overall correctness score than women (Table 3). The mean score for men was 49.56 (SD = 25.42), whereas the mean score for women was 36.39 (SD = 22.31). This difference was statistically significant, $t(453) = 5.72$, $p < .001$, with a moderate effect size (Cohen's $d = 0.56$), indicating that male participants demonstrated a higher level of correct responses on the knowledge assessment than female participants in the unadjusted comparison. Nevertheless, this finding should be interpreted with caution. The observed difference reflects a bivariate association within the study sample and should not be regarded as evidence of an independent effect of gender. The distribution of gender was substantially uneven across teaching specializations, with male participants being more strongly represented in Computer Science and Physics, while female participants predominated in Primary and Preschool Education. Because teaching specialization was itself significantly associated with knowledge scores, the apparent gender difference may be partially attributable to this imbalance. Therefore, the bivariate result provides only a preliminary indication of gender-related variation and should be interpreted alongside multivariate analyses that simultaneously account for teaching specialization and other relevant covariates.

Table 3. Overall correctness score by gender and teaching specialization

Group	n	Mean	SD
Men	159	49.56	25.42
Women	296	36.39	22.31
Primary Education	117	31.20	21.78
Preschool Education	106	30.75	20.13
Computer Science	115	48.00	24.32
Physics	117	53.16	22.08
Total sample	455	40.99	24.24

Table 4 further illustrates the uneven subgroup structure across teaching specializations. In particular, the male subgroup in Preschool Education was very small ($n = 5$), resulting in a wide confidence interval and limited precision of the estimated mean. Consequently, comparisons involving this subgroup should be interpreted with considerable caution. In contrast, the Physics and Computer Science specializations included substantially larger numbers of both male and female participants, allowing for more stable estimates. Within these two specializations, the observed gender differences were notably smaller than the overall bivariate gender gap, suggesting that much of the apparent overall difference may reflect the unequal distribution of men and women across teaching specializations rather than a consistent gender-related pattern. These findings highlight the importance of considering the interaction between gender and teaching specialization when interpreting the results. Overall, the subgroup analyses indicate that teaching specialization is likely to account for a substantial proportion of the observed variation, and therefore gender comparisons should be interpreted within the context of specialization rather than as isolated effects.

Table 4. Gender-by-specialization subgroup means for the overall correctness score

Gender	Teaching specialization	n	Mean	SD	95% CI
Men	Primary Education	22	34.55	27.90	[22.18, 46.92]
Men	Preschool Education	5	18.00	20.49	[-7.45, 43.45]
Men	Computer Science	73	51.10	24.53	[45.37, 56.82]
Men	Physics	59	55.93	22.06	[50.18, 61.68]
Women	Primary Education	95	30.42	20.21	[26.30, 34.54]
Women	Preschool Education	101	31.39	20.00	[27.44, 35.33]
Women	Computer Science	42	42.62	23.28	[35.37, 49.87]
Women	Physics	58	50.34	21.92	[44.58, 56.11]

Item-level gender-related associations are shown in Table 5. At the conventional .05 level, eight items showed statistically significant associations with gender. However, using the Bonferroni-adjusted reference point of $p < .005$, six associations remained clearly below the conservative threshold: *Causes of electromagnetic pollution*, *Meaning of* *specific absorption rate*, *Do smartphones emit radioactivity?*, *Do all mobile phones have the same specific absorption rate value?*, *Radiation emitted by one's mobile phone*, and *Do rooftop television antennas emit electromagnetic radiation?* The association for *Does Wi-Fi stop emitting when no device is connected?* was borderline at $p = .005$, whereas *Are there maximum permissible specific absorption rate limits?* did not meet the conservative threshold ($p = .007$). Cramer's V values ranged from very small to modest, with the largest association observed for the rooftop television antenna item.

Table 5. Gender-related differences in item-level responses

Item	χ^2	p	Cramer's V	Interpretation
Causes of electromagnetic pollution	14.46	< .001	.178	Robust at p < .005
Meaning of ionizing radiation	0.96	.327	.046	Not significant
Meaning of specific absorption rate in a mobile phone / smartphone	8.11	.004	.133	Robust at p < .005
Do smartphones emit radioactivity?	13.32	< .001	.171	Robust at p < .005
Are there maximum permissible specific absorption rate limits?	7.15	.007	.125	Significant at .05 only
Do all mobile phones / smartphones have the same specific absorption rate value?	9.08	.003	.141	Robust at p < .005
Radiation emitted by one's mobile phone / smartphone	9.81	.002	.147	Robust at p < .005
Do wireless networks emit radioactivity?	2.99	.084	.081	Not significant
Does Wi-Fi stop emitting when no device is connected?	7.81	.005	.131	Borderline under Bonferroni
Do rooftop television antennas emit electromagnetic radiation?	27.16	< .001	.244	Robust at p < .005

Differences by Teaching specialization

The overall correctness score differed significantly across teaching specialization groups (Table 3), $F(3, 451) = 30.75$, $p < .001$, $\eta^2 = .170$. Participants from Physics obtained the highest mean score (M = 53.16, SD = 22.08), followed by Computer Science (M = 48.00, SD = 24.32), whereas teachers from Primary Education (M = 31.20, SD = 21.78) and Preschool Education (M = 30.75, SD = 20.13) obtained lower scores. Post hoc comparisons showed that Primary Education and Preschool Education did not differ significantly from each other, and neither did Computer Science and Physics. However, both Computer Science and Physics scored significantly higher than both Primary Education and Preschool Education. This pattern indicates a clear association between teaching specialization and performance on the selected EMR-related items.

Differences by teaching specialization were also visible at the item level. Significant associations between teaching specialization and item performance were observed for all

10 scored items at the conventional .05 level. Nine of these associations also remained below the Bonferroni-adjusted reference point of $p < .005$; the exception was *Radiation emitted by one's mobile phone / smartphone* ($p = .010$), which should therefore be interpreted as a weaker item-level finding. The largest Cramer's V values were observed for *Does Wi-Fi stop emitting when no device is connected?* (V = .333), *Do smartphones emit radioactivity?* (V = .322), and *Do wireless networks emit radioactivity?* (V = .282). Overall, the strongest specialization-related patterns appeared in items concerning radioactivity, wireless networks, and selected SAR-related knowledge.

Joint effect of gender and Teaching specialization

A two-way analysis of variance (ANOVA) was conducted to examine the combined effects of gender and teaching specialization on the overall correctness score (Table 6). The overall model was statistically significant, $F(7, 447) = 14.47$, $p < .001$, explaining 18.5% of the variance in participants' scores ($R^2 = .185$). This indicates that the factors included in the model collectively contributed to meaningful differences in teachers' understanding of electromagnetic radiation. Prior to interpreting the ANOVA results, the assumption of homogeneity of variances was evaluated using Levene's test. The test was not statistically significant, $F(7, 447) = 1.51$, $p = .163$, indicating that the assumption of equal error variances across groups was satisfied and that the ANOVA results could be interpreted with confidence. Because the factorial design was unbalanced, reflecting unequal numbers of participants across the combinations of gender and teaching specialization, Type III sums of squares were employed. This approach provides appropriate estimates of the unique contribution of each factor after adjusting for the unequal cell sizes and the presence of the other factor in the model, thereby yielding more reliable tests of the main and interaction effects.

When gender and teaching specialization were entered simultaneously into the two-way ANOVA model, the main effect of gender was no longer statistically significant, $F(1, 447) = 0.14$, $p = .708$, partial $\eta^2 < .001$. This finding indicates that, after controlling for differences in teaching specialization, gender did not explain a meaningful proportion of the variance in teachers' overall correctness scores. In contrast, the main effect of teaching specialization remained statistically significant, $F(3, 447) = 18.57$, $p < .001$, partial $\eta^2 = .111$, representing a moderate effect size. This result demonstrates that teachers' disciplinary background was a substantially stronger predictor of conceptual understanding than gender, accounting for approximately 11.1% of the explained variance after adjustment for the other factor.

The interaction between gender and teaching specialization was also not statistically significant, $F(3, 447) = 1.34$, $p = .261$, partial $\eta^2 = .009$. Thus, there was no evidence that the relationship between teaching specialization and correctness scores differed systematically for men and women. Nevertheless, these findings should be interpreted with appropriate caution because the factorial design was characterized by highly unequal cell sizes. In particular, the Preschool Education subgroup included only five male participants, resulting in limited statistical power and reduced precision for estimating both the gender main effect and the interaction effect. Small and unbalanced subgroup sizes increase standard errors and make the detection of genuine effects more difficult, especially for interaction terms.

Consequently, the absence of statistically significant gender and interaction effects should not be interpreted as conclusive evidence that gender has no influence on teachers' understanding of electromagnetic radiation. Rather, the results indicate that the gender difference observed in the bivariate analysis was no longer detectable after accounting for teaching specialization and the uneven distribution of participants across subgroups. Taken together, these findings suggest that the apparent overall gender difference is more plausibly explained by differences in disciplinary specialization than by gender itself, although future studies employing more balanced sampling designs are needed to confirm this conclusion and provides greater statistical power to test potential interaction effects, which are certainly clearer and more accurate.

Table 6. Summary of main inferential analyses

Analysis	Statistic	p	Effect size / note
Reliability of 10-item scale	Cronbach's $\alpha = .713$	—	Acceptable for exploratory use
Total score by gender	$t(453) = 5.72$	$< .001$	Cohen's $d = 0.56$; bivariate result
Total score by teaching specialization	$F(3, 451) = 30.75$	$< .001$	$\eta^2 = .170$
Two-way ANOVA model	$F(7, 447) = 14.47$	$< .001$	$R^2 = .185$
Gender main effect with specialization included	$F(1, 447) = 0.14$	.708	partial $\eta^2 < .001$; interpret cautiously
Teaching specialization main effect with gender included	$F(3, 447) = 18.57$	$< .001$	partial $\eta^2 = .111$
Gender × teaching specialization interaction	$F(3, 447) = 1.34$	.261	partial $\eta^2 = .009$; limited by uneven cells
Levene's test	$F(7, 447) = 1.51$	.163	Homogeneity of variance not violated
Sums of squares in factorial ANOVA	Type III	—	Used because of unbalanced design

DISCUSSION

The findings document substantial incorrect responding on selected EMR-related items, especially those involving the distinction between electromagnetic radiation and radioactivity, the identification of electromagnetic emissions from everyday technologies, and specific absorption rate. These patterns are consistent with previous research showing that radiation-related topics are conceptually demanding and often associated with risk, danger, and radioactivity in learners' reasoning (Millar, 1994; Morales López & Tuzón Marco, 2022; Neumann & Hopf, 2012; Plotz, 2017; Plotz & Hopf, 2016; Wong et al., 2023). However, because the present instrument used dichotomously scored items and did not include interviews or open-ended explanations, the results should not be interpreted as direct evidence of stable alternative conceptions or a fully developed danger-based schema. Rather, they show that many teachers selected responses consistent with common misconceptions, particularly on items concerning smartphones, wireless networks, television antennas, and the distinction between EMR and radioactivity. These findings extend previous work by showing that such incorrect responses are also observable among teachers and not only among students or the general public (Gavrilas & Kotsis, 2024).

This finding is educationally important because it suggests that everyday exposure to technology does not necessarily correspond to accurate scientific understanding. Familiarity with smartphones, Wi-Fi, and other wireless systems may coexist with incorrect or incomplete responses about what these technologies emit and how radiation-related terms should be interpreted. The present study did not directly measure scientific-literacy competencies such as source evaluation, evidence appraisal, or resistance to alarmist narratives. Nevertheless, the low performance on several technology-related EMR items indicates why such competencies may be educationally relevant in this topic. This interpretation is consistent with broader work emphasizing the importance of evaluating claims, assessing evidence, and judging source credibility in public scientific contexts (Chinn et al., 2023; Osborne & Allchin, 2024; Osborne & Pimentel, 2023). It is also compatible with studies showing that university students may combine incomplete knowledge about radiation-emitting technologies with negative attitudes, protective behaviors, and health-related concerns (Gavrilas et al., 2022; Gavrilas & Kotsis, 2023b). EMR can therefore be approached not only as a physics content area but also as a context for developing scientific literacy.

The differences observed across teaching specializations represent one of the most robust findings of the present study. Teachers specializing in Physics and Computer Science consistently achieved higher correctness scores than those in Primary and Preschool Education, a pattern that was evident not only in the overall score but also across several individual questionnaire items. These results suggest that teachers' disciplinary background is closely associated with their understanding of key concepts related to electromagnetic radiation (EMR), including the distinction between EMR and radioactivity, emissions from wireless technologies, and the specific absorption rate (SAR). The consistency of this pattern across multiple analyses further strengthens the conclusion that specialization is an important correlate of conceptual understanding in this domain. Nevertheless, the cross-sectional nature of the study precludes any causal interpretation of these associations. The findings do not demonstrate that teaching specialization itself directly improves conceptual understanding. Instead, the observed differences may reflect a range of underlying factors, including greater exposure to physics and technology-related content during university education, more frequent engagement with scientific concepts in professional practice, stronger scientific literacy, more recent disciplinary training, or other educational and experiential variables that were not measured in the present study. Consequently, the relationship between specialization and performance should be interpreted as associative rather than causal.

These findings are broadly consistent with previous research indicating that subject specialization is positively associated with teachers' content knowledge and instructional effectiveness (Hwang & Kisida, 2022). However, the present results should not be interpreted as evidence that disciplinary specialization alone leads to superior scientific reasoning or conceptual competence. Rather, they suggest that teachers whose professional backgrounds are more closely aligned with science and technology are more likely to demonstrate accurate understanding of concepts related to EMR, radioactivity, wireless communication technologies, and SAR. Future research employing longitudinal or experimental designs would be valuable for clarifying the mechanisms underlying these associations and determining the extent to which targeted professional development can reduce conceptual differences across teaching specializations.

The gender-related pattern should be interpreted with particular caution. Although men scored higher than women in the bivariate comparison, the two-way model showed that this difference was not detectable once teaching specialization and the gender-by-specialization structure of the sample were included. This does not prove that gender has no role (Hanif et al., 2025; Nuha & Rahman, 2025; Saputra et al., 2025). The sample was highly unbalanced, with women concentrated in Preschool and Primary Education and men more represented in Computer Science and Physics. Therefore, the study cannot fully disentangle gender from specialization. The safer conclusion is that the observed bivariate gender difference was strongly linked to the uneven distribution of men and women across specialization groups. This interpretation is consistent with broader evidence that gender-related differences in educational technology competencies, technological pedagogical content knowledge, and classroom-related perceptions are often shaped by contextual and educational factors (Rizal et al., 2021; Guillén-Gámez & Rodríguez-Fernández, 2022; Musters et al., 2024). Future studies with balanced sampling across gender and specialization are needed before stronger claims about gender can be made.

From the perspective of teacher education, the implications are important but should be framed cautiously. The present study did not examine classroom practice, student outcomes, or teachers' actual explanations during instruction. Therefore, it cannot demonstrate that teachers' incorrect responses are reproduced in classrooms. Nevertheless, teachers' subject-matter understanding remains relevant because it forms part of the knowledge base through which scientific ideas are selected, explained, and connected to everyday examples (Pajares, 1992). The particularly low correct-response rates on items such as whether smartphones emit radioactivity and whether rooftop television antennas emit electromagnetic radiation suggest that teacher education should give more explicit attention to the EMR–radioactivity distinction and to common technological examples. This concern aligns with recent work emphasizing the need to treat EMR as a scientific-literacy issue and to connect conceptual knowledge with practical teaching situations (Gavrilas & Kotsis, 2024; Kotsis & Gavrilas, 2025).

The findings therefore point to the need for more explicit conceptual work on EMR in teacher education programs, especially in pedagogy-oriented pathways. Such work should directly address conceptual boundaries that are easily blurred: radiation versus radioactivity, ionizing versus non-ionizing radiation, emission versus contamination, exposure versus harm, and scientific evidence versus generalized fear. Instructional activities could, for example, compare Wi-Fi routers, mobile phones, ultraviolet radiation, X-rays, and radioactive materials in terms of frequency, energy, ionization, and risk; examine media headlines about 5G or mobile-phone radiation; and require teachers to explain SAR in relation to absorption rather than danger alone. The literature suggests that conceptual clarification can be strengthened through inquiry-based engagement and carefully designed conceptual change strategies (Kotsis, 2023; Eymur & Çetin, 2024; Kontomaris et al., 2020; Pacaci et al., 2024). In this sense, the present findings should be understood not as proof of teachers' stable alternative conceptions, but as evidence of an urgent curricular need to strengthen teachers' EMR-related knowledge and their ability to interpret everyday technological contexts scientifically.

Several limitations should be noted. First, the study was conducted with teachers in a specific Greek educational setting, which limits the extent to which the findings can be generalized to other educational, cultural, or curricular contexts. Second, the use of a closed-ended questionnaire supported systematic comparison across groups, but it did not allow direct examination of teachers' reasoning, explanations, or confidence in their answers. Therefore, incorrect responses should be interpreted as responses consistent with common misconceptions or limited factual understanding, not as direct evidence of stable alternative conceptions. Third, the 10-item score should be interpreted cautiously. Although internal consistency was acceptable for exploratory use (Cronbach's $\alpha = .713$), the scale was short and included items from related but not identical domains, such as EMR–radioactivity distinctions, SAR-related knowledge, and recognition of EMR sources. Because factor analysis or item-response modelling was not conducted, the total score should be viewed as an exploratory summary index rather than as evidence of a single unidimensional construct. Fourth, some items may have been especially sensitive to wording or contextual interpretation. This concern is particularly relevant for items involving "electromagnetic pollution," radiation from smartphones, and rooftop television antennas, because such terms may evoke risk-related or everyday interpretations rather than strictly physics-based reasoning, especially in relation to public perceptions of wireless technologies (Freudenstein et al., 2015). Fifth, the gender distribution was highly uneven across specialization groups, especially in Preschool and Primary Education. This means that the study cannot fully disentangle gender from teaching specialization, and gender-related findings should not be interpreted as independent gender effects. Finally, because the study was cross-sectional, it cannot show how teachers' responses develop or change through experience, instruction, or professional development.

CONCLUSION

This study documented low performance on selected items concerning electromagnetic radiation and everyday technologies among the participating teachers. Incorrect responses were especially frequent on items involving the distinction between electromagnetic radiation and radioactivity, the interpretation of radiation from wireless technologies, and the recognition of everyday EMR sources. These findings are consistent with earlier work showing persistent confusion around radiation-related concepts among students, pre-service teachers, teachers, and the public (Colclough et al., 2011; Gavrilas & Kotsis, 2023a, 2024; Morales López & Tuzón Marco, 2022).

The findings also showed clear differences across teaching specialization groups. Teachers in Physics and Computer Science obtained higher scores than teachers in Primary and Preschool Education, suggesting that specialization background was associated with performance on the selected EMR-related items. However, this result should not be interpreted causally, because the study did not directly measure prior coursework, professional development, teaching experience, or other factors that may differ across specialization groups. Although men scored higher than women in the bivariate analysis, the study cannot determine whether gender has an independent effect because gender and specialization were strongly confounded in the sample. The safer conclusion is that the observed bivariate gender difference was closely linked to the uneven distribution of men and women across specialization groups.

From a teacher-education perspective, the findings underline the need for more explicit instruction on EMR, especially in pedagogy-oriented programs. Teacher preparation should help educators distinguish between ionizing and non-ionizing radiation, electromagnetic radiation and radioactivity, exposure and contamination, and scientific evidence and generalized fear. Instruction should also connect these distinctions with familiar examples such as smartphones, Wi-Fi routers, antennas, and SAR. Future research should use larger and more balanced samples, especially across gender and specialization groups, and should combine closed-ended items with interviews, open-ended explanations, or intervention designs to examine whether incorrect responses reflect stable misconceptions, fragmented knowledge, or test-related artifacts (Fàbregues et al., 2023; Pacaci et al., 2024).

REFERENCES

Alhassan, H., Essel, H. B., & Kquofi, S. (2025). Navigating the Standard-based Creative Arts Curriculum Challenges in Primary Schools : A Qualitative Exploration. International Journal of Education and Teaching Zone, 4(3), 7–10. https://doi.org/https://10.57092/ijetz.v4i3.497

Basham, J. D., & Editor, G. (2010). Introduction to the Topical Issue: Shaping STEM Education for All Students. Journal of Special Education Technology, 25(3), 1–2. https://doi.org/10.1177/016264341002500301

Bezen, S., Aykutlu, I., & Bayrak, C. (2021). What does black-body radiation mean for pre-service physics teachers? Journal of Turkish Science Education, 18(4), 691–706. https://doi.org/10.36681/tused.2021.98

Boyes, E., & Stanisstreet, M. (1994). Children's ideas about radioactivity and radiation: Sources, mode of travel, uses and dangers. Research in Science & Technological Education, 11(2), 137–146. https://doi.org/10.1080/0263514940120204

Chinn, C. A., Yoon, S. A., Hussain-Abidi, H., Hunkar, K., Noushad, N. F., Cottone, A. M., & Richman, T. (2023). Designing learning environments to promote competent lay engagement with science. European Journal of Education, 58(3), 407–421. https://doi.org/10.1111/ejed.12573

Clough, S., & Bagley, C. A. (2012). UK higher education institutions and the third stream agenda. Policy Futures in Education, 10(2), 178–190. https://doi.org/10.2304/pfie.2012.10.2.178

Colclough, N. D., Lock, R., & Soares, A. (2011). Pre-service teachers' subject knowledge of and attitudes about radioactivity and ionising radiation. International Journal of Science Education, 33(3), 423–446. https://doi.org/10.1080/09500691003639905

Deerinck, T. (2011). Advancing the state of the art. BioTechniques, 51(5), 311. https://doi.org/10.2144/000113758

Economides, S., Karfopoulos, K., Mestousi, E., Founta, P., Carinou, E., & Housiadas, C. (2021). Assessment of high school textbooks addressing radiations. Radioprotection, 56(3), 205–210. https://doi.org/10.1051/radiopro/2021016

Eymur, G., & Çetin, P. S. (2024). Investigating the role of an inquiry-based science lab on students' scientific literacy. Instructional Science, 52(5), 743–760. https://doi.org/10.1007/s11251-024-09672-w

Fàbregues, S., Sáinz, M., Romano, M. J., Escalante-Barrios, E. L., Younas, A., & López-Pérez, B.-S. (2023). Use of mixed methods research in intervention studies to increase young people's interest in STEM:

A systematic methodological review. Frontiers in Psychology, 13, 956300. https://doi.org/10.3389/fpsyg.2022.956300

Firmansyah, R., & Sukma, D. (2025). The Relationship Between Self-Efficacy and Peer Social Support in High School Students ' Career Decision-Making : A Correlational Study in Indonesia. International Journal of Education and Teaching Zone, 4(3), 276–291. https://doi.org/https://10.57092/ijetz.v4i3.496

Freudenstein, F., Correia, L. M., Oliveira, C., Sebastião, D., & Wiedemann, P. M. (2015). Exposure knowledge and perception of wireless communication technologies. International Journal of Environmental Research and Public Health, 12(11), 14177–14191. https://doi.org/10.3390/ijerph121114177

Gavrilas, L., & Kotsis, K. T. (2023a). Assessing elementary understanding of electromagnetic radiation and its implementation in wireless technologies among pre-service teachers. International Journal of Professional Development, Learners and Learning, 5(2), Article ep2309. https://doi.org/10.30935/ijpdll/13191

Gavrilas, L., & Kotsis, K. T. (2023b). Research for self-reported health problems after excessive talking time on mobile phones among university students. Eurasian Journal of Science and Environmental Education, 3(1), 7–15. https://doi.org/10.30935/ejsee/12958

Gavrilas, L., & Kotsis, K. T. (2024). Electromagnetic radiation: A comprehensive review of misconceptions. Eurasian Journal of Science and Environmental Education, 4(2), 19–38. https://doi.org/10.30935/ejsee/15719

Gavrilas, L., Kotsis, K. T., & Papanikolaou, M.-S. (2022). Attitudes and behaviors of university students towards electromagnetic radiation of cell phones and wireless networks. Aquademia, 6(2), ep22009. https://doi.org/10.30935/aquademia/12393

Gilbert, J. K., & Watts, D. M. (1983). Concepts, misconceptions and alternative conceptions: Changing perspectives in science education. Studies in Science Education, 10(1), 61–98. https://doi.org/10.1080/03057268308559905

Guillén-Gámez, F. D., & Rodríguez-Fernández, R. (2022). Meta-analysis on the attitudes of active teachers about the use of educational technology according to gender. Contemporary Educational Technology, 14(1), Article ep339. https://doi.org/10.30935/cedtech/11408

Hanif, F., Afada, A., & Hayati, N. (2025). The Effectiveness of Project-Based Learning on Early Childhood Problem-Solving Skills : An Experimental Study. International Journal of Education and Teaching Zone, 4(2), 208–222. https://doi.org/https://10.57092/ijetz.v4i2.397

Hanum, A. (2026). Developing and Validating a Web-Based Five-Tier DiagnosticInstrument to Identify Student Misconceptions on Temperature and Heat. International Journal of Education and Teaching Zone, 5(1), 38–55. https://doi.org/https://doi.org/10.57092/ijetz.v5i1.617

Hartati, I. (2026). Elementary Teachers ' Acceptance of Digital Learning Platforms for Differentiated and Deep Learning : An Empirical Study Based on the UTAUT Framework. International Journal of Education and Teaching Zone, 5(1), 75–92. https://doi.org/https://doi.org/10.57092/ijetz.v5i1.610

Henriksen, E. K., & Jorde, D. (2001). High school students' understanding of radiation and the environment: Can museums play a role? Science Education, 85(2), 189–206. https://doi.org/10.1002/1098-237X(200103)85:2<189::AID-SCE60>3.0.CO;2-S

Hwang, N., & Kisida, B. (2022). Spread too thin: The effect of specialization on teaching effectiveness. Educational Evaluation and Policy Analysis, 44(4). https://doi.org/10.3102/01623737221084312

Kontomaris, S. V., Malamou, A., Balogiannis, G., & Antonopoulou, N. (2020). A simplified approach for presenting the differences between ionising and non-ionising electromagnetic radiation. Physics Education, 55(2), Article 025007. https://doi.org/10.1088/1361-6552/ab5c00

Kotsis, K. T. (2023). Alternative ideas about concepts of physics, a timelessly valuable tool for physics education. Eurasian Journal of Science and Environmental Education, 3(2), 83–97. https://doi.org/10.30935/ejsee/13776

Kotsis, K. T., & Gavrilas, L. (2025). Review of scientific literacy of pre-service teachers on electromagnetic radiation. European Journal of Contemporary Education and E-Learning, 3(1), 55–64. https://doi.org/10.59324/ejceel.2025.3(1).05

Kuzmickaja, I., Wang, X., Graziotin, D., Dodero, G., & Abrahamsson, P. (2015). In Need of Creative Mobile Service Ideas? Forget Adults and Ask Young Children. SAGE Open, 5(3). https://doi.org/10.1177/2158244015601719

Millar, R. (1994). School students' understanding of key ideas about radioactivity and ionizing radiation. Public Understanding of Science, 3(1), 53–70. https://doi.org/10.1088/0963-6625/3/1/004

Morales López, A. I., & Tuzón Marco, P. (2022). Misconceptions, knowledge, and attitudes towards the phenomenon of radioactivity. Science & Education, 31(2), 405–426. https://doi.org/10.1007/s11191-021-00251-w

Mustafidah, F. Z. (2026). Interactive Local Wisdom E-Book with EARLS Features to Promote Tolerance Among Young Learners. International Journal of Education and Teaching Zone, 5(1), 56–74. https://doi.org/https://doi.org/10.57092/ijetz.v5i1.620

Musters, N., Aarts, R., van Amelsvoort, M., & Swerts, M. (2024). Views on gender differences in the physics classroom. Education Sciences, 14(5), Article 457. https://doi.org/10.3390/educsci14050457

Neumann, S. (2014). Three misconceptions about radiation—And what we teachers can do to confront them. The Physics Teacher, 52(6), 357–359. https://doi.org/10.1119/1.4893090

Neumann, S., & Hopf, M. (2012). Students' conceptions about "radiation": Results from an explorative interview study of 9th grade students. Journal of Science Education and Technology, 21(6), 826–834. https://doi.org/10.1007/s10956-012-9369-9

Nuha, M. S., & Rahman, D. H. (2025). Moral Responsibility of Bystander Role in The Midst of Bullying : A Gender-Based Cross-Sectional Survey. International Journal of Education and Teaching Zone, 4(3), 7–10. https://doi.org/https://10.57092/ijetz.v4i3.465

Osborne, J., & Allchin, D. (2024). Science literacy in the twenty-first century: Informed trust and the competent outsider. International Journal of Science Education, 1–22. https://doi.org/10.1080/09500693.2024.2331980

Osborne, J., & Pimentel, D. (2023). Science education in an age of misinformation. Science Education, 107(3), 553–571. https://doi.org/10.1002/sce.21790

Pacaci, C., Ustun, U., & Ozdemir, O. F. (2024). Effectiveness of conceptual change strategies in science education: A meta-analysis. Journal of Research in Science Teaching, 61(6), 1263–1325. https://doi.org/10.1002/tea.21887

Pahrudin, A., Irwandani, I., Triyana, E., Oktarisa, Y., & Anwar, C. (2019). The analysis of pre-service physics teachers in scientific literacy: Focus on the competence and knowledge aspects. Jurnal Pendidikan IPA Indonesia, 8(1), 52–62. https://doi.org/10.15294/JPII.V8I1.15728

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. Review of Educational Research, 62(3), 307–332. https://doi.org/10.3102/00346543062003307

Plotz, T. (2017). Students' conceptions of radiation and what to do about them. Physics Education, 52(1), Article 014004. https://doi.org/10.1088/1361-6552/52/1/014004

Plotz, T., & Hopf, M. (2016). Two concepts of radiation: A case study to investigate existing preconceptions. European Journal of Science and Mathematics Education, 4(4), 447–459. https://doi.org/10.30935/scimath/9484

Quarshie, B., Amponsah, A., & Ameyaw, H. O. (2026). A Critical Mixed-Methods Analysis of Student-Teachers ' Action Research Challenges and Institutional Mediation in Ghanaian Colleges of Education. International Journal of Education and Teaching Zone, 5(1), 1–19. https://doi.org/https://doi.org/10.57092/ijetz.v5i1.743

Ramaligela, S. M. (2021). Exploring pre-service technology teachers' content and instructional knowledge to determine teaching readiness. International Journal of Technology and Design Education, 31(3), 531–544. https://doi.org/10.1007/s10798-020-09570-5

Rizal, R., Rusdiana, D., Setiawan, W., Siahaan, P., & Ridwan, I. M. (2021). Gender differences in digital literacy among prospective physics teachers. Journal of Physics: Conference Series, 1806, 012004. https://doi.org/10.1088/1742-6596/1806/1/012004

Saputra, J. A., Syefrinando, B., & Susanti, T. (2025). E-Encyclopedia for Biology Education : Design , Development , and Evaluation of an Innovative Learning Resource. International Journal of Education and Teaching Zone, 4(2), 223–242. https://doi.org/https://10.57092/ijetz.v4i2.442

Stylos, G., Siarka, O., & Kotsis, K. T. (2023). Assessing Greek pre-service primary teachers' scientific literacy. European Journal of Science and Mathematics Education, 11(2), 271–282. https://doi.org/10.30935/scimath/12637

Tsoumanis, K., Stylos, G., & Kotsis, K. (2024). An investigation of primary school students' scientific literacy. European Journal of Education Studies, 11(2). http://dx.doi.org/10.46827/ejes.v11i2.5195

Wan, L., Xie, S., & Shu, A. (2020). Toward an Understanding of University Students' Continued Intention to Use MOOCs: When UTAUT Model Meets TTF Model. SAGE Open, 10(3). https://doi.org/10.1177/2158244020941858

Weinberg, A. E., & Sample McMeeking, L. B. (2017). Toward Meaningful Interdisciplinary Education: High School Teachers' Views of Mathematics and Science Integration. School Science and Mathematics, 117(5), 204–213. https://doi.org/10.1111/ssm.12224

Wong, D., Leong, T. K., Ravindran, S., & Lee, S. L. (2023). Students' alternative conceptions and risk perceptions of radiation and radioactivity. The Physics Educator, 5(2), 2350009. https://doi.org/10.1142/S2661339523500099