The Public's Knowledge on Radioactivity

- What effect does the passing of time after graduation and the type of school attended make?-

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Abstract

Physics is an unpopular topic in casual conversation today. This may be due to the fact that many adults do not remember any physics that they supposedly learned at school. This paper will address this hypothesis by seeing if time spent since graduating affects adults' understanding of radioactivity, and if school attended makes a difference in this retention. We created an online questionnaire composed of demographic questions and questions to probe understanding and misconceptions about radioactivity. We then collected data with this questionnaire from N = 386 individuals with Austrian school-leaving qualifications. We performed a three-way ANOVA and found that there is a difference in knowledge about radioactivity between recent school leavers and non-recent school leavers, with recent school leavers performing better. Nevertheless, even recent school graduates exhibited the typical misconceptions (they conflated irradiation and contamination, for example), with school attended making no significant difference.

1. Introduction

Radiation emitted from radioactive decay is unavoidable. Despite that, many believe that radioactivity is man-made, originating exclusively from medical and industrial processes (Morales & Tuzón, 2020, pp. 8–13; cf. Schecker et al., 2018, p. 231; cf. Sesen & Ince, 2010, p. 97). In the MS thesis of the first author, we aimed to quantify the public's ignorance about radioactivity. Concretely, we wanted to investigate 1) what percentage of people are unaware that we are surrounded by radioactivity all the time, and 2) if that number depends upon the type of school attended and the time since last attending school. To this end, we generated two research questions:

- RQ1: How does understanding about radioactivity change with the passing of time after graduation from school?
- RQ2: How does understanding about radioactivity depend upon the school graduated from?

Research question one (RQ1) asks whether understanding about radioactivity depends upon the passing of time after school graduation. Intuitively, we might suppose that people fresh out of school remember more physics than those who have attended school a longer period of time ago. On the other hand, a trend in the opposite direction may indicate a decline in student interest with learning about radioactivity from one generation to the next. Like Alsop, we define "recent school leavers" to be people 25 years old or younger (Alsop, 2001, p. 265). In our study, this corresponds to respondents who reported last attending school less than 10 years ago.

RQ2 considers how understanding about radioactivity is affected by the type of school attended. Students in Austria have a wide range of schools from which they can choose: compulsory school ("Pflichtschule" in German), polytechnical school ("polytechnische Schule"), general secondary school ("allgemeinbildende höhere Schule"), vocational school ("Berufsschule"), 3-year vocational school ("berufsbildende mittlere Schule"), and 5-year vocational school ("berufsbildende höhere Schule") (Bundesministerium Bildung, Wissenschaft und Forschung [BMBWF], 2022).

2. Methodology

2.1. Questionnaire

To answer the two research questions, we created an online questionnaire intended to be appropriate for all persons who have acquired a school-leaving certificate from Austria, regardless of which type of school they attended. The questionnaire can be considered semi-structured in that, in addition to multiple-choice questions, it also contains open-ended questions to elicit additional information to categorize participants (Gillham, 2008, pp. 2–6).

The multiple-choice questions probe basic conceptual understanding of radioactivity while eliciting students' conceptions (for example, the "undifferentiated view" that irradiation results in objects becoming contaminated). The questions are a combination of items taken from Johnson's "Inquiry into Radioactivity" (2021), the "Stochastic World of Radioactive Decay Evaluation" (SWORDE) by Hull and Hopf (formerly known as "FAROS") (2020) and items we created ourselves for this project.

As recommended by Gillham (2008, pp. 41-44), we initially tested this questionnaire via survey validation interviews. Four respondents (none of whom worked in a profession that would give them an above-average knowledge of radioactivity) of various ages participated in the interviews. Analysis of these interviews led to a modified version of the questionnaire that was then tested by an expert panel. While the items borrowed from Inquiry into Radioactivity and SWORDE already had associated correct answers that had been established, this was not the case with the new items we had created. The goal of the expert panel was to confirm our opinions about which selection to these new items is correct. Our condition was that we would only use the new items for which eight out of ten members of the expert panel chose the same response we had as the "correct" one. This expert panel simultaneously 1) justified our coding of whether a response was correct or incorrect and 2) complemented the survey validation interviews in assuring that the wording of the items was sufficiently clear. Due to these survey validation interviews and expert panel, we maintain that our survey fulfills all quality criteria (i.e., objectivity, reliability, and validity) according to Hollenberg (2016, 6-7).

2.2. **Analysis of Variance**

To analyze the results, the three-way "Analysis of Variance" (Backhaus et al., 2018, p. 165) (abbreviated ANOVA) test was applied. The ANOVA tests whether the mean values of two compared factor levels within one factor are about the same or if there is a significant difference. For this research, the three independent variables are whether the series "Chernobyl" has been watched (this independent variable is not part of the research questions, but was added out of interest), the time passed since attending school, and the type of school attended. An ANOVA shows if the dependent variable (in this case, survey score) is affected by the three independent variables. If the difference between the observed means is sufficiently large, it can be assumed that the variance between the factor levels is greater than the variance within the factor levels. It can therefore be concluded that the factor levels did not achieve equal points and, hence, do not have the same knowledge about radioactivity (Bortz & Schuster, 2010, p. 265; Fahrmeir et al., 2016, pp. 478, 486).

Within each of the three factors (independent variables), there are two comparable factor levels. In total, there are hence six factor levels. In Table 1 below, the three factors are indicated with a number 1-3, the first two coinciding with the corresponding hypotheses.

	Factor Level 1	Factor Level 2
Factor 1	Adults who have graduated from school recently (in the last 10 years)	Adults who have graduated from school, but not recently (more than 10 years)
Factor 2	Adults who graduated from a 5-year vocational school	Adults who have not graduated from a 5-year vocational school
Factor 3	Adults who have seen "Chernobyl"	Adults who have not seen "Chernobyl"

Tab. 1: Formation of factor levels for analysis by means of the three-way ANOVA

We created seven null hypotheses (H0) for use with the three-way ANOVA to consider main effects between factor levels as well as interaction effects. Each H0 states that there will be no significant difference between the mean values of the respective factor levels.

The ANOVA requires that the data be normally distributed and that the data variance be homogeneous (that is, that the variances of the data within the factor levels are approximately equal). We used the D'Agostino test of skewness to confirm that the data is normally distributed, and we used the Bartlett test of homogeneity of variances to confirm that the variances are homogeneous (D'Agostino, 1970, p. 680; Keating & Leung, 2010, p. 61).

3. **Results**

We used the SoSci online platform ("SoSci Survey" (Leiner, 2019)) to host the questionnaire. From November 11th to November 29th, 2021, 416 people completed the questionnaire. Respondents who stated that they work with ionizing radiation as part of their profession (usually in the medical profession or research) were excluded from the evaluation, resulting in $N = 386$ responses that were analyzed in this study. The questionnaire contains 16 items, each with a value of 1 point, and no partial credit was awarded. On average, respondents obtained a score of 9.57 points, and the standard deviation was 2.95 points.

The results of the ANOVA are below in Table 2. The first three samples are the main effects of each independent variable (factor). Samples 4 to 6 are the interaction effects between each independent variable. The main advantage of a three-way ANOVA in comparison to conducting several two-way ANOVAs is that we can see if there is an interaction effect between all three independent variables. This is shown in Sample 7, the last row of the table. With an ANOVA, there are degrees of freedom associated with both the numerator (DFn) and with the denominator (DFd). For the numerator, DFn is equal to the number of factor levels (see Table 1) minus 1. Since each case consists of two factor levels, the DFn is 1 for each sample. For the denominator, DFd is equal to the total number of participants minus the number of effects (8 in this study). Hence, Dfd is 378 for each sample. The F-value reflects a difference between the mean values of the respective factor levels. The closer the F-value is to 1, the lower the mean difference. If there is a mean difference between the respective factor levels, the F-value exceeds 1 by far, and the corresponding H0 should be rejected. In addition to the F-test, the p-value checks whether the null hypothesis can be rejected. If the p-value is lower than 0.05, H0 is rejected. When there is a significant difference, the effect size is indicated by "ges". The higher the "ges", the larger the effect size and the more meaningful the result.

Sample	Effect	*F*-value	*p*-value
1	Time Passed	22.3	3.32e-06*
2	School Types	1.39	2.40e-01
3	"Chernobyl"	1.13	2.89e-01
4	Time Passed : School Types	6.0e-03	9.39e-01
5	School Types : "Chernobyl"	0.280	5.97e-01
6	Time Passed : "Chernobyl"	2.73	1.00e-01
7	Time Passed : School Types : "Chernobyl"	1.79	1.82e-01

Tab. 2: Results obtained from the ANOVA. The DFn and Dfd for each sample is 1 and 378, respectively. The "ges" value for Sample 1 is 5.60e-02.

As can be seen in Table 2, H0 is rejected only for the first sample, as the p-value is less than the cutoff of 0.05 and the F-value is much larger than 1. The effect size for sample 1 is 0.056, which is denoted as medium effect (Backhaus et al., 2018, p. 194; Bortz & Schuster, 2010, p. 270; Cohen, 2008, p. 690; Effect Size in Statistics - The Ultimate Guide, n.d.; Fahrmeir et al., 2016, p. 266). Only for sample 1 is the p-value lower than the α-error. Every other main effect and interaction has a p-value greater than 5%, which means that the H0 is not rejected. The rejection of H0_1 means that there is a difference in the adults' knowledge on radioactivity in relation to the passing of time after school. As a result, the alternative hypothesis, which states that there is a difference in the adults' knowledge on radioactivity between "recent school leavers" and "non-recent school leavers" is accepted. On the other hand, there is no significant main effect on the adults' knowledge on radioactivity if they have graduated from a 5-year vocational school or another type of school ($F = 1.4$, $p > 0,05$). Hence, H0_2 is not rejected. Contrary to expectation, adults who attended a 5-year vocational school do not have the highest understanding of radioactivity. Additionally, there is no advantage in watching "Chernobyl" in regard to the understanding of radioactivity.

The boxplot in Figure 1 illustrates the difference in means according to the three independent variables. The colored boxplots represent the factor of "time passed since last school attendance", with the blue boxes indicating the factor level "recent school leavers" and the yellow boxes representing "non recent school leavers". The independent variables "Types of Schools" and "Have Seen 'Chernobyl'" are represented on the x-axes. This representation was chosen to display the difference in factor levels that the ANOVA found to be significant (for the factor "Time Since Last School Attendance"). Regardless of the school attended and regardless of whether the adult had watched "Chernobyl" or not, the mean values (asterisks within the boxes) of "recent school leavers" are higher than the mean values of "non recent school leavers". Furthermore, the medians (horizontal lines within the boxes) of the blue boxes are always higher than those of the yellow boxes. This indicates that 50% of the "recent school leavers" reached higher points than 50% of the "non-recent school leavers".

Consolidating the data, the mean value of "recent school leavers" is 10.16 points whereas the mean value of "non recent school leavers" is 8.76 points. There is a clear difference between these two factor levels. Based on this analysis, we have shown that recent school leavers are more knowledgeable about radioactivity than those who attended school more than 10 years ago.

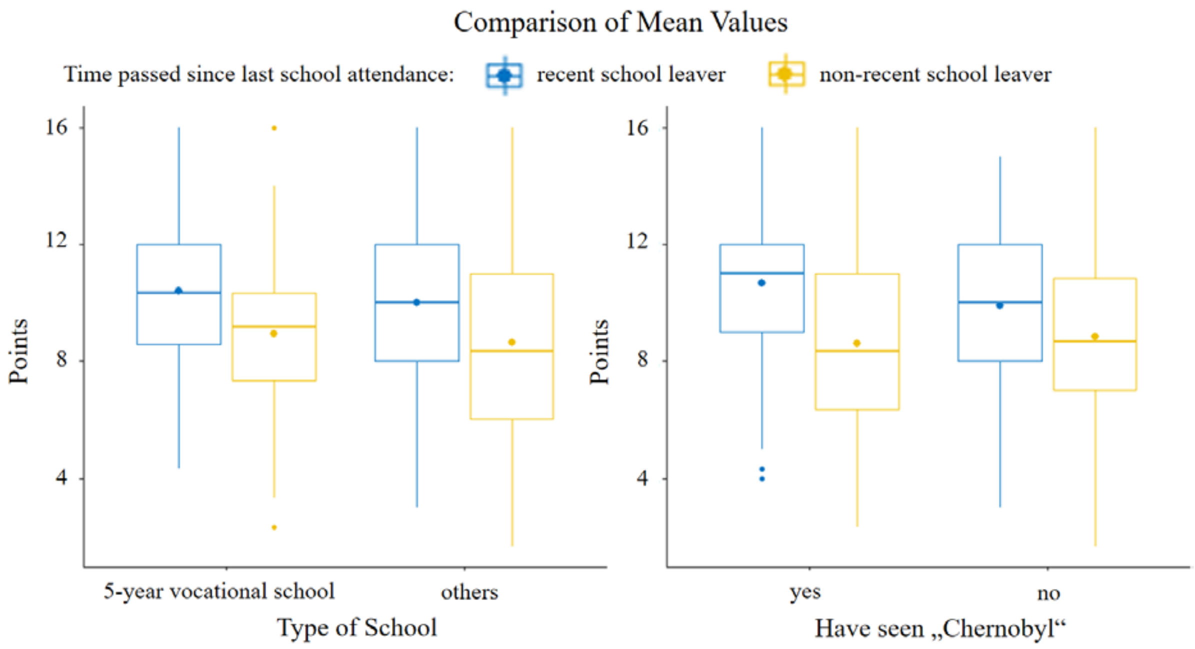

Fig. 1: Boxplots showing that recent school leavers perform better on the survey than non-recent school leavers, regardless of whether they graduated from a 5-year vocational school, and regardless of whether they have seen "Chernobyl".

4. Discussion

Our main research finding is that recent school leavers (within 10 years) have a greater understanding of radioactivity than non-recent school leavers. We have also reported an important null result, that having attended a 5-year vocational school does not leave adults with a greater likelihood of understanding radioactivity than attending other kinds of school. In addition, we can also use the survey findings to gain more specific insight into the understanding (or lack thereof) of adults about radioactivity.

Item 4 on the questionnaire asks respondents to select all objects that would make a radioactivity detector click (with the correct answer to select all objects, including "a school child"). The majority of respondents did not answer this item correctly, indicating a lack of awareness of radioactivity being ubiquitous. However, the majority of respondents on this same item did select that concrete walls of rooms in which X-rays were performed are radioactive. Although it is correct to select this answer, it is likely that respondents preferentially chose it not because all concrete walls are radioactive, but rather because they assume (incorrectly) that the walls were made radioactive by the X-rays, as found by Millar et al. (1990).

Item 5 of the questionnaire asks respondents to choose the correct response that defines "radioactivity". The majority of respondents of every factor correctly answered this item. However, many respondents did not use this answer when responding to Item 13, which concerns the irradiation of a kiwi. On this latter item, the majority of the "non-recent school leavers", for example, answered that the radiation itself is "radioactive", whereas the correct answer is that only the source of radiation is radioactive. This failure to distinguish between radioactivity and radiation mirrors the failure of conflating irradiation and contamination discussed above for Item 4. We see indicators of this "undifferentiated view" also in responses to Items 12 and 14. Item 14 is a follow-up question to Item 13, where respondents are asked if the kiwi has become radioactive if the radioactive source is now removed. Only about a third of respondents correctly answered with "no, it did not become radioactive due to the radiation." Item 12 involves the situation of what to do if you encounter a radioactive object. Approximately one quarter of respondents said that they would "move away from the rock to avoid becoming radioactive myself."

Item 7 asks for the definition of half-life, and this was answered correctly by most participants. Item 8 asks how much Iodine-131 will remain after one and two half-lives. The vast majority of respondents correctly said that half of the Iodine-131 sample will have not yet transformed after one half-life, and only about 10% of respondents said that the Iodine-131 would be entirely gone after two half-lives (the majority correctly said that it would be reduced to 25% the original amount).

Item 10 asks respondents how long they would wait if their closet would become filled with Iodine-131 gas, which, the questionnaire tells them, has a half-life of 8 days. Approximately one third of respondents answered that they would never open the closet, consistent with Alsop's (2001) study, which found that people tend to view radioactivity and associated radiation as unstoppable and eternal.

Item 6 asks respondents to select all from a list that are examples of radiation. Most respondents correctly selected "alpha", "beta", and "gamma" radiation and did not select the fictitious "theta" radiation. Items 16 and 17 aimed to see if respondents view radioactive decay as "uncontrollable" and "dangerous", respectively. The majority of participants, however, correctly selected that radioactive decay "can be controllable and can be uncontrollable" and "can be harmless and can be dangerous" for the human organism.

Item 19 asked respondents for their emotions regarding radioactivity, and we found them to not be as negative as expected. In particular, more participants of the "5-year vocational school" and "recent school leavers" factor levels tended to have neutral emotions (as opposed to negative) than participants from other types of schools and "non-recent school leavers".

A final item of the survey asked respondents how difficult they had found the items to answer. More than half of the participants said the survey had been difficult. In response to a free-response follow-up question asking to explain why, the most common reasons were coded as "too little knowledge on radioactivity/physics", "school time too long ago" and "no knowledge on radioactivity".

The items asking for definitions about radioactivity and half-life (Items 5 and 7, respectively), as already noted, were answered correctly by most respondents. Respondents had a greater struggle when trying to apply these definitions to answer other items (such as Items 10 and 13). This could be due to the fact that in the minds of many students, passing a test or getting good grades is considered more important than learning the concepts and processes of physics in a way which allows them to be understood thoroughly and applied correctly.

5. Literature

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