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Radioactivity as “quintessentially eternal”: two survey prompts

Introduction

Today, more than ever, it is critical for the public to be educated regarding the risks and benefits of nuclear energy, particularly regarding the issue of waste storage and treatment. In November 2020, the IAEA discussed Finland’s building of Onkalo, the world’s first deep geological repository for spent fuel. Research pertaining to learners’ understanding of such nuclear waste, however, has produced conflicting findings. On the one hand, Alsop (2001), for example, described how learners have an image of radioactivity as being “quintessentially eternal”. On the other hand, it is not uncommon to find media reports from the Chernobyl or Fukushima nuclear disasters which describe half-life as “the period in which a radioactive isotope loses its radioactivity” (Lijnse et al. 1990, Eijkelhof and Millar 1988), and a Delphi study revealed that some radiation experts have encountered the lay idea that “after the half-life there is no danger left” (Eijkelhof *et al.* 1990). Lucas (1987) found that 25 % of respondents think that nuclear waste is no longer radioactive after 100 years. Here we share survey results to compare how students in 8th grade (who had not learned about half-life in school prior to our study) and in 12th grade (who had) think about the lifetime of radioactive materials, and how, they report, that affects real-world decisions they would make.

Methodology: Two Survey Prompts

Our report draws upon student responses to two prompts on the Fission as a Random Occurrence Survey (FAROS). The first prompt, the “Many vs One” (or “MvO”) prompt has been discussed elsewhere (Hull, 2019; Hull & Hopf, 2020). The second prompt, “CLOSET”, is discussed here for the first time. The current version of CLOSET presents students with the situation of having valuables within a closet that is filled with a radioactive gas and taped shut (the student is outside the closet). Like MvO, CLOSET existed first as a free response prompt. Responses were collected from N = 55 students visiting the University of Vienna in the spring semester of 2019 who had not yet learned about radioactivity and half-life. In this first version of CLOSET, the radioisotope used was Rn-222, and it was explained to respondents that Rn-222 has a half-life of 4 days, which means that, “wenn man zu Anfang eine große Anzahl dieser Atome hat, dann würde nach 4 Tagen nur die Hälfte übrig bleiben, weil sich die andere Hälfte in ein anderes Atom umgewandelt hat.” As Hull and Hopf had previously done with MvO (2020), the three authors coded the responses to CLOSET using qualitative content analysis (Mayring, 2014). These codes were then turned into options for a two-tier multiple-choice test form. Prior to individual coding, the three authors looked at six example responses (~10 % of the N = 55 responses) to consider category labels proposed by Hull. The agreed-upon labels to be used with the remaining 49 free responses were:

Code 1 (Answer) Labels*: Less than 1 day, More than 1 but less than 4 days, 4 days, more than 4 but less than 8 days, 8 days, more than 8 but less than 12 days, 12 days, more than 12 days, depends (“It depends on how gas much is present at the start”,* which we considered to be correct), *all gone* (“when all the Rn has transformed, whenever that is”), *never, OTHER, NONE*

Code 2 (Reason) Labels: *the gas is never gone, the gas never completely transforms, Half gone in $T_{1/2}$, Half transformed in $T_{1/2}$, Danger(radiation) is halved in $T_{1/2}$, All gone in 2 $T_{1/2}$, All transformed in 2 $T_{1/2}$, Danger(radiation) is all gone in 2 $T_{1/2}$, Get help/info* (which we considered to be correct), *OTHER*, *NONE*

Coding of the remaining 49 responses led to changes to the codes (see Table 1 below). There were N = 49 respondents and an independent code of "Answer" and "Reason" for each respondent, totaling 98 codes. After coding independently, Hull and Jansky then calculated percentage of agreement (identical codings divided by all codings) (Mayring, 2014). Out of these 98 responses, the authors agreed perfectly on 65 (66 %) of them. On 10 of the remaining 33 (98 – 65) responses, there was partial agreement (a number of respondents were assigned multiple labels for their answer and/or their reasoning codes). The largest disagreement was regarding the labels for Code 2 (Reasoning). One of the coders felt that a response of "I would wait until as much is gone as possible" should be coded as OTHER since it contains a reason for not opening the closet immediately (that is, as time passes, the gas goes away). The second coder, however, felt that a code of NONE is more appropriate as such an answer does not add more than what is in the problem description (about the half-life of the isotope and what that implies). It was agreed to code these responses as NONE. This resolved 6 of the 33 disagreements. A total of 5 disagreements were resolved from the remaining 27 (33 - 6) by making additional adjustments to the coding scheme. First of all, for the labels for Code 2 (Reason), we found it difficult to agree on whether the student was thinking about the gas atoms being "gone" or "transforming into another atom" from the limited data provided by this survey question. We decided to hence subsume the "gone" codes into the "transform" codes after all. This resolved 2 disagreements. An additional 3 disagreements were resolved with the addition of two codes, "Radiation can get through the door" and "Closet becomes radioactive". The remaining 22 (27 - 2 - 3) disagreements were resolved on a case-by-case basis until full agreement had been reached, with the exception of one Answer code for respondent B9:
Ich glaube, dass radioaktive Strahlung durch den Kasten und das Klebeband durchgeht, aber ich würde es trotzdem geschlossen lassen (für sehr lang). (oder entsorgen. Ich glaube das radioaktive bleibt… ich habe gehört, man könne Marie Curies (schreibt man sie so?) Tagebuch noch immer nicht normal angreifen, wegen der gespeicherten radkioaktivität oder so…) Ich würde den Kasten am ehesten einfach wegschmeißen, samt allem was drinnen ist.

Although both coders reached agreement to label Code 1 as "Never", only one of the coders felt that "für sehr lang" should be given a second label of "More than 12 days, but eventually I would open the closet." The latter controversial label ("More than 12 days, but eventually I would open it") for this student is excluded from Table 1 below.

Since some students (especially those choosing ClA1: "Less than 1 day" as their answer) had thought that the prompt is asking what you would do if you were INSIDE the closet, this was clarified when the multiple choice version of CLOSET was administered to 12th grade students in 2021. After the free response version was created, 6 survey validation interviews were conducted to ensure the quality of the multiple choice form of CLOSET. Only one interview led to a change with the prompt. Since the interviewee had interpreted "all" in ClR9 to mean "enough to be safe", we specified in the multiple choice option that the wait would be until "100 % of the atoms" had fissioned. We made similar changes to both Tier 1 and Tier 2 options. We then administered the multiple-choice version of FAROS as an online survey in between Nov. 9th 2020 and March 24th 2021 to students in 12th grade. After removing respondents who did not complete the survey or who claimed to have not learned about half-life previously, N = 266 respondents remained. Finally, the first part of MANY (asking for how much of the radioactive substance will remain after one half-life) served as a screening question to remove an additional 32 respondents. Specifically, despite the explanation about half-life just prior to the prompt, these students nevertheless selected either “100 million” (the starting amount), “0”, or “100 million OR 0” as the amount that would have not yet transformed. Since we had encountered no difficulty in understanding this prompt in any of the survey validation interviews that were involved with the survey creation, we assumed that these responses were due to random guessing, and the respondents were removed. After these measures were taken, a total of N = 234 responses remained.

Answer	**N**	**%C**	**%P**	**Reasoning**	**N**	**%C**	**%P**
ClA1: Less than 1 day	6	10	11	ClR1: The gas never completely fissions	3	5	5
ClA2: More than 1 but less than 4 days	1	2	2	ClR2: Radiation is halved in $T_{1/2}$	1	2	2
ClA3: 4 days	4	7	7	ClR3: Radiation is all gone in 2 $T_{1/2}$	0	0	0
ClA4: More than 4 but less than 8 days	3	5	5	ClR4: Half fissioned in $T_{1/2}$	5	8	9
ClA5: 8 days	2	3	4	ClR5: All fissioned in 2 $T_{1/2}$	2	3	4
ClA6: More than 8 days, but eventually…	7	12	13	*ClR6: Get help/info	12	19	22
*ClA7: Depends	4	7	7	ClR7: Radiation can get through the door	3	5	5
ClA8: Never	11	18	20	ClR8: Closet becomes radioactive	2	3	4
OTHER	10	17	18	ClR9: All gone	4	6	7
NONE	12	20	22	OTHER	6	10	11
				NONE	25	40	45

Table 1. Survey responses to free response form of CLOSET, 2019, N = 55 8th grade students. N = Number of codes, %C = % of codes, %P = % of respondents. The desired response is indicated in the table with an asterisk (*).

Results and Conclusion

On MANY, only 5 % of the 8th grade students and 4% of the 12th grade students said that all the radioactive material would be gone after two half-lives. Although this might be expected of the 12th grade students who had previously learned about half-life, it is somewhat of a surprise that so few of the 8th grade students did not assume this to be the case.

Similarly, only 4% of the 8th grade students and 3% of the 12th grade students said that the closet would be safe after two half-lives. On the other hand, one of the most common responses to CLOSET was that the student would never open the closet. This data suggests that the idea that radioactivity is quintessentially eternal (Alsop 2001) is stronger than the idea about half-life being the active or dangerous time. This suggests that, in the classroom, efforts should be made to clarify to students that we are surrounded by nuclear radiation, and that this level of background radiation can be used as a benchmark to productively make risk-benefit decisions.

Literatur

Alsop, S. (2001). Living with and learning about radioactivity: A comparative conceptual study. *International Journal of Science Education*, 23(3), 263–281. https://doi.org/10.1080/095006901750066510.

Eijkelhof, H. M. C. and Millar, M. (1988). "Reading about Chernobyl: the public understanding of radiation and radioactivity." *School Science Review* 70.251: 35-41.

Eijkelhof, H. M. C., Klaassen, C. W. J. M., Lijnse, P. L., & Scholte, R. L. J. (1990). Perceived incidence and importance of lay-ideas on ionizing radiation: Results of a delphi-study among radiation-experts. *Science Education*, 74(2), 183–195. https://doi.org/10.1002/sce.3730740205.

Hull, M. M. (2019) Emergent Aspects of Radioactivity: Creation of a Survey on Half-life. *GDCP Conf. Proc.*, 590–593.

Hull, M. M., & Hopf, M. (2020) Student understanding of emergent aspects of radioactivity. *International Journal of Physics & Chemistry Education*, 12(2), 19–33.

IAEA (2020) Finland's Spent Fuel Repository a "Game Changer" for the Nuclear Industry, Director General Grossi Says. https://www.iaea.org/newscenter/news/finlands-spent-fuel-repository-a-game-changer-for-the-nuclear-industry-director-general-grossi-says

Lijnse, P. L., Eijkelhof, H. M. C., Klaassen, C. W. J. M., & Scholte, R. L. J. (1990) Pupils' and mass-media ideas about radioactivity. *International Journal of Science Education*, 12(1), 67–78. https://doi.org/10.1080/0950069900120106.

Lucas, A. M. (1987) "Public knowledge of radiation." *Biologist* (London) 34.3: 125-129.

Mayring, P. (2014) Qualitative content analysis: theoretical foundation, basic procedures and software solution. Klagenfurt.