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Emergent Aspects of Radioactivity: Creation of a Survey on Half-life

Introduction

Ionizing radiation is utilized around the world for energy, industrial, and medical purposes. However, common use of a technology does not mean that it is commonly understood. Students fail to distinguish radioactive substances from the radiation they emit and consequently think that plumes of radiation arose from the destruction at Chernobyl and were carried by the wind (*e.g.*, Riesch & Westphal, 1975; Eijkelhof, 1990; Neumann & Hopf, 2013; Millar *et al.*, 1990; Johnson & Hafele, 2010; Schrader & Bolte, 2017). Many mistakenly assume that exposure to nuclear radiation makes objects and people radioactive themselves (*e.g* ., Eijkelhof 1990; Millar *et al.*, 1990; Johnson & Hafele, 2010; Prather & Harrington, 2001).

It has been argued (Eijkelhof 1990) that the randomness inherent in radioactivity contributes to student difficulty in understanding the topic. Students tend to attribute predictable characteristics which emerge when there are enough random events taking place to the individual events themselves. Consistent with previous findings by other researchers, a pilot study consisting of seven interviews of Gymnasium students in Vienna last year indicated a student tendency to apply the half-life concept to a single nucleus, for example, to say that the nucleus must transform prior to the half-life (Eijkelhof *et al.*, 1990; Hull & Nakamura, 2018), that the nucleus is half-gone after the half-life (Klaassen *et al.*, 1990), or that the nucleus has a 50% likelihood to transform on the day marking the end of one half-life (Hull & Nakamura, 2018). Based upon prompts used in these interviews, I created and administered an open-ended survey to Gymnasium students. In this report, I will discuss 1) the results of this survey, and 2) how I am using these results to create a fixed-response version of the survey that I plan to administer in the future.

Survey Creation and Analysis

The survey contained several of the prompts that had yielded fruitful data in the prior interview study, as well as several additional prompts that also related to student understanding of half-life. Although the full survey is available upon request, here I will only discuss two of the prompts, the “Many vs 1” prompt (Hull & Nakamura, 2018) and the “Cage” prompt (Jansky 2019). The former consists of two parts, the first of which reads:
Radon-222 is an example of a radioactive atom. It has a half-life of about 4 days, meaning if you start with a whole bunch of the atoms, only half of them will still remain after 4 days. Imagine that you begin with 100 million Radon-222 atoms. How much Radon-222 will remain after a) 4 days, b) 8 days, and c) 12 days? Explain briefly, how you reached your answers.

The second part of the prompt is similar, except it asks students how much Radon would remain if there is only one atom in the beginning. So as to minimize student tendency to just assume that the answers to this second part are the same as those to the first part, the two parts are on different pages, with the “Cage” prompt placed between them:
Suppose you have a friend who has just freshly created one of these [Radon-222] atoms and is keeping it in a cage. You really want to see the atom transform, but your parents will only let you take one day off from school to go watch the nucleus. Would you go on the day your friend first created the atom to go watch and see if it transforms? Or would you wait until a later day? Which day?

A native German-speaking colleague who is an expert in student understanding of radiation translated this survey into German. I then conducted survey validation interviews with three high school students in German. This led to minor changes to wording of the prompts. Finally, I administered this survey in June 2019, to 55 junior high school students (13-14 years old) visiting the University of Vienna. These students took the survey prior to a lesson from pre-service teachers on radioactivity. Before their visit, these students had not yet had any instruction on radioactivity. Once the data had been collected, I carried out an abridged version of inductive category formation (Mayring 2015) with the same colleague, looking at a small number of student responses to serve as discussion points for the generation of coding categories. I then applied these codes to the remaining survey responses. The results of this analysis are presented in Tables 2 and 3 below (N = Number, C = Codes, P = Respondents). The desired response is indicated in the table with an asterisk (*).

Category	N of C	% of C	% of P
Answer to part 2 of the "Many vs 1" prompt			
MA1: 1/2 ; 1/4; 1/8	32	62	62
MA2: 1/2 ; 0 ; 0	4	8	8
MA3: 1; 1; 1 // 0; 0; 0 // 1; 0; 0 // 1; 1; 0	8	15	15
*MA4: 1 OR 0; 1 OR 0; 1 OR 0	2	4	4
MA5: 111; 55; 27.5	2	4	4
Reasoning on part 2 of the "Many vs 1" prompt			
MR1: Half-gone after T 1/2	20	43	57
MR2: "Same as the first part of the prompt"	9	20	26
*MR3: Unpredictable	2	4	6
MR4: Cannot have half an atom	4	9	11
MR5: Atoms do not disappear	3	7	9
MR6: The atom is all gone in 2*T1/2	2	4	6
MR7: The atom is eventually gone	3	7	9

Table 2. Survey responses to the second part of the “Many vs 1” prompt

The most frequent response, indicated by 62% of the 52 respondents who answered the prompt with a legible and relevant response, was MA1, that half of the atom would remain after 4 days (one half-life) had passed, ¼ of the atom would remain after two half-lives had passed, and 1/8 of the atom would remain after three half-lives. About a quarter (26%) of the 36 respondents who explained their answer noted that they had solved the problem the same as they had solved the first part of the prompt (indicated by code MR2), where 100 million atoms are present in the beginning. In total, 41 of the 55 respondents described in at least one of these two prompts the idea that half of an atom would remain after one half-life (coded with MA1 and/or MA2 and/or MR1 and/or CR1). To be clear, respondents *had* learned previously about atoms. In fact, a total of 8 respondents from the remaining 14 students explicitly rejected the idea of having half an atom (coded with MA3 and/or MA4 and/or MR4, but not with the former “half of an atom remains” codes). However, only 3 of these 8 respondents answered at least one of these two prompts with ideas of randomness (coded with MA4 and/or MR3 and/or CR3). An example of such a response (translated into English) was “I would go on the day that the atom is made, because one cannot (quite) predict when it will transform” (coded CA2 and CR3). On the other hand, considering that these students had not previously learned about half-life in school, it is noteworthy that ANY students answered in terms of randomness.

Category	N of C	% of C	% of P
Answer to the cage prompt			
CA1: Half-life	18	41	41
CA2: A day NOT T 1/2	23	52	52
*CA3: All days are equally good	0	0	0
Reasoning on the cage prompt			
CR1: Half-gone after T 1/2	8	24	30
CR2: The decay is a process, but not referencing T 1/2	16	48	59
*CR3: Unpredictable	4	12	15
CR4: The decay takes place at T1/2	2	6	8
CR5: Decay goes quickly	1	3	4
CR6: Turns into a different atom after becoming half the size	1	3	4
CR7: One should not wait too long	1	3	4

Table 3. Survey responses to the "Cage" prompt

It is also noteworthy that three students had responses on the second part of the "Many vs 1" prompt that contradicted their responses to the "Cage" prompt. The student quoted above, for example, who wrote for the "Cage" prompt that one cannot predict when the atom will decay, wrote on the "Many vs 1" prompt that the atom would already be gone by 4 days because "One cannot have half an atom" (coded MA3 and MR4). It may seem strange that in one prompt, the response suggests that the student understands that the decay of a single atom is random, whereas in response to another prompt on the same survey, the student seems to think that it occurs predictably, immediately after the creation of the atom. Indeed, if the student's ideas about radioactivity are unitary (in the sense that the student has just one conception of radioactive decay), then we would not expect this to occur. The data, then, suggest that, at least for these three respondents, the student ideas about radioactivity are *not* unitary, but rather more fluid and changeable in nature. Knowledge in Pieces frameworks, for example the P-Prims Theory of diSessa (diSessa 1993), have accounted for such fluidity in student reasoning by arguing that student ideas consist of smaller knowledge pieces that can be, but need not be, firmly bound to each other. Such frameworks are fruitful for thinking not only about the seemingly inconsistent data from this survey, but also in the variability in reasoning observed in student interviews (Hull and Nakamura, 2018).

Future Work

In this report, I have discussed results from just two of the items on the survey. I intend to analyse the remaining items from the survey and to use the results to construct a two-tier multiple choice survey. This survey will be validated first through survey validation interviews. Following this, the revised survey will be administered and pilot data collected. Rasch analysis will then be used both for further validation as well as for assessing reliability of the instrument.

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