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Reasoning Fluidly about Half-life on a Two-tier Multiple-choice Survey

Introduction

To date, researchers have documented a number of student naïve ideas regarding radioactivity (*e.g.*, Eijkelhof, 1990; Lijnse, Eijkelhof, Klaassen, & Scholte, 1990). Specific to the lifetime of radioactive materials, many students assume that if half of a radioactive substance has transformed after one half-life, then half of each individual atom making up the sample must have half-transformed (Klaassen, Eijkelhof, & Lijnse, 1990). We have also documented the naïve idea that the nucleus has a 50% likelihood to transform on the day marking the end of one half-life (Hull & Hopf, 2020). It has been argued that part of the underlying difficulty could be a failure to understand the random nature of radioactivity (Eijkelhof, 1990; Hull, Jansky, & Hopf, 2020). We have also argued that, particularly regarding these latter ideas about the timing of the fission of an individual atom, the difficulty could arise in part because of a failure to understand radioactivity as an emergent process. Using the language of Wilensky *et al.* (*e.g.*, Wilensky & Resnick, 1999), we have discussed how students demonstrate a "level confusion" when they assume that the agent level (that is, individual nuclei) and the system level (the radioactive sample) share the same property (being half-transformed after one half-life) (Hull & Hopf, 2020). More generally, a student with a level confusion might reason *"If the amount of radioactive stuff in the radioactive sample can be predicted, then the individual atom cannot exhibit randomness."* In our prior work, we have documented through both pilot interviews (N=7) and a follow-up survey (N=55) that this "level confusion" is not necessarily a stable and rigid cognitive structure, but rather something that can fluidly shift from context to context (Hull, 2019; Hull & Hopf, 2020; Hull & Nakamura, 2018). Here, we will describe our current efforts to systematize data collection for seeing how wide-spread and to what degree this context-dependency is. In particular, we have utilized two features in our survey: 1) isomorphic problems and 2) confidence ratings.

Methodology: Isomorphic Problems and Confidence Ratings

Isomorphic problems are problems that require the same conceptual understanding to answer, but have different surface features that may result in a given student answering correctly on only some of the problems. Singh argues that the reason for this fluidity in reasoning is that "problem context with distracting features can trigger the activation of knowledge that a student thinks is relevant but which is not actually applicable in that context" (Singh, 2008). In such a case where knowledge is triggered in some problem contexts but not others, it would be inappropriate to think of students as having a rigid misconception. Although the use of isomorphic problems is a relatively direct indicator of how context-sensitive a student's reasoning is, it has the disadvantage of requiring additional survey items, potentially increasing the length of the survey dramatically. The second tool we consider for indicating the robustness of a learner's ideas is that of confidence ratings. After each item in our survey, we ask the respondent how confident he or she is with the answer to that item. Hasan *et al.* (1999) have argued that confidence ratings can "differentiate between a lack of knowledge and a misconception" and Lemmer (2013) has argued that expressing confidence can "confirm the existence of stable existing [knowledge] structures". Asking respondents for a confidence rating increases the survey length only marginally. To minimize testing time, then, we would like to use only confidence ratings, provided responses on isomorphic problems provide no additional information beyond the confidence ratings. Our current research is to investigate whether or not that is the case. That is, our present research question is: *"Is there sufficient correspondence between confidence ratings and responses to isomorphic problems that we can keep just one of the two approaches? In particular, are students who answer (in)consistently across the isomorphic problems more likely to report (a lack of) confidence?"*

Our survey utilized 3 isomorphic prompts, the "Cage" (Jansky, 2019) and "Many vs One (MvO)" prompts, which we have previously described (Hull, 2019), and the "Ant" prompt, the free response version of which is shown in Fig. 1 below. Like the Cage and MvO prompts, the Ant prompt existed first as a free response prompt. Responses were collected from N = 37 students who had already learned about radioactivity and half-life. As the first and third author had done with the Cage and MvO prompts (Hull & Hopf, 2020), the first and second author coded the responses to the Ant prompt using qualitative content analysis (Mayring, 2014). These codes were then turned into options for a two-tier multiple-choice test form. In addition, from beginning to current state of the survey creation process, a total of N=7 survey validation interviews have been conducted, resulting in relatively minor improvements. The data presented below was collected the summer semester of 2020 from N = 84 students in the 6th-8th Klasse of a local Gymnasium in Vienna.

Results

Of the 84 students who started the survey, 79 of those students answered the Ant prompt (the first of the three isomorphic problems). Of those, 75 students answered Q.1B (see Fig. 1) with "Meine Antworten würde sich nicht ändern" or "Es ändert sich nicht außer, dass der Stein nun länger Strahlung abgibt". We coded these responses as indicating a level confusion. Our research interest is to investigate whether this level confusion is a stable and robust misconception, or whether it was incorrect reasoning appearing only in this context. To that end, we compared these responses with what the same students had responded to our other two isomorphic prompts, Cage and MvO.

A total of 75 students answered all three prompts and 74 of these exhibited a level confusion on at least one of the prompts. Of these, only 25 students exhibited a level confusion consistently across all three prompts. Our first finding, then, is that most students who show evidence of a level confusion do not do so consistently; rather, this difficulty is heavily context-dependent. We now turn our attention to our research question, combining this data with the confidence ratings reported by students.

A subset of the students who answered all three prompts were also asked confidence ratings for these prompts (N=44). Of these, 43 students exhibited a level confusion on at least one of the prompts, but only 12 exhibited a level confusion consistently across all three prompts. Although this is insufficient data to answer our research question (especially since very few students expressed confidence), there seem to be just as few consistent students expressing

Iod-131 ist ein Beispiel eines radioaktiven Atoms. Eine Ameise steht, wie im Bild rechts dargestellt, neben einem Stein, der eine Menge von Iod-131 Atomen enthält. Die Ameise bewegt sich zehn Minuten lang nicht. Betrachte die Aussagen von vier Lernenden, die mit einander über die Strahlung diskutieren, die während dieser zehn Minuten die Ameise erreicht.

1A) Mit welchen dieser vier Aussagen, zu einem Stein, der eine sehr geringe Menge von Iod-131 Atomen enthält, stimmst Du überein? Warum? Mit welchen stimmst Du nicht überein? Warum? Begründe Deine Entscheidung mit 2-3 Sätzen.
1B) Wie würde sich Deine Antwort zu Frage 1A ändern, wenn der Stein anstatt einer geringen Menge, eine riesige Menge an Iod-131 enthalten würde? Warum?

Fig. 1. The free-response form of the "Ant" prompt. Responding "my answers would not change" for part B was taken to indicate a "level confusion".

confidence as there are inconsistent students expressing confidence.

Conclusions

Our prior findings suggested that the "level confusion" (Wilensky & Resnick, 1999) exhibited by students when faced with the random and emergent nature of radioactivity may not be a rigid and robust misconception; rather, it may be a manifestation of smaller knowledge pieces aligning themselves in context-sensitive ways in response to problem features that are salient to students (Singh, 2008). The findings that we have presented here involving student responses to three isomorphic prompts suggest that fluidity of student reasoning is the norm, and not the exception. We have also found that most students also express a lack of confidence in their answers. However, it does not seem to be the case that the minority of consistent students are the same minority of confident students. As such, we are cautious of using confidence ratings as a proxy for detecting misconceptions, and favor the use of isomorphic problems as it is a more direct indicator. We intend to soon acquire a larger pool of data with which we can support or refute this suspicion.

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