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RESEARCH ARTICLE

Half-life and Lifeworld: The Omission of School Knowledge in Writing about Radioactive Waste

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Abstract
We report on a pilot study investigating student writing about radioactive waste before and after instruction on half-life. We found that none of the ($N = 21$) 12th-grade students mentioned half-life on the post-test writing task. This is consistent with previous research conducted by Eijkelhof *et al.* which showed that students are unlikely to be influenced in terms of their views about topics in the lifeworld (such as where to store waste from nuclear power plants). Our study is pioneering in that we analyze both student writings and responses to survey questions in our assertion that the issue is neither student writing ability nor conceptual understanding. We hypothesize, rather, that students do not think the topic of half-life is relevant to the writing task. Instruction aiming to improve student writing about science issues in the lifeworld should provide scaffolding to emphasize the usefulness of school knowledge in that writing.

Keywords
half-life, radioactive waste, writing assessment, epistemological framing, lifeworld

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Introduction
In their 2030 Agenda for Sustainable Development, the United Nations described climate change as "one of the greatest challenges of our time" (United Nations, 2015). They listed 17 "Sustainable Development Goals", with goal number 7 being to "ensure… sustainable and modern energy for all," particularly for least-developed countries, which are expected to require significant increases in energy per capita as they develop. Energy sources which are "sustainable", in the sense that they do not exacerbate climate change, are ones which emit minimal greenhouse gases. The International Atomic Energy Association, a subgroup of the United Nations, describes nuclear fission power as being a candidate for such an energy source, and they encourage developing nations to consider adding nuclear energy to their "energy mix" (International Atomic Energy Agency, 2017). Over the source life cycle, nuclear power plants produce fewer greenhouse gases per kilowatt-hour than even photovoltaic cells, and air pollution is similarly marginal (International Atomic Energy Agency, 2017).

Despite these benefits, there are significant disadvantages to nuclear energy as well. Fission reactors rely upon rare-earth elements, so named because they are relatively scarce. Although the Organisation for Economic Co-Operation and Development estimates sufficient uranium supply for over 135 years, that is assuming that growth remains restricted (OECD, 2016). The upfront capital investment in building a nuclear power plant is prohibitively high. Even more prohibitive is the struggle to find waste storage sites which can withstand the extremely long time required for the waste's radioactivity to reach acceptable limits. The primary ingredient in spent fuel pins, like in the mined uranium ore itself, is U-238, which has a half-life of 4.5 billion years. As such, these repositories must outlive not only political changes and shifting territory boundary lines, but dramatic geological changes (like the next ice age) as well. There are currently no operating

State of the literature
- The student idea that half of an individual atom decays after one half-life has been documented and shown to be prevalent, but it is unclear how that idea develops when students learn about half-life.
- Research has shown that students activate knowledge resources in response to how they are framing an activity epistemologically, but not much has been done looking at radioactivity.
- Students struggle with integrating subject-specific language into their vocabulary and, in a second step, into their writing. Previous research has focused on how the learners' use of subject-specific language may be improved and found that, amongst others, teaching language and content in an integrated approach such as CLIL or linguistically responsive teaching supports students in learning and acquiring domain-specific language (Bonnet, 2004; Cummins, 2000; Dalton-Puffer, 2008; Tajmel, 2017).

Contribution of this paper to the literature
- We present baseline data of improving student conceptual understanding about half-life as a result of instruction.
- We show that even students who have succeeded in coming to understand half-life might not feel inclined to use the concept in writing about lifeworld topics where it would be appropriate to do so, such as where to store waste from nuclear power plants.
- We further show that student hesitancy to use the concept of half-life in writing does not come from writing inadequacy. Even the best essays that would otherwise receive full points did not mention half-life. The disconnect, we argue, seems to be rather at the level of student expectations about what is appropriate content for writing about lifeworld topics.

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permanent repositories for high-level nuclear waste (although Finland may change that in the near future (El-Showk, 2022)). While part of the difficulty to find appropriate waste storage locations is technological, much of the challenge comes from a "not in my backyard!" mindset from the public. Generally, the public has a very negative image towards nuclear energy which includes the above reasons as well as a host of other ideas which are either exaggerations or falsehoods (for example, that a nuclear power plant can explode with the devastating power of a nuclear bomb (Eijkelhof et al., 1990)).

When it comes to making decisions about the future of energy, the public should be educated and informed about nuclear energy, both the benefits and challenges. One of the key challenges is the issue of where to store nuclear waste. Central to understanding this difficulty is an understanding of the concept of half-life. Previous research has shown that students struggle to understand half-life. Although the point at which an individual nucleus decays is taken to be random, there is nevertheless a characteristic time necessary for half of a large number of nuclei of a given radioactive isotope to decay (the "half-life"). Several studies have demonstrated students applying the concept of half-life not only to the collective substance, but also to individual nuclei, viewing the nucleus itself as being half-decayed or having lost half its radiation after one half-life (Hull & Hopf, 2020; Jansky, 2019; Klaassen et al., 1990). Many students think that a radioactive sample loses half of its total number of atoms (and hence mass and volume as well) after one half-life[1] (Prather, 2000, 2005). Lucas (1987) administered a survey to over 1000 adults and over 25% said that radioactive waste would "decay within 100 years." Eijkelhof mentioned that some of the difficulties people face in understanding radioactivity could arise in part because radioactive decay is stochastic in nature (Eijkelhof, 1990), and we have supported and expanded upon this idea in a recent literature review of probability-related students' conceptions across physics topics (Hull et al., 2021). Part of the issue, it has been argued, is how radioactivity is discussed in the media (Eijkelhof & Millar, 1988). Eijkelhof & Millar (1988) surveyed over 500 articles that were published between April 29th and June 30th 1986 (the first few months immediately after the nuclear reactor accident at Chernobyl). One finding was that "radiation/radioactivity appears to be seen as something with a definite life-time." Sources described some radioisotopes as having a "short life" corresponding to the half-life. Others described radioisotopes as retaining their "maximum radioactivity" for the duration of the half-life. The authors concluded that "the model is of something which is 'active' or dangerous' for a certain time and then becomes 'safe' or 'spent'". A casual look online today reveals that the situation is largely unchanged. The first hit produced with a Google search on Feb. 7, 2023 of "nuclear energy waste" was U.S. Energy Information Administration's site "Nuclear explained: Nuclear power and the environment." Although the site does offer a definition and explanation of half-life (3 of the first 10 hits did so), it also states "A major environmental concern related to nuclear power is the creation of radioactive wastes such as uranium mill tailings, spent (used) reactor fuel, and other radioactive wastes. These materials can remain radioactive and dangerous to human health for thousands of years," which conjures an image of the material having a definite life-time, just as writings after Chernobyl did. Eijkelhof and Millar argued that part of the reason for inaccuracies in writing about radioactivity may be a lack of conceptual understanding about half-life, but it may also be motivated by consideration of the readers' interests.

> "The journalists who wrote articles on Chernobyl ranged across the expert/lay divide. It clearly cannot be taken for granted that what they wrote always reflected their own understandings … The demands of popularization, of writing for a lay audience, impose their own constraints" (Eijkelhof & Millar, 1988).

This is a point that we will return to, first in the Literature Review, and then in the Discussion, in making sense of our own study results.

Research conducted by M.M.H. on student understanding of half-life (e.g., Hull, Holzinger, et al., 2022; Hull, Jansky, et al., 2022) has shown that it is difficult for learners to grapple with the idea that random behavior of individual atoms can give rise to predictable patterns in the collective. Many students have said both on the Stochastic World of Radioactive Decay Evaluation (SWORDE) and in interviews that, if you are looking at an individual atom, half of the atom will have decayed after one half-life. Findings have indicated, however, that this idea (of individual atoms decaying in a predictably continuous manner) is often not a robust and intact mental structure; rather, in other contexts, the same students correctly discuss decay as being instantaneous and unpredictable (Hull, Holzinger, et al., 2022; Hull, Jansky, et al., 2022). In this paper, we investigate a new context, that of a writing prompt about a real-world situation. Our research question is **"how are student understanding about half-life and writing about radioactive waste affected by instruction on the topic of half-life? In particular, do students continue to discuss radioactive waste as having a 'life-time', or do they appropriately and correctly draw upon the concept of half-life in their writings?"** Our study is pioneering in that, through analysis of both student writings and responses to survey questions, we find that students fail to draw upon school-learned content knowledge in their writing not because of poor writing ability or lack of conceptual understanding. Rather, we posit that students who do not draw upon the concept of half-life in writing about radioactive waste *do not see it as relevant information* to include.

[1] In fact, the daughter nuclei, which remain in the sample, are essentially the same mass as the parent nuclei.

This study is important for an additional reason as well. Prior work investigating student understanding of half-life, both of the first author and the other works discussed above, generally takes the form of a snapshot of student understanding, looking at a single interview or a single set of survey responses. There is a lack of data pertaining to student growth in understanding of half-life pre/post instruction. This is a significant gap that our work aims to help fill. In this paper, we present data of student conceptual understanding pre- and post-instruction about half-life. This data can serve as a baseline from which to compare other pedagogical approaches towards teaching the topic of half-life.

Literature Review

In addition to the studies described above in the Introduction pertaining to student ideas about radioactivity and half-life, there are two bodies of research literature relevant for our study, both of which we will discuss in this section. The first, that of "epistemological framing", attends to the question of what kind of "game" do students think they are playing (for example, in the classroom)? What are the "rules" of this "game"? What are valid "moves", and what kind of behavior would be inappropriate? The second body of research pertains specifically to student writing and its assessment.

Epistemological framing

Eijkelhof's PhD thesis discussed the results of an attempt initiated in the 1970's to relate physics with the world outside the classroom, the "Dutch Physics Curriculum Development Project" (an English translation, with the original Dutch name abbreviated "PLON"). In particular, Eijkelhof discussed one of the units called "Ionizing Radiation", which had the goal that "pupils [in 12th grade] should learn to use scientific knowledge in situations in which risks of ionizing radiation have to be assessed" (Eijkelhof, 1990, p. 24). The 102 students completed a 16 item-attitude test before and after instruction, and student attitudes (particularly those of the girls) towards radioactivity were seen to improve after instruction. Furthermore, student ranking of five risk-bearing situations showed that "living near a nuclear reactor" decreased in perceived risk after instruction, aligning more closely with the expert ranking (Eijkelhof, 1986). Nevertheless, Eijkelhof concluded that "the aim of increasing the reasoning ability of pupils by including knowledge from the unit has not been obtained satisfactorily" (Eijkelhof, 1990, p. 29). Specifically, two free response prompts were administered to the students pre- and post-instruction. The first prompt asked students to comment on the opinion that "the disposal of radioactive waste in sea [*sic*] is not very serious." Approximately 80% of students disagreed with the statement both before and after instruction, and students were equally unlikely after instruction to use content they had learned in their responses. Instead, responses were "mainly of a commonsense nature, such as: 'When the vessels are damaged the fish will die'" (Eijkelhof, 1986). On the second prompt, on the other hand, "Food which has been irradiated by a radioactive source in order to preserve it, should be banned in the Netherlands," student views became more tolerant towards radioactivity on the post-test, and students were more inclined to draw upon what they had learned in class, with responses like "if the food itself does not become radioactive it is not a problem" (Eijkelhof, 1990, p. 29). A plausible explanation for the differing outcomes between these two prompts is that the first prompt, pertaining to radioactive waste management, was "a much debated issue in the Netherlands. Previously held opinions are not easily changed… Irradiation of food is a less well-known application of radiation. It may be that the content of the unit has a greater influence on students' opinions on topics which are not the subject of recent public debates" (Eijkelhof, 1986). One hypothesized reason for why "the aim of … the unit has not been obtained satisfactorily" was that "the questions asked in the pre- and post-tests evoked ready answers from the lifeworld which were evident in the eyes of the pupils; in this case there was no need felt to apply scientific knowledge" (p. 30). Although Eijkelhof did not use the phrase himself, this idea of not feeling a need to apply knowledge (for example, in responding to something that one has already frequently heard discussed outside of the classroom) is something that other education researchers have discussed with the lens of "epistemological framing", which we will now discuss.

Eijkelhof's point was that there is something going on with the students learning about radioactivity that was not purely conceptual in nature. Redish, in discussing similar situations to this, offers the explanation that "errors… may occur not only because of lack of knowledge but also through … mismatches of situations and expectations about the task that result in students *failing to access knowledge they actually have*" (italics in original) (Redish, 2014). In Eijkelhof's study, there was an attitudinal piece, a disconnect between the teacher and the students about the nature of the knowledge being learned that resulted in students failing to access the knowledge they had gained through their learning. Student views about the nature of knowledge and learning (or "epistemology" (Hofer & Pintrich, 1997)) is one that has received much attention in the field of physics education research (e.g., Adams et al., 2006; Hammer, 1994; Redish, 2003; Redish & Hammer, 2009). On a societal level, epistemology plays a role in that the public's perception of science affects funding for scientific research. On an academic level, it has been shown that epistemology correlates with which physics courses students choose to take, how much they learn in those courses (Halloun & Hestenes, 1998; Perkins & Gratny, 2010), how interested in physics they will be (Perkins et al., 2005), and on whether or not they become a physics major (Perkins & Gratny, 2010). This is not altogether surprising, if we consider that students who robustly perceive physics to be a plethora of disconnected facts, for example, might be content to memorize equations without considering how they relate to each other or to the real world (Hammer, 1989; Lising & Elby, 2005; Rosenberg et al., 2006). Unfortunately, in introductory physics courses, it is common for students' views about the learning of physics to become less expert-like over the course of the semester (e.g., Adams et al., 2006; Redish et al., 1998). This applies to courses taught with traditional pedagogy as well as to many courses that adopt reform curricula and interactive engagement techniques.

Epistemological framing (Hammer et al., 2006; Redish, 2004, 2014) is a cognitive (often subconscious) activity that draws upon one's epistemology to answer the question "what kind of knowledge/learning is appropriate in this situation?" Similar to how a picture frame serves to create a space through which to view the picture, students frame what is going on in the classroom. That framing is developed through past experiences, both in and out of school. For example, by high school, most students have developed the expectation that they will sit in an assigned seat and that they will watch and listen to their teacher. When student framing is strongly affected by epistemological views, it is frequently referred to as "epistemological framing". One common epistemological frame is what is referred to as the "classroom game", expecting knowledge to come in the form of ready-to-use bits (such as a physics formula) received directly from the instructor. An alternative epistemological frame (that is unfortunately much less common in physics classrooms) is "make sense of phenomena", where students expect knowledge to have the potential of coming from anywhere, so students play the role of producing and assessing that knowledge for whether or not it matches what they believe and understand (Hutchison & Hammer, 2010). Redish describes epistemological framing as something students do any time they are "put in a situation in which they have to construct some knowledge – answer a question, solve a problem, analyze a text or experiment." Students "make a quick and dynamic decision (again, not necessarily consciously) about 'what is going on'. They decide how to restrict their search space in their long-term memory – what knowledge they have that might be relevant to bring to bear and how to approach what they need to do" (Redish, 2014).

We find it at least plausible that students in Eijkelhof's study did not apply what they learned in the classroom to the lifeworld questions they were asked because of epistemological framing. We can easily imagine a student who (probably subconsciously) thinks something like "this question is asking me about a real-world situation, so physics content is not an appropriate thing to discuss."

Writing tasks and assessment

Being able to understand and use scientific and academic language appropriately is a prerequisite for being scientifically literate (Markic et al., 2013). In other words, "being able to use, understand and explain main ideas of science or participate in social debate about a science related issue, *e. g.* climate change" (Markic et al., 2013, p. 129) necessitates linguistic competence. As a consequence, teachers, as 'interpreters' and competent users of academic and scientific language (Laszlo, 2013; Mönch & Markic, 2022), must offer their linguistic knowledge and opportunities for the students to develop their linguistic skills in natural science classes. This knowledge may be seen as part of the teachers' pedagogical content knowledge (PCK) (Bishop & Denley, 2007; Carlson et al., 2019; Mönch & Markic, 2022). Linguistically responsive lesson plans in particular support learners in how to comprehend and produce subject-specific linguistic structures and in how to develop their linguistic skills, *i.e.*, reading, speaking, writing, and listening (Butler & Goschler, 2019).

In the physics classroom, linguistic structures are generally offered within the boundaries of text-types, *i.e.* spoken or written texts grouped together due to shared characteristics (Hedge, 2019; Paltridge, 1996). Here, text-types such as reports, descriptions, and recounts of a procedure are of great importance. In order to be able to compose and produce these scientific texts, both the learners' knowledge about science and their linguistic competence are needed. For that reason, linguistically responsive lesson plans and scaffolding come into play (Butler & Goschler, 2019; Kniffka, 2013; Petersen & Tajmel, 2015; Tajmel, 2017). According to van Lier (1996), scaffolding should offer several avenues of support:

- contextual support,
- continuity between routine and variation,
- intersubjectivity in the form of mutual engagement during a lesson,
- existence of flow in the working process,
- contingency as support that caters to individual students' needs, and
- handover in that scaffolding is removed over time.

Scaffolds in general aim at providing learners with tasks that target their zone of proximal development (Lloyd & Fernyhough, 1999), so learners are both challenged and supported. Consequently, subject-specific writing tasks should offer both support concerning what language the learners are supposed to use to produce the text and what scientific background knowledge is needed to complete the task. These writing processes can take place in an *imitative* manner (in which correctness is not important) or in a *controlled* way (in which learners are to use appropriate vocabulary and lexis in a given context). Learners can produce *responsive* text to a task description, or they can write freely in an *extensive* manner. To offer scaffolding in these writing settings, a text may be broken down into parts by offering the learners descriptors (*describe* the situation, then *give reasons* for this), highlighting important vocabulary or offering sentence structures (Brown & Abeywickrama, 2010). Scientific background knowledge can be supported by activating students' prior knowledge, drawing upon previous lessons, or explicitly stating the facts necessary to fulfil the task (Hedge, 2019). Students also profit from the opportunity to revise their writing, or from obtaining feedback during the writing process (Brown & Abeywickrama, 2010). Each of the aforementioned writing processes demands for different kinds of assessment. As imitative writing does not generally play a role in the natural sciences classroom – the main focus here is on learning spelling, grammar, and punctuation in short tasks and texts – its assessment will not be discussed in detail here. Controlled writing, on the other hand, plays an important role in the natural science classrooms, as this is the type of writing employed in short questions and fill-the-gap exercises. From a science teacher perspective, content is assessed for correctness here. In addition, linguistic accuracy may be assessed, and feedback may be given to the learners based upon their use of scientific and academic language. Responsive writing constitutes a response to a writing prompt such as the one given in the course of this study (see Survey design and administration). With both responsive and extensive writing, assessment can focus on lexical range, accuracy, layout, and structuring of the text as well as the fulfilment of the task description (Brown & Abeywickrama, 2010; Hedge, 2019).

Methodology

Our study concerns a written survey that was administered pre- and post-instruction on the topic of half-life. In this section, we will first discuss the instruction that took place. We will then describe the survey. Finally, we will discuss our assessment of the survey responses.

Instructional unit on half-life

On Nov. 22, 2021, one of us (F.B.) taught an hour-long lesson on half-life to his 12th grade students. Prior to this lesson, he had met with M.M.H. to brainstorm ideas for the lesson. We had decided that the lesson would utilize the activity of flipping coins to simulate radioactive decay (Hull & Hopf, 2022; Kowalski, 1981). We had also agreed that F.B. would utilize Peer Instruction (Crouch & Mazur, 2001) in having students answer questions first individually ("Think"), then share ideas with a partner ("Pair"), and finally share with the whole class ("Share"). As a result of the Corona pandemic, the school decided somewhat last-minute that the lessons that day would take place in a hybrid format. As such, some students were at home (streaming in via Google Meet) while others were in the classroom, resulting in the lesson being more challenging than anticipated. An online coin flip simulation was used for the home learners, but the instruction given to the students turned out to be confusing, resulting in the data collected with the simulation being in a different form than that collected in the classroom (amount of coins remaining instead of amount that had "decayed" in that time step). Other than that, however, F.B. reported that students did not seem to be particularly confused by the lesson contents. Although the Peer Instruction proved unmanageable in the hybrid format with such short notice (resulting in there being minimal, if any, discussion between students), the students who F.B. called upon to answer the questions he posed answered the questions correctly. Nevertheless, it is important to note for interpreting the results of the writing task that there was minimal opportunity for students to verbalize their understanding during the lesson.

Survey design and administration

The survey administered before and after the instruction (which took place on Nov. 25th, 2021) described above contained two parts: a multiple-choice section and a writing task section. Although the multiple-choice section was identical pre- and post-instruction, the writing task was different on a superficial level. That is, although the writing prompt and instructions were not identical, the prompts can be considered isomorphic (Singh, 2002, 2008) in that both on the pretest and post-test, students were asked to make a lifeworld decision involving nuclear waste. On the pretest, students were asked where radioactive waste should be stored. On the post-test, students were asked whether or not they think nuclear energy can be considered "green energy" as a helpful contributor to meeting climate goals. We will discuss each of these components of the survey in turn. The survey, like the instruction, was conducted in German. Excerpts from the survey and from survey responses reported here were translated by the authors into English.

The multiple-choice section of the survey consists of two prompts, "CAGE" and "Many vs One" (or "MvO"). These prompts aim to investigate how students reason about the decay of an individual nucleus; for example, do students think that half of the nucleus will be "gone" after one half-life has elapsed? The creation of these prompts is motivated by an interview study, and the prompts themselves have been evaluated through survey validation interviews (Hull, Jansky, et al., 2022; Hull & Hopf, 2020). On CAGE, respondents are told that the half-life of I-131 is 8 days and they are asked what day they would go to watch a single I-131 atom decay and why (multiple select). On MvO, respondents are asked how much I-131 would have not yet decayed after one and then two half-lives if one begins with 100 million atoms (MvO:MANY) and if one begins with just one atom (MvO:ONE). For both parts, students are also asked to provide one or more reasons.

Box 1 displays the writing prompt given on the pretest (translated from German into English by the authors):

BOX 1. ***<u>New nuclear waste repository in Austria to be determined by 2024</u>***

Environment Minister Gewessler promised a transparent process. Medicine, industry and research have already filled 12,000 barrels in the Seibersdorf interim storage facility (Jun 20, 2021, 8:56 p.m. 286 posts)

Vienna/Seibersdorf – Environment Minister Leonore Gewessler (Green Party) recalled the new start for a national disposal program for radioactive waste in the ORF program "ZiB 1" on Sunday. The search for a location for a domestic nuclear waste repository actually started in 2018, the waste has been stored at the Seibersdorf site in Lower Austria since 1974, and around 12,000 barrels, each with a capacity of 200 liters, are now in the interim storage facility.

© derstandard.at, https://www.derstandard.at/story/2000127570300/neues-atommuell-endlager-in-oesterreich-soll-bis-2024-fixed-been (last accessed on October 28, 2021)

Write a blog post (150 words maximum) about this article, addressing the following points:

- *Give reasons why, in your opinion, such a repository is necessary*
- *Describe which requirements, in your opinion, the location of the repository should meet*
- *Assess where you think this should best be built*

Since this writing task came immediately after the CAGE and MvO prompts in the survey, we anticipated that some students would mention half-life in the writing task (for example, in discussing the requirements of the storage facility) despite not having learned the concept formally in class. On the post-test, the writing task again came immediately after the multiple-choice prompts, and the survey itself came only a few days after instruction on half-life, so we expected to find many more references to half-life in the writings. The writing task for the post-test is given in **Box 2**:

BOX 2. *Radioactive waste: WWF warns against green classification of nuclear power*

There are efforts to classify nuclear energy as well as gas as "green" energy. However, radioactive waste is still a problem when it comes to disposal.

Environmental organizations warn the European Commission against classifying nuclear power and natural gas as environmentally friendly energies. Such a step would contradict the measures needed to limit climate change to 1.5 degrees, said Sébastien Godinot from the WWF on Thursday. The inclusion of nuclear power and natural gas in the so-called EU taxonomy would be "grossly irresponsible," said Greenpeace activist Silvia Pastorelli. The background to this is ongoing work by the EU Commission on a classification system for sustainable investments. This classification system should give investors clear guidelines as to which investments are considered climate-friendly - the label therefore offers enormous financial advantages.

© https://www.nau.ch/news/europa/radioaktiver-Waste-wwf-warnt-vor-gruner-einsetzung-der-atomkraft-66038700

Write a blog post (150 words maximum) about this article, addressing the following points:

- *Give reasons why "nuclear power" could be classified as environmentally friendly energy*
- *Describe the problems caused by radioactive waste*
- *Assess whether, in your opinion, "nuclear power" can contribute to meeting the climate targets*

Evaluation of survey responses

In this study, we were interested in whether conceptual understanding about half-life would influence student writing. In particular, we were interested in whether or not improved understanding about half-life would result in writing responses that were more likely to utilize the content that had been learned in instruction. We operationalized "understanding about half-life" in terms of providing a correct response on the first tier (the answer) for MvO and in terms of *not* providing an incorrect response on the second tier (the reason) for CAGE.[2] Specifically, responses to MvO:MANY that there would be 50 million I-131 atoms after 8 days and 25 million I-131 atoms after 16 days were coded as "correct" and "incorrect" otherwise. Similarly, responses to MvO:ONE that there would be "1 or 0" I-131 atoms after 8 days and after 16 days were coded as "correct" and "incorrect" otherwise. Selecting any of the following responses to CAGE resulted in the response being coded as "incorrect" (and "correct" otherwise): "the atom transforms continuously," "after the half-life, half of the atom will have transformed," "the atom transforms on the day of the half-life."

[2] The first tier of CAGE is not coded, as valid student reasoning was observed for each of the tier 1 selections (Hull, Jansky, et al., 2022).

For assessing the writing task responses, M.M.H. and F.B. began by individually writing what they would consider to be an ideal response to the task and then compared their responses with each other. On the post-test, for example, we both had the following four points, and so we considered that these four points should be in the responses to warrant full credit:

1. Nuclear power plants give off little CO_2 emissions
2. Society does not yet have a solution to the waste
3. Waste has a long half-life (which we flagged as being most important, considering the previous instruction on half-life)
4. The storage facility needs to withstand a long test of time. We considered this fourth point to be an add-on to the third. In other words, we felt that this fourth point could not stand alone as a substitute for the third point, as students should explain in their writings *why* the waste needs to be stored for a long time.

We then met with the third author, R.K., to gain her insights into what should be evaluated in scientific writing. Generally, in addition to the content knowledge F.B. and M.M.H. had identified as being important, effective scientific writing should also be coherent, have an appropriate structure and layout, and utilize appropriate scientific terminology. We should also assess whether or not the student had fulfilled the assigned writing task in the first place. We began with the L2 (second language) / B2 (language level) rubric used in the scoring of the high school graduation exams in Austria (the *Matura*) and other scoring rubrics for text production (e.g., TOEFL) in order to devise an appropriate assessment grid for the analyzed texts (Brown & Abeywickrama, 2010). Although the essays were written in German, we justified using rubrics established for assessing second language proficiency, as education researchers have argued that learning scientific language is similar to learning a foreign language; whilst scientific language is a register of the standard variation, learning to use the subject-specific lexis and syntax has parallels to second language learning (Butler & Goschler, 2019; Petersen & Tajmel, 2015; Rösch, 2011; Tajmel, 2017). The initial rubric consisted of four categories:

1. task achievement,
2. organization and layout,
3. lexical and structural range, and
4. lexical and structural accuracy.

We attempted to code the first respondent on the pretest together to clarify misunderstandings regarding the rubric. In so doing, we found it difficult to reach agreement on what would be appropriate language targets (since it is for an online blog). R.K. felt the written responses should contain three paragraphs (as students are asked to answer three points), but the "ideal responses" produced by F.B. and M.M.H. had been just a single paragraph. Generally, we felt that the texts were too short for the rubric to be very useful as is. Inspired from those four assessment categories of the B2 writing rubric, we created our own four categories, which we planned to assess using evaluative qualitative text analysis (is the category criteria met completely, partially, or not at all?):

1. Task achievement: all three questions answered = 2 points; only one or two questions answered = 1 point; no questions answered = 0 points
2. Organization: clear and systematic = 2 points; somewhat clear/systematic = 1 point; random without logical connection = 0 points
3. Language features: appropriate scientific language and complex sentence structure = 2 points; somewhat appropriate scientific language/ complex sentence structure = 1 point; everyday language = 0 points
4. Subject matter knowledge (based upon the earlier discussion of F.B. and M.M.H. in comparing their "ideal responses": More than two half-lives are necessary before the waste is safe, specify what the facility must be able to withstand (e.g., earthquakes) = 2 points; vague ideas (e.g., storage facility must last a "long time") = 1 point; incorrect (e.g., "the radioactive waste will soon explode, so a tight but short-term storage structure is what is needed") = 0 points

All three authors coded the first ten pretest responses independently. There were a total of 40 codes (4 categories per respondent) that each of us assigned. On only 12 codes did we reach perfect agreement between all three raters (Cohen's Kappa = 0.34). We had a strong disagreement (where at least one coder assigned 2 points when at least one other coder assigned 0 points) on 4 codes. For example, SA26 was awarded 2 points for Organization (due to its coherence) by two of us and 0 points (due to lacking cohesion in terms of sentences connecting to each other via signposts) by the third. We settled on awarding 1 point and modified our coding scheme to account for both coherence and cohesion (see below).

Pretest, SA26: *Of course, such a repository is necessary, it is even urgently needed. There is a difference between "normal" and nuclear waste. While the normal one can theoretically be stored anywhere, this is not possible with atomic ones because of the radioactive radiation. This waste should therefore end up in repositories that are as far away from people as possible. It should also be noted that radioactive radiation is not good for groundwater. This waste is also quite unfavorable for food - see the radioactive mushrooms after Chernobyl. The repositories should therefore be as sealed off as possible and secured as well as possible. What we should avoid, however, is France's approach, which is to throw the waste into the sea (or into lakes in our case). That harms namely the fish, algae, etc. So we need an isolated place where the rubbish doesn't harm anyone.*

The remaining 24 codes were smaller disagreements where no labels differed by 2 points. For example, SO17 was awarded 2 points for Language by two of us and 1 point by the third:

Pretest, SO17: *Dear Ladies and Gentlemen,*

Radioactive waste is known to be a lengthy and extremely present dilemma in today's society. Therefore, correct and careful handling, as Leonore Gewessler already said, is necessary. Complex catastrophes like those in Chernobyl or Fukushima must of course be avoided at all costs. Shouldn't that be our top priority? A suitable location for storing this threat must be carefully selected and chosen with care. From this it can be concluded that, if possible, an uninhabited area that is not often hit by natural disasters is chosen as the winner.

With the exception of the Language code for SO17, we reached consensus on the remaining 27 disagreements. This discussion also resulted in several modifications and specifications added to the coding scheme. First and foremost, motivated by the fact that there was greatest disagreement (8 out of 10 codes) with the Language labels, and justified by the fact that the first two authors are not language teachers and found it too difficult to disentangle language skills from science writing skills, we decided not to code for "language" and only to code for "achievement", "organization", and "subject matter knowledge". In addition, we made the following specifications to the remaining codes:

- Achievement: many students conflated the second and third questions, and may have thought they were answering the question about "where to put the waste" by specifying that it should be away from people (and also simultaneously thought that it answers the question pertaining to "what properties should the facility have?"). These students should not receive full points. We also noted that if achievement is 0, then Organization and Subject Matter Knowledge are to receive the label "too little to code".
- Organization: we recognized that there are different ways to interpret "clear and systematic": one interpretation is "is it clear which question is being answered in each sentence?" An additional interpretation is "does the writing read like a good story (is the order of sentences sensible, is the writing cohesive and coherent?)". We found it important in this latter interpretation to distinguish between cohesive and coherent. A written passage is cohesive if linking words are used, even if the writing is not coherent (which is when it makes sense content wise). For this cohesion, it is important for the sentences to refer to each other, using linguistic "signposts". We decided that for a written passage to receive 2 points for organization, the writing must i) have it be clear which question is being answered in which sentence, ii) use signposts, and iii) be coherent (make sense).
- Subject matter knowledge: we decided that, since (as discussed in the introduction), content knowledge is rarely used in student written text, everyone who used science content about half-life would receive full (2) points; 1 point would be given if anything is correct and relevant about radioactive waste.

After this discussion and clarification of our coding labels between all three authors, M.M.H. and F.B. then independently coded the remaining 9 pretest responses. Out of a total of 27 codes (3 categories for each respondent), we reached perfect agreement on 22 codes (81%, Cohen's kappa

= 0.79: "substantial agreement") and had no strong disagreements on the remaining 5 codes, which were codes pertaining to *Organization* (2 codes) and *Subject Matter Knowledge* (3 codes). After discussion, we reached consensus on all codes and made final modifications to the coding scheme:

- *Achievement*: Full credit requires: 1) Reasons why a storage facility is necessary, 2) What properties the storage facility must have (being "far from people" is sufficient), 3) Where the facility should be located ("in the countryside" is sufficient and distinguishable from "far from people").
- *Organization*: a pronoun is insufficient to be considered a "signpost". Rather, clauses that connect sentences or preface sentences are needed. Points assigned are not affected by layout: students can answer in a single paragraph, three paragraphs, or three bullet points.
- *Subject matter knowledge*: many students said that it is important for the waste to be stored someplace far away from the water table, and this should receive 1 point as being knowledge about the topic. On the other hand, saying that the waste should be stored some place "away from rivers" is insufficient because students may mean this just in a spirit of "there is life also in the rivers, and so we shouldn't put bad stuff into it". Although this latter response would warrant 1 point from "Achievement" (answering where the facility should be located), it would not simultaneously warrant a point from "Subject matter knowledge."

M.M.H. then applied this finalized coding rubric to the original 10 pretest responses to ensure that no decisions made during round 1 contradicted the changes to these categories from round 2. He then coded the post-tests using this finalized scoring rubric.

Results

The results of our study are summarized in **Table 1**. Our sample size from this pilot study is small, and our goal in this paper is just to discuss general trends in student responses. We chose not to perform statistical tests because the proportions are too small to perform χ^2 tests of distinguishability. Furthermore, our primary finding is one that requires no formal statistical support: as can be seen in **Table 1**, *no* students received full marks on the post-test for subject matter knowledge coding of the writing task.

Despite the technical difficulties that arose from the last-minute requirement of teaching in a hybrid format, we see that the lesson succeeded in helping students progress in their understanding about half-life. Specifically, looking at the two left columns of **Table 1** (MvO:MANY), we see that students SY20, EV23, and UR06 were able to correctly answer on the post-test that there would be 50 million I-131 atoms after 8 days and 25 million after 16 days, although they had not answered correctly on the pretest. Looking at the next two columns (MvO:ONE), we see that BA28, SY20, EV23, TE28, and UL18 answered correctly on the post-test (and not the pretest) that there would be 1 or 0 I-131 atoms remaining after 8 days and after 16 days. Although ideas about "the atom transforms continuously," "after the half-life, half of the atom will have transformed," and "the atom transforms on the day of the half-life" remained attractive to students (as evidenced by the lack of change on CAGE, the next two columns in **Table 1**), we see that, as measured by MvO, the majority of students left the instruction on half-life with an acceptable understanding of the topic: although it is unpredictable when a given nucleus will transform, we can predict the length of time necessary for half of the sample to do so. A natural implication of this that we wanted to see in the student writings is the idea that radioactive waste will not be "all gone" even after two half-lives have passed, resulting in waste storage facilities needing to survive a very long test of time. However, as the right-most column in **Table 1** indicates, no students mentioned half-life on the post-test (and hence did not receive full points in the "Subject matter knowledge" category).

Table 1. Labels given to survey responses to the multiple-choice conceptual questions about half-life (left three boxes) and to free-response essays about radioactive waste (right three boxes).

	Conceptual Understanding of Half-Life						Writing about Radioactive Waste					
	MANY		ONE		CAGE		ACHIEVE		ORGANIZE		KNOW	
Student	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
GI24	1	1	0	0	0	0	2	2	2	2	2	1
SE08	1	1	0	0	0	0	1	1	1	1	1	1
BA28	1	1	0	1	0	0	2	2	2	2	1	1
EV04	1	1	1	1	1	1	2	2	2	2	1	1
CH23	1	1	1	1	1	1	2	1	1	1	1	1
SY20	0	1	0	1	1	1	2	1	2	2	1	1
GI27	1	1	0	0	1	1	1	1	2	2	0	1
EV23	0	1	0	1	1	1	1	2	1	2	0	1
MA16	1	1	1	1	0	0	2	2	1	2	1	1
SA26a	1	1	1	1	0	0	1	2	2	2	1	1
NA26	1	1	0	0	0	0	1	1	1	0	0	1
BR08	0	0	0	0	0	0	1	2	2	2	1	1
TE28	0	0	0	1	0	0	2	2	1	2	1	1
UR06	0	1	1	1	1	1	1	1	2	1	1	1
UL18	1	1	0	1	1	0	0	2		2		1
MI12	0	0	0	0	0	1	1	1	1	1	1	1
ES12	1	1	1	1	1	1	2	2	2	1	1	1
SA26b	1	1	1	1	0	0	2	1	1	1	0	1
SO17	1	1	0	0	0	0	1	1	1	2	1	1
ED03		0		0		0		2		2		1
RU09		1		1		1		1		1		1

Note: Improvement on the post-test (right column of each box) is indicated with green shading. Note that students ED03 and RU09 were absent from class when the pretest was administered. Note also that, as UL18 received a label of "0" for the pretest essay Achievement score, the Organization and Knowledge scores were coded as N/A as there was too little to code.

Discussion

Henriksen (1996) speculated upon the issue of students choosing not to apply the science content they had learned to questions about real-life situations involving radioactivity:

> For instance, one of the respondents was able to give excellent 'classroom' definitions of becquerel, alpha, beta and gamma radiation, but nevertheless stated in a subsequent question that meat became radioactive after the Chernobyl disaster 'because the animals ate food which had been irradiated', thereby betraying that the confusion between radiation sources and radiation was still present. Thus, the answers to the questions concerning real-life situations which had been treated in the media, might not measure what the school education had taught the students, but rather what the media had taught them.

It seems likely, however, that many students would not have found "definitions of becquerel, alpha, beta, and gamma radiation" to be helpful in answering questions about "meat… after the Chernobyl disaster" due to purely conceptual reasons: the concepts of 1) radiation properties and 2) the effects of radiation on matter may be too distant from each other in student reasoning. In our study, on the other hand, we had students respond to a real-life prompt that is, from a purely conceptual perspective, tightly connected to the "classroom" knowledge they had learned; namely, both concerned the concept of half-life. Our decision to put the writing tasks immediately after the multiple-choice questions on the survey was intentional: we wanted to make the idea of half-life as salient in student minds as possible when they began their writing. Nevertheless, students did not pick up on this "hint" to use the answers they had just provided on the prior pages in the writing task. As can be seen in comparing individual students' scores on the conceptual questions about half-life and the subject matter knowledge score of the essay, it is not the case that knowledge about half-life was unavailable to students. Rather, it is that they did not access that knowledge in the writing task. The content they had learned in the classroom was *omitted*.

Just as the issue was not a lack of conceptual understanding, so too was it not a deficit in general writing ability. On the post-test, just under half (10/21) of the students received full points for both task achievement and organization. In terms of the *Matura* B2 writing rubric from which our rubric originated, almost all students would pass. Although a follow-up interview study is needed to investigate the issue more carefully, we suspect that students did not write about half-life when talking about radioactive waste because they did not think the concept is important for discussing the issue.

Conclusion and limitations

In our study, we saw that even students who "understand" half-life (as evidenced by their multiple-choice responses) did not use the idea in their writing. This was true even soon after successful instruction (as evidenced by the increase in correct scores on the multiple-choice questions) on half-life. The issue, we saw, is not that students are incapable of writing; even the best essays that would otherwise get full points did not mention half-life. Rather, we hypothesize that the issue is an epistemological one, relating to what students perceive to be the nature of the knowledge they have learned; namely, students do not think that the concept of half-life is important for discussing these issues, at least in the context of a social media forum.

In response to concerns that traditional science assessments of free response and short answer questions restrict students from expressing the depth and nuance of their conceptual understanding, writing and writing assessment has become a growing area of interest in science education research (Wallace et al., 2004). It is important to bear in mind, however, that students may have an understanding about a topic that even a writing task is not successful at eliciting. As Eijkelhof and Millar pointed out about science writers discussing Chernobyl (Eijkelhof & Millar, 1988), the writing of authors is shaped by their image of their target audience and by their image of what the intention of the writing task is. This has implications for assessment of student understanding through writing tasks. What a student does or does not write about is not a direct indicator of what is in the mind of students. "Student responses don't simply represent activations of their stored knowledge. They are dynamically created in response to their perception of the task and what resources are appropriate to bring to bear" (Redish, 2014).

Our conclusions should be considered with the limitations of the study in mind. We only had a limited sample of 20 students from one class in one school in Vienna. A larger sample of randomly selected students from different schools would have made our study more representative. Furthermore, students were not very motivated for the writing tasks, especially in the posttest. This was mainly because they knew that the study would not affect their grade in physics. Therefore, some of them did not address all three points specified in the task or wrote less than the requested 150 words. This made coding more difficult (*e.g.*, as seen in **Table 1**, one student did not write enough for the authors to assign scores to the essay's organization and demonstration of subject matter knowledge). If their performance in the pre- and posttest would have contributed to their grade, students very likely would have shown more effort in writing the postings. As discussed above, the instructional intervention had to be adapted to a hybrid format on very short notice due to COVID-19 regulations. Although F.B. tried to adapt teaching to this situation, it cannot be determined if the students who followed the lesson online had the same learning experiences as the students in class. However, as none of the students used the concept of half-life in their writing in the posttest, we assume that there were no major differences between those two groups.

Future research

In this study, we did not provide the students with much scaffolding to produce their texts. As a rule, learners are not accustomed to transferring text-types learned in language classes into the natural science classroom. Consequently, they may not be aware of subject-specific language that is appropriate to use in these texts and thus feel overwhelmed. Future studies should offer both subject-specific and linguistic scaffolding to the students to see how performance is improved. It would also be interesting to see if students were more likely to discuss half-life if given a different target audience in the writing task (such as a panel of experts). Finally, it would be valuable to interview the participating learners to see how salient the ideas of half-life are in the interview context, and to ask them who do talk about half-life in person why they did not write about it.

Declaration of Interests

The authors have no competing interests to declare.

References

Adams, W. K., Perkins, K. K., Podolefsky, N. S., Dubson, M., Finkelstein, N. D., & Wieman, C. E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado learning attitudes about science survey. *Physical Review Special Topics - Physics Education Research*, *2*(010101), 1–14. https://doi.org/10.1103/PhysRevSTPER.2.010101

Bishop, K., & Denley, P. (2007). *Learning science teaching*. Maidenhead, England: McGraw Hill/Open University Press.

Bonnet, A. (2004). *Chemie im bilingualen Unterricht*. VS Verlag für Sozialwissenschaften.

Brown, H. D., & Abeywickrama, P. (2010). *Language assessment: principles and classroom practices*. White Plains, NY: Pearson Education.

Butler, M., & Goschler, J. (2019). *Sprachsensibler Fachunterricht*. Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-27168-8

Carlson, J., Daehler, K. R., Alonzo, A. C., Barendsen, E., Berry, A., Borowski, A., Carpendale, J., Chan, K. K. H., Cooper, R., Friedrichsen, P., Gess-Newsome, J., Henze-Rietveld, I., Hume, A., Kirschner, S., Liepertz, S., Loughran, J., Mavhunga, E., Neumann, K., Nilson, P., … Wilson, C. D. (2019). The refined consensus model of pedagogical content knowledge in science education. In A. Hume, R. Cooper, & A. Borowski (Eds.), *Repositioning Pedagogical Content Knowledge in Teachers' Knowledge for Teaching Science* (pp. 77–94). Singapore: Springer. https://doi.org/10.1007/978-981-13-5898-2_2

Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics*, *69*(9), 970–977. https://doi.org/10.1119/1.1374249

Cummins, J. (2000). Language, power and pedagogy. In *Bilingual Education et Bilingualism*. Multilingual Matters. https://doi.org/10.21832/9781853596773

Dalton-Puffer, C. (2008). Outcomes and processes in Content and Language Integrated Learning (CLIL). current research from Europe. In W. Delanoy, & L. Volkmann (Eds.), *Future Perspectives for English Language Teaching* (pp. 139–157).

Eijkelhof, H. (1986). Dealing with acceptable risk in science education: the case of ionizing radiation. In M. J. Frazer, & A. Kornhauser (Eds.), *Ethics and social responsibility in science education* (pp. 189–199). Pergamon. https://doi.org/10.1016/B978-0-08-033911-5.50029-8

Eijkelhof, H. M. C. (1990). *Radiation and risk in physics education*. Utrecht: CD-β Press.

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

Eijkelhof, H., & Millar, R. (1988). Reading about Chernobyl: the public understanding of radiation and radioactivity. *School Science Review*, *70*(251), 35–41.

El-Showk, S. (2022). Final resting place. *Science*, *375*(6583), 806–810. https://doi.org/10.1126/science.ada1392

Halloun, I., & Hestenes, D. (1998). Interpreting VASS dimensions and profiles for physics students. *Science Education*, *7*, 553. https://doi.org/10.1023/A:1008645410992

Hammer, D. (1989). Two approaches to learning physics. *The Physics Teacher*, *27*, 664–670. https://doi.org/10.1119/1.2342910

Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction*, 12(2), 151–183. https://doi.org/10.1207/s1532690xci1202_4

Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2006). Resources, framing, and transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (Vol. 1, pp. 89–121). IAP.

Hedge, T. (2019). *Teaching and learning in the language classroom*. Oxford University Press (Oxford English).

Henriksen, E. K. (1996). Laypeople's understanding of radioactivity and radiation. *Radiation Protection Dosimetry*, 68(3–4), 191–196. https://doi.org/10.1093/oxfordjournals.rpd.a031863

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88-140. https://doi.org/10.2307/1170620

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

Hull, M. M., & Hopf, M. (2022). *Vor- und Nachteile gängiger Analogien in der Radioaktivität*. Plus Lucis.

Hull, M. M., Holzinger, E., Jeidler, M., & Wintersteller, M. (2022). Student understanding of half-life and background radiation. *PhyDid B - Didaktik der Physik - Beiträge zur DPG-Frühjahrstagung*, 267–273.

Hull, M. M., Jansky, A., & Hopf, M. (2021). Probability-related naïve ideas across physics topics. *Studies in Science Education*, 57(1), 45–83. https://doi.org/10.1080/03057267.2020.1757244

Hull, M. M., Jansky, A., & Hopf, M. (2022). Does confidence in a wrong answer imply a misconception? *Physical Review Physics Education Research*, *18*(2), 020108. https://doi.org/10.1103/PhysRevPhysEducRes.18.020108

Hutchison, P., & Hammer, D. (2010). Attending to student epistemological framing in a science classroom. *Science Education*, *94*(3), 506–524. https://doi.org/10.1002/sce.20373

International Atomic Energy Agency. (2017). *How nuclear power helps meet global energy demand the role of the IAEA.*

Jansky, A. (2019). *Die Rolle von Schülervorstellungen zu Wahrscheinlichkeit und Zufall im naturwissenschaftlichen Kontext* [Doctoral dissertation, University of Vienna].

Klaassen, C. W. J. M., Eijkelhof, H. M. C., & Lijnse, P. L. (1990). Considering an alternative approach to teaching radioactivity. In P. L. Lijnse, P. Licht, W. de Vos, & A. J. Waarlo (Eds.), *Relating macroscopic phenomena to microscopic particles: A central problem in secondary science education* (pp. 304–315). Utrecht: CD-β Press.

Kniffka, G. (2013). Scaffolding - Möglichkeiten, im Fachunterricht sprachliche Kompetenzen zu vermitteln. In M. Michalak, & M. Kuchenreuther (Eds.), *Grundlagen der Sprachdidaktik Deutsch als Zweitsprache* (pp. 208-225). Baltmannsweiler: Schneider Verlag Hohengehren.

Kowalski, L. (1981). Simulating radioactive decay with dice. *The Physics Teacher*, *19*(2), 113. https://doi.org/10.1119/1.2340711

Laszlo, P. (2013). Towards teaching chemistry as a language. *Science & Education*, *22*(7), 1669–1706. https://doi.org/10.1007/s11191-011-9408-6

Lising, L., & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics*, *73*(4), 372-382. https://doi.org/10.1119/1.1848115

Lloyd, P., & Fernyhough, C. (1999). Lev Vygotsky. In *Critical assessments of leading psychologists*. Routledge. http://www.worldcat.org/oclc/772310840

Lucas, A. M. (1987). Public knowledge of radiation. *Biologist (London)*, *34*(3), 125–129.

Markic, S., Broggy, J., & Childs, P. (2013). How to deal with linguistic issues in chemistry classes. In I. Eilks & A. Hofstein (Eds.), *Teaching Chemistry – A Studybook. A Practical Guide and Textbook for Student Teachers, Teacher Trainees and Teachers* (pp. 127–152). Rotterdam: SensePublishers (Educational Research E-Books Online, Collection 2005-2017). https://doi.org/10.1007/978-94-6209-140-5_5

Mönch, C., & Markic, S. (2022). Science teachers' pedagogical scientific language knowledge—A systematic review. *Education Sciences*, *12*(7), 497. https://doi.org/10.3390/educsci12070497

Organisation for Economic Co-operation and Development (OECD). (2016). *Uranium 2016: resources, production and demand.*

Paltridge, B. (1996). Genre, text type, and the language learning classroom. *ELT Journal*, *50*(3), 237–243. https://doi.org/10.1093/elt/50.3.237

Perkins, K., & Gratny, M. (2010, July 21-22). Who becomes a physics major? A long-term longitudinal study examining the roles of pre-college beliefs about physics and learning physics, interest, and academic achievement. *Proceedings of the 2010 Physics Education Research Conference, Portland, Oregon*, 253–256.

Perkins, K., Gratny, M., Adams, W. K., Finkelstein, N. D., & Wieman, C. E. (2005, August 10-11). Towards characterizing the relationship between students' interest in and their beliefs about physics. *Proceedings of the 2005 Physics Education Research Conference, Salt Lake City, Utah*, 137–140.

Petersen, I., & Tajmel, T. (2015). Bildungssprache als Lernmedium und Lernziel im Fachunterricht. In *Bildungssprache als Lernmedium und Lernziel im Fachunterricht* (pp. 84–111).

Prather, E. E. (2000). *An investigation into what students think and how they learn about ionizing radiation and radioactivity* [Doctoral dissertation, The University of Maine].

Prather, E. E. (2005). Students' beliefs about the role of atoms in radioactive decay and half-life. *Journal of Geoscience Education*, *53*(4), 345–354. https://doi.org/10.5408/1089-9995-53.4.345

Redish, E. F. & Hammer, D. (2009). Reinventing college physics for biologists: Explicating an epistemological curriculum. *American Journal of Physics*, *77*(7), 629-642. https://doi.org/10.1119/1.3119150

Redish, E. F. (2003). *Teaching physics with the physics suite.* John Wiley & Sons Inc.

Redish, E. F. (2004). *A theoretical framework for physics education research: Modeling student thinking.* Arxiv. https://arxiv.org/abs/physics/0411149

Redish, E. F. (2014). Oersted lecture 2013: How should we think about how our students think? *American Journal of Physics*, *82*(6), 537-551. https://doi.org/10.1119/1.4874260

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1998). Student expectations in introductory physics. *American Journal of Physics*, *66*(3), 212-224. https://doi.org/10.1119/1.18847

Rösch, H. (2011). Deutsch als Zweit- und Fremdsprache. In *Akademie Studienbücher - Sprachwissenschaft.* Akademie Verlag. https://doi.org/10.1524/9783050052816

Rosenberg, S., Hammer, D., & Phelan, J. (2006). Multiple epistemological coherences in an eighth-grade discussion of the rock cycle. *Journal of the Learning Sciences*, 15(2), 261-292. https://doi.org/10.1207/s15327809jls1502_4

Singh, C. (2008). Assessing student expertise in introductory physics with isomorphic problems. I. Performance on nonintuitive problem pair from introductory physics. *Physical Review Special Topics-Physics Education Research*, 4(1), 010104. https://doi.org/10.1103/PhysRevSTPER.4.010104

Singh. (2002). When physical intuition fails. *American Journal of Physics*, *70*(11), 1103-1109. https://doi.org/10.1119/1.1512659

Tajmel, T. (2017). *Naturwissenschaftliche Bildung in der Migrationsgesellschaft.* Wiesbaden: Springer VS. https://doi.org/10.1007/978-3-658-17123-0

United Nations. (2015). *Resolution adopted by the general assembly on 25 September 2015 70/1. Transforming our world: the 2030 Agenda for Sustainable Development.*

van Lier, L. (1996). *Interaction in the language curriculum: Awareness, autonomy and authenticity.* London: Routledge. https://doi.org/10.4324/9781315843223

Wallace, C. S., Hand, B., & Prain, V. (2004). *Writing and learning in the science classroom.* Springer Dordrecht. https://doi.org/10.1007/978-1-4020-2018-6