The Influence of "The Radiation Around Us" on Student Conceptual Understanding and Interest

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Abstract

The MS thesis of the first author focuses on a special method of teaching called "Hypothesis–Experiment Class" (HEC), developed in Japan by Kiyonobu Itakura. In this method, the teacher is provided with a "Classbook" with which to conduct the lesson. In HEC, students are asked a question and choose between several possible answers. The number of votes for each answer choice is recorded on the blackboard. Individual learners are asked to explain why they chose one of the answer options. Afterwards, all learners have the opportunity to change their choice. Finally, an experiment decides which answer was the correct one. This process is repeated in a cycle with new questions and experiments. HEC has three goals (Itakura, 2019, p. 19-23): 1. make sure each and every student gains the ability to use the central theory or concept. 2. structure the class so that most students report that they like both science and these science classes. 3. make all necessary preparations so that any teacher sufficiently passionate about education, not just special veteran teachers, will be able to teach this type of class. In my work, I will focus on the first and second goals for the Classbook "The Radiation Around Us" (TRAU), which deals with where ionizing radiation can be found in what amounts in our everyday life. The third goal of HEC is discussed in the accompanying paper first-authored by Markus Wintersteller.

1. Introduction

The MS theses of the first and second authors concern assessment of a Japanese instructional module on radioactivity; in particular, the first author aims to see how effective this module is when used with Austrian school children. The module (“The Radiation Around Us”, abbreviated “TRAU”) is an excerpt from a larger module created by Yamamoto in 2011 titled “Radiation and Sievert” (Yamamoto, 2011). Although some studies were conducted during the creation and revision of Radiation and Sievert, they were primarily unpublished and anecdotal in nature. Likewise regarding TRAU, there is a paucity of data regarding whether the curricular goals are being met, and this is a gap that our study sets out to fill. As we will discuss more in the Methodology section, we draw upon the pretest / post-test paradigm of physics education research (PER) to compare learning outcomes of students who learn with TRAU to those of students who don’t. This study is relevant, as it can inform future curricular decisions in Austrian schools (for example, in the most extreme case, wide-spread adoption of TRAU).

Radiation and Sievert (and, by extension, TRAU) are examples of Hypothesis–Experiment Class (HEC), an educational approach developed by Kiyonobu Itakura that is well known throughout Japan. As the name suggests, the carrying out of experiments and the building of hypotheses (informed by the outcomes of those experiments) play a central role in HEC. The writings of Itakura about HEC have recently been translated into English and compiled in a book that is commercially available. According to this book, HEC concerns itself with learners developing "mental recognition", also referred to as "investigated perception" (Itakura, 2019, p. 4), which "requires the perceiver to conduct some action with intent to confirm something about the object" (Itakura, 2019, p. 3). HEC defines “experiment” from this theoretical stance as being a special form of observation that involves a specific intention to investigate (Itakura, 2019, p. 4). In the HEC sense of the word, merely moving physical apparatus around does not suffice to qualify as an “experiment”: the person performing the action must have the intention to find something out. Similarly, merely replicating a natural phenomenon (for example, to demonstrate something in the textbook) is not “conducting an experiment” in the HEC sense of the word (2019, p. 10f). “Hypothesis” in Hypothesis–Experiment Class refers to a "more-or-less general theory or principle" (Itakura, 2019, p. 9). It differs from a simple expectation, which refers only to a single event (Itakura, 2019, p. 9). In HEC, learning is conceptualized as a cyclical process in which experimental results inform the development of hypotheses that then produce expectations about the outcome of the subsequent experiment (Itakura, 2019, p.

9). Itakura described how the HEC conceptualization of learning stands in sharp contrast to approaches in which teachers present students with experimental facts and show how a theory can be derived via an inductive process (Itakura, 2019, p. 10). Imposing a theory upon students like this, Itakura argues, often only results in the theories being rejected by students (Itakura, 2019, p. 11).

Consistent with these definitions, when students conduct an "experiment" in HEC, they should maintain intention behind their investigating. To strengthen this intent, students should make a concrete prediction and specify their "expectation" before the experiment is conducted. In so doing, by the end of the Classbook, students should develop the scientifically accepted theory with which they can then correctly expect the results of the last experiment (Itakura, 2019, p. 12f).

Moreover, HEC emphasizes science as a social process (2019, p. 13). A theory becomes meaningful only when it has been accepted by society, which requires the accumulation of sufficient evidence for the theory to be accepted by each hypothetical individual (Itakura, 2019, p.14). Ideally, students should build their own understanding of a theory as they discuss with each other to reconcile experimental results they have collected with their everyday experiences and naïve ideas that they may bring with them into the classroom (Itakura, 2019, p. 16-17). In the school context, the social aspect of science is highlighted by having Classbooks utilize a whole class discussion format as expectations about experiments are discussed and the experiments are carried out. The concrete procedure is as follows:

First, learners are asked a "Question" or posed a "Problem", generally regarding an experiment that will be conducted. Learners tentatively commit to an "Expectation" of what the outcome of that experiment will be by choosing one possible answer from several options provided to them (multiple choice). The teacher takes a tally of the expectations by having students raise their hands. The teacher then calls on individual learners to explain why they have chosen a particular answer. At the end of this discussion, the teacher invites the learners to change their answer, based upon what had been said in the discussion. Finally, an experiment decides objectively which answer option was the correct one. The result is recorded by the students and the next question is asked. These questions are contained in the Classbook, as are explanations that, generally, learners take turns reading out loud. In this process, teachers are not arbiters of knowledge, but rather facilitators of this cyclical process (Itakura, 2019, p. 25ff). We wish to emphasize how this process is consistent with the background theory behind HEC discussed above. Theories are not imposed upon students by the teacher; rather, hypotheses are developed by the student in a social manner as they make sense of experimental results. The experiments in turn are only conducted if there is a real intention to confirm or refute expectations.

HEC places 3 specific goals on each Classbook:

Goal 1: "Make sure each and every student gains the ability to use the central theory or concept" (Itakura, 2019, p. 20). HEC practitioners generally check this by confirming that more than 90% of the students correctly predict the answer to the last problem in the Classbook. In addition, it is advised to give a test on the material covered one to two weeks after completing the Classbook (Itakura, 2019, p. 20). Problems in the Classbook are carefully chosen and arranged such that this goal can be accomplished. At the same time, HEC urges teachers to refrain from testing students on things not directly discussed in the Classbook.

Goal 2: "Structure the class so that most students report that they like both science and these science classes" (Itakura, 2019, p. 21). The explicit goal is that over 50% of learners report that they "liked" or "really liked" science and the Classbook and that virtually no one reports that they "disliked" the Classbook. To ascertain this, HEC practitioners generally ask students directly whether they enjoyed their learning by having students answer a one-question survey administered immediately after the Classbook has ended (Itakura, 2019, p. 21). This question is referred to as the "tanodo" (Japanese for "degree of fun") survey. Participants choose a selection from a five-point scale, with 1 being "it was very enjoyable" and 5 being "it was very boring".

Goal 3: "Make all necessary preparations so that any teacher sufficiently passionate about education, not just special veteran teachers, will be able to teach this type of class" (Itakura, 2019, p. 22). In short, this means that HEC lessons should be easy to carry out with the help of the Classbook by any teacher, regardless of that teacher's extent of teaching experience.

Itakura claimed that all 3 goals are realistic, describing a study in which 150 school classes and over 20 teachers participated (Itakura, 2019, p. 23). Unfortunately, he did not provide a citation to a published work. Similarly, although he claimed that "almost all classes run with the Classbooks developed ... have demonstrated good reproducibility of class performance, independent of teachers and students" (Itakura, 2019, p. 25), no citation was provided to support this claim.

1.1. Traditional instruction about radioactivity and student views on the topic

Our study aims to assess the effectiveness of TRAU by comparing learning gains of students who learn with TRAU to a control group of students who do not learn with TRAU. Although the notion of a "control group" is problematic in that instruction can vary greatly from class to class within the non-TRAU learners, we can nevertheless describe what typical instruction about radioactivity entails. In 2006, Eijkelhof described "the usual approach" being "to start with the structure of the atom and the nucleus, followed by concepts such as half-life, activity, nuclear fission and fusion. Towards the end of the series of lessons, some applications are usually mentioned, such as carbon dating, irradiation, and the nuclear reactor. Safety issues are dealt with only superficially" (Eijkelhof, 2006, p. 273). If one looks at various Austrian textbooks intended for the 8th grade (when students learn about radioactivity for the first time in their K-12 education), one sees great accord with Eijkelhof's statement, even today. In addition, Austrian textbooks often begin the chapter on radioactivity with historical contexts (see Mašin & Grois, 2020; Barmeier, 2009; Breyer et al., 2011; Apolin, 2018). According to the national curriculum, students are to accomplish the following, either in 12th grade or in 8th grade:

a) Gain insights into changes in the atomic nucleus as the cause of "radioactivity" (properties of alpha, beta and gamma rays);
b) Recognize radioactive decay as a constantly occurring process;
c) Understand the basic processes of energy conversion in the sun, stars, and nuclear reactions (nuclear fusion, nuclear fission).

Unfortunately, traditional instruction about radioactivity seems to do little to improve student understanding about the topic. Slovic found that the public has strong beliefs about the risks associated with radioactivity that differ from the views of experts, for example, by being generally more negative (Slovic, 1996, p. 1). Regarding these ideas, Eijkelhof wrote that “the public has a lot of knowledge and beliefs about radiation risks which in the expert’s view may be wrong and inconsistent, but which are not so perceived by the audience” (2006, p. 277). Both Slovic and Eijkelhof called for radioactivity education to be improved; in particular, Eijkelhof argued that “… most students in Europe are not in school to prepare themselves for future studies in the physical sciences, but to be educated for life in modern society” (Eijkelhof, 2006, p. 273). There is a need for better education regarding radioactivity that is suitable for any student, regardless of the student’s subsequent career choices.

TRAU is very different from the usual path described above. Nuclear decay, which is usually at the beginning of the textbook chapter on radioactivity, plays a subordinate role in the Classbook. In general, technical terms are used rather sparingly (hence the choice of the word “Radiation” in the title instead of “Radioactivity”) and are often only roughly explained. The focus is on the fact that radioactivity is a natural, constantly occurring phenomenon, a fact that we see as necessary knowledge for students who are to be “educated for life in modern society” (Eijkelhof, 2006, p. 273). In so doing, the Classbook primarily addresses the second point in the Austrian curriculum. The first and third points, however, are discussed only marginally. The implication of this is that we must recognize that use of TRAU by itself cannot suffice to “solve the problem” of learning about radioactivity in Austria. Teachers wishing to use the Classbook and satisfy the national curriculum will need to add the missing topics either before or after using TRAU. With this limitation in mind, we begin our study of how effective the Classbook can be to help Austrian students “recognize radioactive decay as a constantly occurring process” that is all around them.

2. Research Design and Methodology

Our research discussed in this paper aims to fill a gap in published literature regarding the effectiveness of TRAU by looking at interest and learning gains of Austrian students who use the Classbook. In so doing, we investigate the extent to which the first and second goals of HEC are met. In comparison with pupils who are not taught with TRAU, we will investigate whether pupils who learn with TRAU exhibit a significantly greater gain in conceptual understanding. In addition, we will investigate whether students who learn with TRAU enjoy the radioactivity instruction more than students who learn without the Classbook. We predict that pupils who learn with TRAU will better develop an understanding of radioactivity as a natural, constantly occurring phenomenon. We also predict that pupils will enjoy learning with the Classbook.

So far, we have collected most of the data from students learning with TRAU as well as pretest data from the non-TRAU learners (the “control group”). We used TRAU with six cohorts of students in the 8th grade (when they first learn about radioactivity in school). Four of these cohorts were from a single Gymnasium and the remaining two cohorts were from a single Mittelschule. Four of these six cohorts have already completed all questionnaires. The control group is comprised of an additional six cohorts of 8th grade students from two additional Gymnasien.

Because TRAU does not discuss all topics required by the national curriculum, teachers who used TRAU were asked to begin their instruction with the Classbook and to then supplement with instruction on the other topics listed in the national curriculum at their own discretion. In the control groups, no particular instruction was given; the entirety of the instruction about radioactivity was at the teacher’s discretion.

We utilize a variety of multiple choice surveys to address our research questions. To assess increase in understanding about radioactivity, we prepared a conceptual survey with items taken from the questionnaire developed by Holzinger in her MS thesis (2022). This survey addresses various topics pertaining to radioactivity, including topics that TRAU directly discusses as well as topics that are not discussed by TRAU at all. Students take this conceptual survey as a pretest before learning about radioactivity and as a post-test within a two-week interval after instruction about radioactivity has ended. In Figure 1 below are two example items from the conceptual survey for which we expected a relatively large increase in the experimental group.

Q.1) Du siehst nun eine Reihe von Begriffen. Kreuze alle Begriffe an, bei welchen ein Messgerät für Radioaktivität klicken würde. Mehrfachantwort möglich.

Smartphone; Umgebungsluft; Ein Schulkind; Betonwände in der Rezeption eines Krankenhauses; Betonwände eines Krankenhausraumes, in dem Röntgenaufnahmen gemacht wurden; Betonwände eines Schulgebäudes; Zigarettenrauch; Sonnenlicht; Popcorn aus der Microwelle; Banane

Q.10) Wie verändert sich die Strahlung in einem Flugzeug im Vergleich zum Boden?
A) Sie nimmt mit der Höhe zu
B) Sie nimmt mit der Höhe ab
C) Sie bleibt gleich
D) Keine der Antwortmöglichkeiten ist richtig

Fig. 1: Two items from the conceptual survey for which we expected students learning with TRAU to significantly outperform students in the control group.

To assess the HEC goal that learners come to enjoy both science and the Classbook, we examine also the self-concept and interest of learners. For interest, we utilize relevant items from the IPN interest study (Hoffmann et al., 1998). We administer these items at the same time as the conceptual survey just discussed. In addition, with the experimental groups, we administered the interest and self-concept survey also immediately after completing learning with TRAU. This was done to determine more precisely what effect TRAU had on interest and self-concept, as opposed to the rest of the lessons on radioactivity that followed TRAU. All items on interest and self-concept are multiple choice, with a 5-point Likert scale. In addition, we also included the "tanodo" question used in HEC (see above) in this post-TRAU questionnaire and on the post-test.

Students complete all questionnaires online while sitting in the classroom by following a link provided to them by their teacher. Students enter both a class code and a person code to protect their anonymity while still enabling us to compare pre and post-test scores between the TRAU and control groups.

As the post-test data from all control groups has not yet been collected, we are limited in what claims we can make in this paper. Nevertheless, we are at a point where we can talk about learning gains for the students who did learn with TRAU. We analyse our data using classical test theory. In particular, we calculate mean values and standard deviations for each item. Regarding the conceptual survey, we awarded no more than one point for each survey item. On some items, several answer selections are considered correct and one point is awarded if the respondent chooses any of those selections. With other items, respondents must select all of the correct answers to receive one point; otherwise, their response is scored as zero points. In Q.1 of the conceptual survey (see above), for example, respondents receive one point only if all answer options are ticked. To see which answer options were preferentially ticked before and after instruction, we examine also a frequency graph for each selection.

3. Results

To date, 76 students from the experimental group have completed the pretest, 69 the intermediate test that immediately followed instruction with TRAU, and 72 the post-test questionnaires. The numbers vary because some pupils were absent from class when a given questionnaire was administered. So far, 113 pupils from the control group have completed the pretest questionnaire and no one has completed the post-test questionnaire (recall that the intermediate test is only taken by students who learn with TRAU). Therefore, it is not yet possible to compare learning gains between the two groups. Nevertheless, we can discuss learning gains of the students who learned with TRAU, and we can also compare pretest scores between the two groups. The conceptual survey contains 10 items that are scored for 1 point each, totalling 10 points. The mean score achieved by students in the experimental group was 3.4 on the pretest and 5.0 on the post-test. Fig. 2 shows the mean values of points achieved per question.

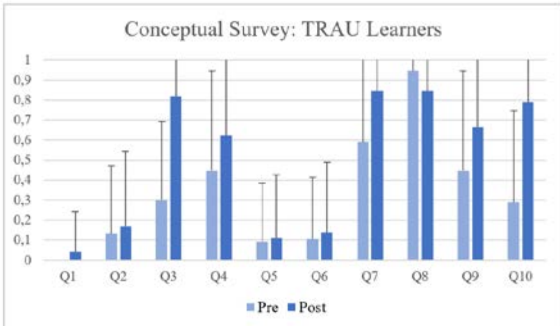

Fig. 2: Pretest and post-test results of the conceptual survey for the experimental group. Error bars are standard deviation. $N = 76$ on the pretest and 72 on the post-test.

In general, there was an increase in correct answers on all items except Q.8, with the largest increases being on Q.3 and Q.10. We had expected a large increase on Q.1, as TRAU focuses directly upon the content of this question. Examination of Figure 2 indicates that our expectations were not met. Part of the reason for the particularly low score on Q.1 is that no points were awarded unless students selected every one of the ten objects in the list as being something that would make a radioactivity detector click. We can investigate this item further by comparing frequencies of object selections on the pretest and post-test. In the pretest, an average of 3.5 objects were selected. This number increased modestly on the post-test 5.5 (out of 10). The overview of the percentage of participants who selected each object can be found in Figure 3 below.

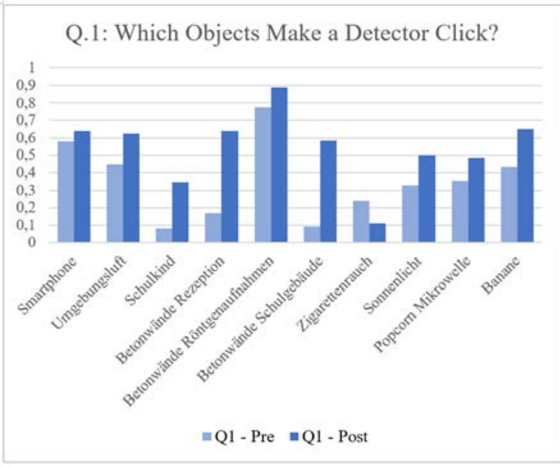

Fig. 3: Pretest and post-test results for Q.1 of the conceptual survey for the experimental group. The correct answer is to select all 10 objects.

On the pretest and post-test, respondents were asked to indicate their emotion regarding radioactivity. Figure 4 shows the relative proportion of participants who chose the respective answer options.

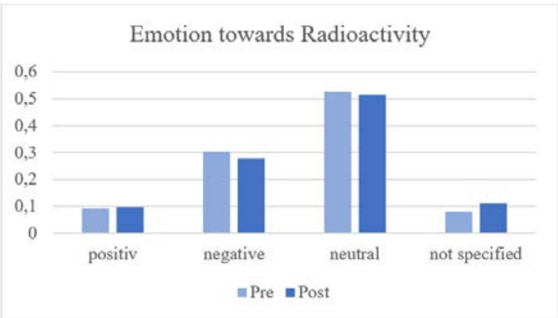

Fig. 4: Respondent self-reports of their emotion towards radioactivity. The y-axis indicates percentage of respondents.

On the pretest, intermediate test immediately after TRAU, and post-test, respondents were asked questions about their self-concept and interest. The results are in Figures 5 and 6, respectively. Finally, we administered the HEC "tanodo" question both on the intermediate test (to ask about the Classbook) and at the end of all instruction about radioactivity (to ask about learning the topic of radioactivity overall). The mean score on the intermediate test was 1.6, and the mean score on the post-test was even closer to 1, at 1.5 (recall that the item is five-point Likert scale, with 1 being "it was very enjoyable").

As mentioned above, only pretest questionnaires have been completed by the control group so far. The results are equivalent to those from the pretest of the experimental group. The average score on the conceptual survey was 3.9 in the control group, a little higher than the average of the experimental group, but within the standard deviation. Figure 7 compares the points achieved on the pretest for each question and for both groups.

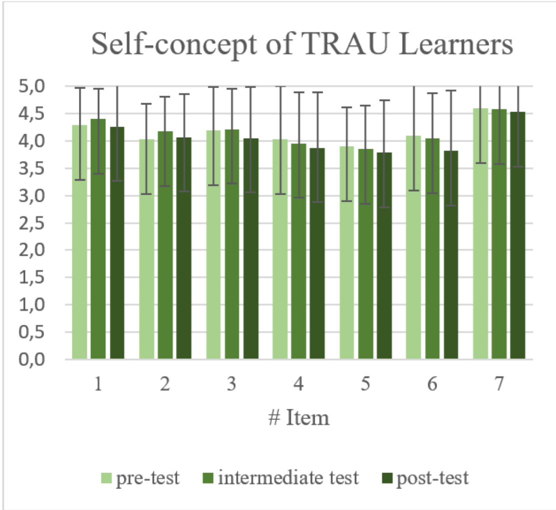

Fig. 5: Respondent answers to the IPN survey items pertaining to self-concept. Selection of "5" indicates "very good" and "1" indicates "very bad".

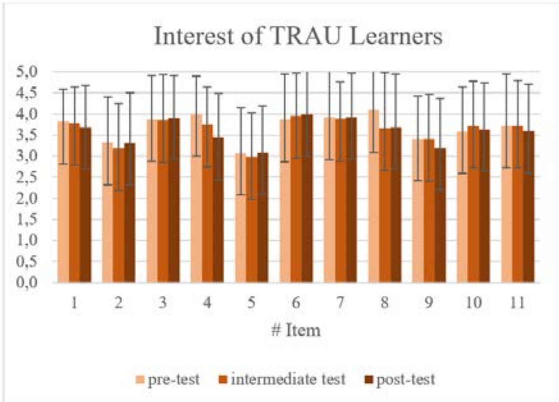

Fig. 6: Respondent answers to the relevant IPN survey items pertaining to interest. Selection of "5" indicates "very high interest" and "1" indicates "very low interest".

As can be seen, scores were comparable for all items except for Q.1, as no students in the experimental group answered this item correctly on the pretest. Pretest responses to emotion towards radioactivity, self-concept, and interest of the control group were also comparable with the TRAU group. Specifically, although emotion in the control group was slightly less positive (see Figure 8, below), interest and self-concept were somewhat higher.

4. Discussion

As we have not yet collected post-test data from the control group, it is not possible for us to fully assess the effectiveness of TRAU. However, from the data of the students who learned with TRAU, we can gain some insight even at this point in time.

As expected, the mean number of points achieved on the conceptual survey pretest was small, and this number increased on the post-test. In particular, the large increase in Q.10, which is discussed explicitly in TRAU, matches our expectations. It is likely that this increase is the result of using TRAU and that a similar gain will not be found in the control group. Question 3, on the other hand, which probes awareness of types of ionising radiation, likely saw a large increase in correct responses as a result of instruction that took place after TRAU, since this is a topic only briefly discussed in the Classbook. We anticipate similar growth on this item in the control group.

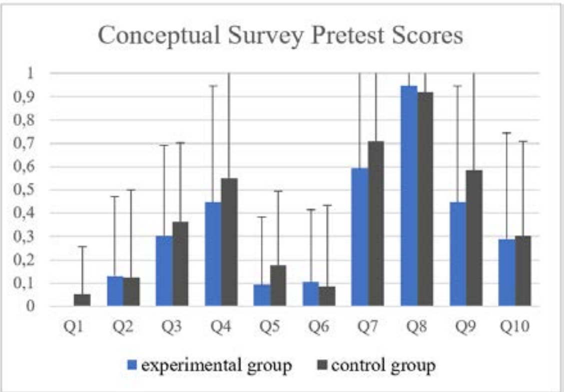

Fig. 7: Comparison of points achieved per question between experimental (blue) and control group (grey) on the pretest.

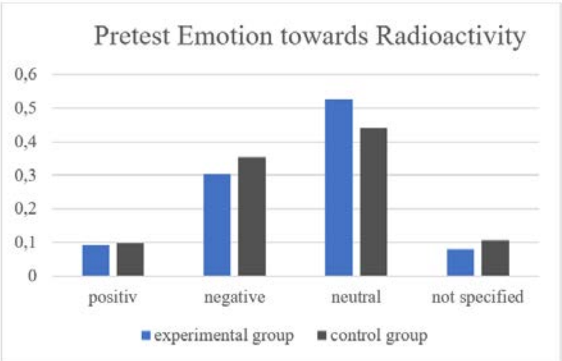

Fig. 8: Comparison of emotion towards radioactivity between experimental (blue) and control group (grey) on the pretest.

The very small increase in correct responses to Q.1 was surprising. Looking at the frequency of objects selected (Figure 3), we see that each object was ticked more often on the post-test than on the pretest, except for "cigarette smoke", which is never mentioned in the Classbook. After TRAU, respondents were particularly more likely to say that a concrete wall is radioactive (the exception is walls of a room in which X-rays are taken; as so many students selected this object already on the pretest, there was no gain seen on the post-test). Concrete walls are explicitly discussed in one of the “Problems” of TRAU, so we expect to not see this increase in selection frequency in the control group. The answer option "a schoolchild" also experienced a notable increase. Actually, we expected a much greater increase, as the final “Problem” of the Classbook asks students if they think that they themselves are radioactive. According to the HEC goals, the Classbook up until that point should prepare students so that almost all students correctly can hypothesize that they are radioactive. The subsequent pages of the Classbook which tell students that, indeed, they are radioactive, are meant to give students a sense of satisfaction in the theory they have developed.

Regarding emotion, we had expected there to be more selections of "negative" than "positive", and this is confirmed in Figures 4 and 8. We were surprised, however, that the most common response was “neutral” instead of “negative”. We see in Figure 4 a small decrease of negative emotions. Had more students started TRAU with negative emotions, we might have observed a greater improvement in emotion. According to Lijnse et al. (1990, as cited in Henriksen, 1996, p. 195), media plays a major role in how a person's basic attitude towards radioactivity develops. One reason why most of the students were neutral towards the topic could be that they had generally not learned much about radioactivity from the media or elsewhere. All participants are probably too young to recall the media coverage of the Fukushima accident, let alone any incident that happened before that.

It was also surprising that the students reported such high interest and self-concept on the pretest. The values are so high that any improvement that may have resulted from instruction with TRAU are masked by this ceiling effect. Although we cannot claim that interest and self-concept did or did not increase, we can say that they did not decrease, either as a result of the Classbook or of the instruction that followed the Classbook. Students in the experimental groups also explicitly stated that they enjoyed the lessons on radioactivity on the “tanodo” item, both immediately after TRAU and at the end of all instruction on radioactivity had taken place. One possibility is that students enjoyed the instruction that took place after TRAU just as much as they enjoyed TRAU. Another possibility is that students enjoyed TRAU so much that, when asked after additional lessons on radioactivity, their impressions from TRAU dominated their response to the “tanodo” item. We will be able to see which of these two interpretations is more likely by analyzing the responses of students in the control group to the “tanodo” question on the post-test. Subsequently, the lessons of the individual teachers should also be roughly analyzed, especially to see what the “control group” entails.

5. Conclusion

Although our study is still in the data-collection stage, what we have accumulated so far suggests that the goals of HEC can be partially achieved with TRAU in Austrian schools.

As far as HEC's first goal is concerned, the results we have obtained are sobering. It is encouraging that many students who learn with TRAU improve their understanding on Q.10. However, until we have compared with data collected from the control group, we cannot say for certain how much this increase can be attributed to the Classbook itself. The results for Q.1 suggest that the first goal of HEC is not obtained with this Classbook. It is true that many students came to recognize concrete walls as emitting ionizing radiation. However, within two weeks after completing TRAU, only about one third of students said that a school child would make a radioactivity detector click. The first goal of HEC specifies that almost all learners should correctly expect the result of the last Problem in the Classbook and that they should do well on an exam given within two weeks after the Classbook has concluded (2019, p. 29). Although this goal of HEC is not met with TRAU, the Classbook may nevertheless be superior to traditional instruction on radioactivity in Austria. To determine this, comparison with data from the control group is necessary.

In contrast to the first goal, the results we have presented indicate that the second goal of HEC is attained with TRAU. Students reported that they greatly enjoyed the Classbook on the “tanodo” item, and interest and self-concept remained high after instruction with TRAU. Comparison with data from the control group can reveal whether the Classbook has an advantage in these regards compared to the usual way of teaching radioactivity.

In comparing TRAU instruction with the control group, it is important to bear in mind that the “usual way” of teaching about radioactivity varies from teacher to teacher. Future studies should compare TRAU with what, specifically, takes place in the “usual” instruction of the teachers in the control group of our study to see what in particular is effective and what should be improved.

6. Literature

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