Increased conceptual learning through a guided discovery approach of the ISP

Does a good cookbook make a great chef?

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ABSTRACT

The cookbook style experiments of the ionising radiation practical (closed ISP) have been used for 40 years by 350 schools in the Netherlands annually. Ten “open ISP” experiments were developed in 2012 to meet the desire from teachers for more discovery based learning in these experiments. First, this study tries to connect this desire to a growing body of research that advocates guided discovery learning. Secondly it measures the conceptual learning as a result of participating in the open ISP compared to the closed ISP of 42 exam year students in three different high schools throughout the Netherlands using a pre and post test. Thirdly it records the experiences of teachers and students to inform the interpretation of those results using questionnaires and recorded student teacher interactions.

A method for guided discovery learning in practical laboratories was found that emphasizes a good preparation by student and teacher, an awareness of the scientific aim and didactical purpose of the laboratory and meaningful guidance and feedback during the preparation and execution of the laboratory.

A significant increase ($p=0,021$) in test scores was measured after participating in the ISP. There was however no significantly greater($p=0,595$) increase between the open and closed variants. The effect size, Cohen’s d, of the open ISP ($d=0,564$) was slightly greater than that of the closed ISP ($d=0,360$). However, because of the small sample size this is not a very powerful result.

A qualitative analysis of the questionnaires and student teacher interactions shows that students which participated in an ISP that followed the guided discovery guidelines felt more challenged, spend less time on the actual experiments and showed greater motivation to do guided discovery learning in the future. Unfortunately, the pooling of all schools to increase sample size led to a mediation of the test results from students so no connection to increased conceptual learning can be shown.

This study recommends that the number of open ISP experiments be increased and that teachers be given all the tools they need to effectively use guided discovery learning to increase conceptual learning.

1 INTRODUCTION

When in the 1960's and 1970's ionizing radiation became a bigger part of popular culture it also became part of the dutch high school curriculum. Many schools struggled to produce interesting yet safe experiments to demonstrate the key concepts of radiation and X-rays. Not all the experiments designed by schools could be considered safe for students to work with. To deal with this unsafe situation the Dutch government changed the law and permit structure for schools to handle radioactive materials. This meant that most schools could not maintain their own supply of radioactive materials. As a safe way for high school students to still be able to experiment with radioactive materials a mobile laboratory was established by the University of Utrecht in 1972. The mobile practical, called "Ioniserende Straling Practicum (ISP)", was made to be self guided for the student so that the student could gain meaningful and real experience with radioactive materials and concepts. This hands-on approach for the students was seen as an improvement over the more passive demonstration style lessons of the past.

Over the years the ISP was expanded and now, in 2016, there are 23 different experiments that can be done spanning four categories: half life, absorption, X-rays and a spare category for miscellaneous topics like the Wilson chamber or the backscattering of β particles. Usually a student dyad will choose three to four experiments to do in a one and a half to two hour period. To facilitate a self guided experience the experiments were designed to be done by students using a fill out worksheet. This worksheet is a step by step guide to do the experiment. An example of one of these fill out worksheets can be found in the appendix A. Usually there is no preparation or much prior knowledge needed to complete one of these worksheets. This approach with a worksheet can make the experiments feel like a recipe that has to be followed. That is why experiments with such a fill out sheet and step by step instructions are sometimes called cookbook experiments

In the decades following the creation of the ISP these cookbook experiments have met some critique in the physics education research field. According to Arons (1997)and Stinner(1992) these cookbook type experiments do not help students with understanding physics concepts. In other studies the main concerns of students are addressed: "the fundamental concern of many students while in the laboratory is completion of the task, this concern can overwhelm any serious learning possibilities" (Edmondson & Novak 1993; Berry, Mulhall, Loughran, & Gunstone, 1999a, 1999b). In this paper the old, cookbook, style ISP will be referred to as the "closed" ISP.

In a 1999 report by the Stichting Leerplan Ontwikkeling about the feasibility of and experiences with the ISP specifically, teachers and users of the ISP were very satisfied with its structure, didactical approach and execution. However a few teachers said there was a need for a more open variant. These teachers wanted a more modern approach to the experiments that would take into account the developments in physics teaching (Hulsbeek, Meijerink, Schurink, & Wiegman, 1999). As a reaction to this report Koos Kortland, former leader of the group that organises the ISP, and Rob van Rijn have developed a few experiments that can be done on the existing experimental setups but have lost the cookbook style. These were first tested in a small scale bachelor research by Blasse in 2011. She developed and tested a procedure of execution for the teacher and a set of information sheets with which the students could prepare themselves for the ISP by making a research plan that had to be discussed with the teacher. In this paper these revised experiments will be referred to as the "open ISP".

The research done by Blasse was a small (two school and 18 students) design based research with as a main research question: How should a well functioning open ISP be designed? What should be the content and how should it be organised? In her report she proposes various steps to improve the ISP as to make it easier for the students to complete the experiments in a way that they get actual results and learn something new while still being able to do them autonomously. She also proposed ways the teachers could better help the students and how the could keep the extra work introduced by the open ISP to a minimum. Her recommendations were taken up into the design of the open experiments and guiding documentation. She also tried to assess the learning effects of the open ISP by asking what the students had learned in a questionnaire. This study also aims to further assess these learning effects with a larger sample and a control group.

Goal and research questions

The goal of this study is to firstly expand on the theoretical background given by Blasse to try to explain why an open ISP might increase conceptual learning and what it needs to look like for it to be effective. Secondly, an empirical study be performed to detect any advances in conceptual learning by the students as a result of the open ISP compared to the closed ISP. Lastly, student and teacher experiences are collected to inform the interpretation of the results. This leads to the following four main research questions:

1. How do teachers experience the preparations for the open ISP and the coaching of the students before and during the lab work.
2. How do students experience the preparations for, execution of, and reporting on the open ISP.
3. Are there indications of enhanced conceptual learning as a result of the open ISP in comparison to the closed ISP.
4. Are there ways to increase the effectiveness of the ISP in the future with regard to conceptual learning and research skills.

Chapter 2 discusses the theoretical background of a more guided discovery physics practical. Chapter 3 outlines the used methods in answering the research questions. Chapter 4 reports the results from the taken surveys, observed questions during the ISP and the results from the pre and post test. Chapter 5 discusses these results and their implications and limitations.

2 THEORETICAL BACKGROUND

In this chapter the literature about student engagement and learning effect due to a more open Physics laboratory will be explored. First the need for a more open ISP is discussed and then the limits to the openness.

2.1 Between a cookbook and pure discovery

The closed ISP experiments tend to be very structured and completely guided. These types of experiments are sometimes called cookbook laboratories. In the introduction it has already been mentioned that students are more concerned with completing the task than to actually learn something. Redish explains what the downsides are of such a style of lab:

> The lab is the single item in a traditional physics course where the student is expected to be actively engaged during the class period. Unfortunately, in many cases the laboratory has turned into a place to either "demonstrate the truth of something taught in lecture" or a place to "produce a good result". The focus in both of these cases is on the content and not on what might be valuable for a student to learn from the activity. In the USA, "cookbook" laboratories -- ones in which highly explicit instructions are given and the student doesn't have to think -- are common. They are unpopular with students and tend to produce little learning (Redish, 2000, p.10).

A way to focus more on the learning goals of a laboratory could be structured in a way to make the students feel like actual scientists making a discovery or as Deacon and Hajek put it:

> Laboratory activity should not focus explicitly on scientific concepts at the beginning, but on structured discoveries which provide the opportunity for students to discover physics rules for themselves. This approach, according to the authors, will give students the ability to develop an intuitive understanding of what a scientific approach is about and, equally important, to experience how it feels to be a 'knowledge creator' rather than a 'knowledge consumer' (Deacon & Hajek, 2011, p946).

This focus on scientific process reality is often called discovery learning. There are however problems with a purely discovery based laboratory.

> Pure discovery—even when it involves lots of hands-on activity and large amounts of group discussion—may fail to promote the first cognitive process, namely, selecting relevant incoming information. In short, when students have too much freedom, they may fail to come into contact with the to-be-learned material. There is nothing magical to insure that simply working on a problem or simply discussing a problem will lead to discovering its solution. If

> the learner fails to come into contact with the to-be-learned material, no amount of activity or discussion will be able to help the learner make sense of it (Mayer, 2004, p17).

This is what Blasse encountered in an experiment where without enough prior knowledge a dyad of students never came to a conclusion that was one of the goals of that particular experiment. Mayer continues to explain that although a more constructivist approach to experiments is not necessarily wrong.

> Yet the failure of pure discovery as a method of instruction does not necessarily mean that constructivism is wrong as a theory of learning or that hands-on activity is necessarily a wrong method of instruction. A basic premise in constructivism is that meaningful learning occurs when the learner strives to make sense of the presented material by selecting relevant incoming information, organizing it into a coherent structure, and integrating it with other organized knowledge. It follows that instructional methods that foster these processes will be more successful in promoting meaningful learning than instructional methods that do not. (Mayer, 2004, p17).

Instead of just going through the motion of a researcher as in a cookbook style experiment a learning activity that actually is meaningful contains cognitive activities such as selecting, organizing and integrating knowledge (Mayer 2004).

> Instead of depending solely on learning by doing or learning by discussion, the most genuine approach to constructivist learning is learning by thinking. Methods that rely on doing or discussing should be judged not on how much doing or discussing is involved but rather on the degree to which they promote appropriate cognitive processing. Guidance, structure, and focused goals should not be ignored (Mayer, 2004, p17).

This guided approach to discovery is of the called guided discovery and is well explained by Janssen, Westbroek and Van Driel (2014):

> The common aspect in different Guided Discovery Learning (GDL) practices is that teaching starts by posing a challenging problem, and that students themselves contribute to the knowledge development needed to solve the problem (Hmelo-Silver et al. 2007). When students receive sufficient support in developing the necessary knowledge, GDL can help them to become more motivated, develop flexible knowledge, and learn how knowledge is developed in a specific domain (Janssen, Westbroek & Van Driel, 2014, p68).

The importance of the meaningfulness of the laboratory is confirmed by Deacon and Hajek (2010):

> there is a growing sense that learners learn by solving real and meaningful problems. The laboratory can provide such opportunities for students if the teacher provides meaningful

investigations upon which they can construct scientific concepts within a community of learners in their classroom (Deacon & Hajek 2010 p.946).

2.2 Guided discovery

To apply Guided Discovery Learning as proposed by Janssen et al., a number of important factors can be identified:

Preparation and Content Knowledge

- "The extent to which students know the content knowledge assumed by laboratory activities (students with little or none of the assumed content knowledge find it difficult to derive any meaning from the activity or their results)" (Hart et al., 2000, p662).
- The degree to which students are prepared to participate in an experiment will impact their understanding of its purpose, their ability to complete it on time, and their enjoyment. When a concept is not taught in the classroom prior to conducting an experiment on that concept, students are more challenged to understand the theory and methods used (Deacon & Hajek, 2010, p962).
- Providing direct access to domain information seems effective as long as the information is presented concurrently with the simulation, so that the information is available at the appropriate moment (De Jong & Van Joolingen, 1998, p193).

Knowing the aim and purpose of a laboratory

- The extent to which students are aware of the aim of a laboratory activity and the pedagogical purpose within their current science learning (students make better sense of what they are doing when they are aware of the aim and the purpose) (Hart et al., 2000, p662).
- Providing learners with assignments (or questions, exercises, or games) seems to have a clear effect on the learning outcome (De jong & Van Joolingen, 1998, p193).

Feedback, reflection and modification of ideas

- "If students' understandings are to be changed toward those of accepted science, then intervention and negotiation with an authority, usually a teacher, is essential" (Driver, 1995).
- "We also identified the important role of the teacher in clearly articulating the purposes of a laboratory task and encouraging students to make links between their laboratory work and concurrent science class work." (Hart et al., 2000, p662)
- When laboratory experiences are integrated with other metacognitive learning experiences such as "predict–explain–observe" demonstrations, etc. (White & Gunstone, 1992) and when they incorporate the manipulation of ideas instead of simply materials and procedures, they can promote the learning of science (Deacon & Hajek, 2010, p962).

- There is a need to provide students with frequent opportunities for feedback, reflection, and modification of their ideas. Moreover, there is a growing sense that learners learn by solving real and meaningful problems. The laboratory can provide such opportunities for students if the teacher provides meaningful investigations upon which they can construct scientific concepts within a community of learners in their classroom (Deacon & Hajek 2010, p962).
- We suggest that laboratory activities should engage students in making choices based upon physical principles and receiving feedback about those choices. Observing performance related feedback amounts to finding the tracks of that otherwise elusive creature, interactive engagement. It’s not just the gadgets, it’s how you use them that counts (Royuk & Brooks, 2003, p324).

3 METHOD

3.1 Demographics

Four schools participated.

School 1:	
Location:	South of Limburg, small rural town, students from a wide region.
Students:	1300 total students, available grades HAVO, VWO, Technasium
Remarks:	This school was a Technasium school with a heavy focus on research. Students were trained to always have a measurement plan/sheet whereupon all data could be recorded. No measurement sheet meant that the students couldn't participate in the experiment. These students were best prepared for the ISP and spend less time on the open experiments than on the closed experiments. Unfortunately the data that as collected after the ISP visit was lost in the mail. That meant there were no C and D questionnaires and no posttest. Their pretest data was not used in the test data analysis. The data from questionnaires A and B however where used qualitatively.
School 2:	
Location:	province of Utrecht, mid-size town next to Utrecht city
Students:	1650 students in total, Available grades: VMBO (G)T, HAVO, VWO
Remarks:	At this school the teacher was most enthusiastic about the open ISP. He put in most time in the preparation and made sure the students didn’t only understand the aim but also the purpose of the experiment.
School 3:	
Location:	South Holland, Big City
Students:	1100 in total, available grades HAVO, VWO
Remarks:	At this school the students and teacher were least prepared. The students didn’t spend much time on a research plan and usually had no measurement plan. They also had to ask a lot of questions during the ISP.

School 4:	
Location:	Small rural town in the south of South Holland, Students from a wide region.
Students:	A total of 1500 students, with all high school levels available.
Remarks:	At this school, the teacher was very directive and helped the students during the research plan meeting with directive feedback on what to do instead of asking questions as to preserve the openness.

Table 1: Characteristics of participating schools

The four physics teachers of these four schools all had experience with the closed ISP. Each of them gathered 4 to 5 student dyads to prepare a research plan for one of the ISP experiments suited for the open approach.

In total there were 83 students that participated in the open and closed ISP. Of those 83 students there were only 42 complete data-sets. The complete set of post tests and closing questionnaires of one school were lost in the mail. The rest of the incomplete datasets were caused by illness of the students during one of the tests or the experiment. 23 of these 42 students participated in the open ISP. Of those 42 there were 14 were female and 28 were male. All of the students were in grade 6 VWO.

	Male	Female	
Experimental group (open ISP)	18	5	23
Control group (closed ISP)	10	9	19
	28	14	

Table 2: control and experimental group demographics

Of the 21 students that participated in the experimental open ISP group 12 indicated they had been given the choice and had chosen to be in the experimental group.

3.2 Intervention - the open ISP

For practical reasons the open ISP experiments are based upon the existing experimental set-ups. The experimental set-ups are the same. The only difference being the worksheet or research guide they received. Ten of the original 23 experiments were adapted by dr. J. Kortland of the Freudenthal institute to be more open. The experiments that were adapted were chosen from all categories. (Blasse, 2011 & Freudenthal Institute, 2015).

1 penetration depth of α-particles in air
2A Radioactive decay of Radon-220 wit an amp-meter
2B Radioactive decay of Radon-220 wit an x,t plotter
4 backscattering of ß-particles
5 Absorption of ß-particles by aluminium and perspex
8 Radiation Intensity and distance
12 Absorption of γ-radiation by lead
18 Elastic modulus of rubber
19 Penetration depth of α-particles dependent on air pressure
20 Radioactive decay of Protactinium-234

The students participating in the open ISP chose or were appointed one of the open experiments about 2 weeks before the visit of the ISP to their school. They would receive a research guide for their particular experiment. This research guide also started with the aim of the research, a description and a schematic depiction of the experimental set-up, just like the worksheets of the closed ISP. From there the research guides differs from the worksheets. The students were asked to write their own research plan with their own research question and with a researched hypothesis. When possible they were also asked to sketch a possible diagram of the relationship. Lastly they needed to write a measurement plan that should take safety and background radiation into account.

At least a week before the ISP the students were invited for a research plan meeting where they could get feedback from their teacher or technical education assistant (TOA). In this meeting the teacher was asked to refrain from directive comments but to use the socratic method as to maintain the openness of the ISP. The teachers were provided with a manual for each of the experiments so they were able to see if the student's research plan was complete and, if necessary, quickly ask the right questions to steer the students into the right direction. With the received feedback the students can alter or complete their research plan that they can then execute on the day the ISP visits their school.

After the students have done the measurements and processed the results they could be asked by the teacher to do up to three more closed experiments. This way the students can complete an experiment from all four categories and they were also able to compare the experience of the open vs. the closed experiments.

After the ISP the students were asked to write a rapport on the open experiment. In the research guides of some of the experiments the students are asked to explain the origin of a particular relationship or to calculate a specific value. The report is they handed in to the teacher. The teacher may decide to give a grade or a completion mark or nothing at all for completion of the report.

3.3 Instruments

In this section the instruments used to answer the four research questions will be covered.

Pre and Post tests

To measure effects on learning domain knowledge, parallel pre- and posttests were developed. The tests consist of ten items each, covering the topics of absorption, half life and X-rays.
The questions on the pre and post tests were the same with multiple choice answers rearranged and other values for the questions were calculations needed to be done. The test questions were based on example questions provided by dr. J. Kortland. The example questions were specifically designed to test the effectiveness of the ISP on the increase conceptual understanding. Some of these questions were designed to be used in the new physics book Newton and Impact by ThiemeMeulenhoff.
The pre and post tests were filled out by all students of the control group and the experimental group. These tests are added in appendix B and C.

Recordings

The research plan meetings with students in the experimental group of all four schools were recorded in order to qualitatively answer research questions 2 and 4. The meetings were analysed for directiveness of the teacher and how well the students were prepared before this meeting.
During the ISP the questions the students had were recorded as to asses how much they needed help and the things that the students needed help with during the ISP.

Questionnaires

To measure the attitudes of students and teachers with respect to the open ISP four questionnaires for the teachers and four for the students in the experimental group were designed. These questionnaires are added in appendix D and E.

Timing of instruments

Timing of questionnaires and tests					
Teachers activities			Students activities		
			Pre test		
			Writing research proposal		
Questionnaire A	Before meeting		**Questionnaire A**	Before meeting	
Short research proposal meeting with teacher feedback**(recording)**					
Questionnaire B	For each group		**Questionnaire B**	Immediately after meeting	
ISP: Ionising radiation practical**(recording of questions)**					
Questionnaire C	Immediately after ISP		**Questionnaire C**	Immediately after ISP	
			Writing of a rapport		
Grading rapport			**Post test**		
Questionnaire D			**Questionnaire D**	Immediately after post test	

Table 3: Timing of measurements before, during and after ISP. Only the pre and post test were administered to the control group.

Answering the research questions

Table 4 shows what instruments were used to answer the research questions.

Instrument Research question →	1	2	3	4
Questionnaires	x	x		
Recordings during research plan meeting and questions	x	x		
Pre and post test			x	
Literature research				x

Table 4: Answering the research questions with instruments.

4 RESULTS

All quotes in this chapter were translated from dutch by the researcher and checked by a high school English teacher for correctness.

4.1 Pre and post test results

First, analysis of the pre test results was done. There was no significant difference ($t(42)=-1.572$, $p = 0.124$) between the results of the students in the experimental group (open) and the control group (closed). This is supported by the fact that there is no statistical difference ($t(36)=-0.730$, $p = 0.470$) between the subject (physics) grades of the students doing the open and closed variants.

Second, a mixed anova was used to determine if there is a significant interaction between the open ISP and the results on the pre and post test. The results show there is a significant increase ($p=0,021$) between the ISP in general (open and closed) and increased results on the post test. However, there is no significant interaction ($p=0,595$) between the open variant ISP variant and increased results on the post test.

Descriptive analysis		Mean test score	Standard deviation	N
Pre test	Closed Open total	0,4679 0,5361 0,5053	0,15258 0,12788 0,14205	19 23 42
Post test	Closed Open total	0,5180 0,6150 0,5711	0,12414 0,15095 0,14621	19 23 42

Table 5: pre and posttest results descriptive analysis

Another observation is that although there is no significant effect of the open variant on the results we see that the average score on the post test of the students doing the open ISP are higher (0,6150) than that of the group doing the closed variant (0,5180). When we calculate Cohen's d to assess the effect size for the open ISP we find :

	d	r
open	0,564	0,271
closed	0,360	0,177

Table 6: Effect size with Cohen's d

This shows that the effect size of the open is larger than that of the closed ISP and for both the effect size is small to medium.

4.2 Pre ISP observations

In this section the results from questionnaire A and B from the students in the experimental group (open ISP) and the teachers will be discussed.

Teachers	● All teachers say the students preparing to do an open ISP had "trouble to understand what is asked of them" and that students had a hard time to imagine what the aim of their research was. A teacher said: "the aim is not clear for the students" ● Some teachers also indicated that some students did not have a "well argumented hypothesis or clear research question". ● Another teacher said some students "didn't think of a measurement plan" ● One of the teachers mentioned that "the students have no idea on how many times they should/can measure. Others simply "didn't think about a research question and the processing of data" according to a teacher.
Students	● Students think it's hard to "imagine what [they] exactly will have to do" to answer the research question and what they should take into account when measuring. Some of them say the learned to "think deeper about what and how they want to research" before they start to do an experiment and that "a good preparation is half the battle". After the students had a feedback meeting with their teachers about their research plan they had the following observations: ● A little over half (50,5%) of the students said the only had to work on the research plan a little bit more while about 40% of the students said they had to change quite a bit. 9,5% of the students said they didn't need to edit anything. ● When asked what they had to change or add to their research plan over half (61%) said they had to revise their measurement plan. A bit less but still the majority (57%) of the student said they had to work on their hypothesis. Fewer still(23%) had to work on the research question. ● Measurement plan: The students say they learned that "a research plan should take into account everything" on how to do the research.." ● Hypothesis: Students said they had trouble imagining what would happen because they "had never worked with radioactive[sic] before". ● Research Question: The students mention that they found it hard when they had to "think deep about how and what to research".

Table 7: experiences of teachers and students during the ISP

4.3 During ISP observation

During the ISP all questions to the teachers were recorded. The teachers were instructed to use the socrative method when helping students as to preserve the openness of the open ISP. The students asked for help on questions that can be categorized in four main themes: (1)unfamiliarity with the experimental set-up, devices and materials, (2)background radiation, (3)Safety, contamination vs. irradiation and appreciation of health risks, and (4)statistical nature of decay. Next are some quotations from students that are representative of those four categories.

1. **Unfamiliarity with the experimental set-up, devices and materials.**

Most of the questions asked by students concerned the experimental setup. Some students felt like they were “thrown in at the deep end” *(Student remark during ISP)* with devices they had never seen.

Other students had questions about the materials they were working with. Students asked for the thickness of the aluminium plates used the shield a radioactive source.

> Student 3: And erm.. What’s the thickness of this?
> Teacher: Erm.. How would you want to measure that?
> Student 3: Oh, do we also have to measure that? Well, ten we must..
> Teacher: Yes, I don’t have a clue how thick it is, but there must be a way for you to measure it.
> Student 3: yes, with a cali...
> Teacher: a caliper, indeed.
> Student 3: Yes, with a caliper
> (Dialogue between students and teacher during ISP)

2. **Regarding (the measurement of)background radiation:**

A few students asked questions regarding the background radiation and the influence of the environment on measuring it. The quote presented below shows that the student didn’t understand the range of alpha and beta particles nor how to effectively eliminate their effects on a background radiation measurement.

> *Student 1: But in principle the background radiation in this room is slightly increasing per unit of time, right?*
> *Teacher: Why would it increase?*
> *Student 1: There is a lot of radiation getting out, right?*
> *Student 2: Because there are a lot of people working with erm.. With a radioactive source. Look, here we obviously still have erm.. A lead lid. But if… if everybody would, let’s say, take it off?*
> *Student 1: The background radiation would increase.*
> (Dialogue between students and teacher during ISP)

3. Safety, contamination and irradiation, appreciation of health risks

A student made a remark about the safety of the experiments they were doing. When helped to open a containment vessel they remarked: “Now I feel like it is getting really terribly dangerous” (student remark during ISP)

4. Statistical nature of decay

There was one student who asked about the fluctuating activity measured by a GM-tube. He didn’t understand why, with the same setup a repeated measurement should return different results. “But even if this [the GM tube] just stays in the same place[distance from the source] it [the particle count] will change all the time.” *(Student question during ISP)*

These four categories of questions indicate the need for the opportunity for students to be well prepared for the ISP concerning the basic concepts, such as safety and background radiation. Also they need to be able to anticipate what devices and experimental materials they will encounter during the ISP. During the ISP there should be a database or knowledge system where they can find extra information themselves just when they need it. Lastly it is very important that a teacher or lab assistant should be present to help the students when needed and ask clarifying and directing questions when they see an experiment going wrong.

4.4 Post ISP observations

In questionnaires C and D questions were asked about the experience of participating in the open ISP versus the closed assignments in the ISP. In this section the the teachers opinions and then the students opinions will be discussed.

Teachers

The teachers were asked just after the ISP, in questionnaire C, if they thought the students were well prepared at the start of the ISP, whether the required time of completion was as expected and if they might have any explanations for this. After they graded the reports they filled out questionnaire D with the question if they had and suggestions for improving the ISP. From two of the four schools interesting results were collected which are represented in table 8. The post ISP data of one other school was lost in the mail and the teacher of the fourth school did not fill in questionnaire C and D.

	Teacher A	Teacher B
C.1. Do you feel the students were well prepared for the open ISP? (0/4 = not prepared)	2/4 Not very well prepared	4/4 Very well prepared
C.4. Did the open experiments take longer or shorter than expected? (3/4 = as expected)	4/5 A bit more than expected	3/4 A bit less than expected
C.5. Why do you think it took longer or shorter?	“There was no recipe. They had to make their own decisions which made them insecure”	“Students were very well prepared so they knew right away how the experiment worked”
D.3. Do you have any suggestions for improvements to the open ISP?	-“The information supplied to the teachers was complete. -The student had a hard time to see the aim of the experiments”	-”the feedback meeting about the research plan costs extra time” -I think it’s a good thing the students have to think beforehand about what they will have to do [during the experiment].” -”students don’t think of using logarithmic paper… that causes them to miss certain insights”

Table 8: comparison of answers to questionnaire questions by two teachers from different schools

These results agreed with the observations done by the researcher. The students at the school of teacher A were not very prepared to start the ISP. As we will see in the next section the students of the school of teacher A were also the ones with the most criticism of the open ISP. Also teacher A spend the least amount of time preparing himself for the feedback meeting with the students. In those meetings teacher A was very directive with which he might have diminished the openness of the ISP. During the interview he used a lot of directives like: “Yes, so add that. While you’re at it, add a fitting table there.” while teacher B had a lot more questions that needed to be answered by the students themselves. “Yes, so what does that actually mean?” and “You are going to make a diagram, why would you need a table?

Students

In a questionnaire taken directly after the ISP (questionnaire C), the students indicated they didn’t need a lot of help during the open ISP. In the questionnaires, a little over half (57%) of the students indicated they had to ask for help on technical questions like: how does the x,t-plotter work, how to place a radiation source in the experimental setup or how to use the x-ray tube.

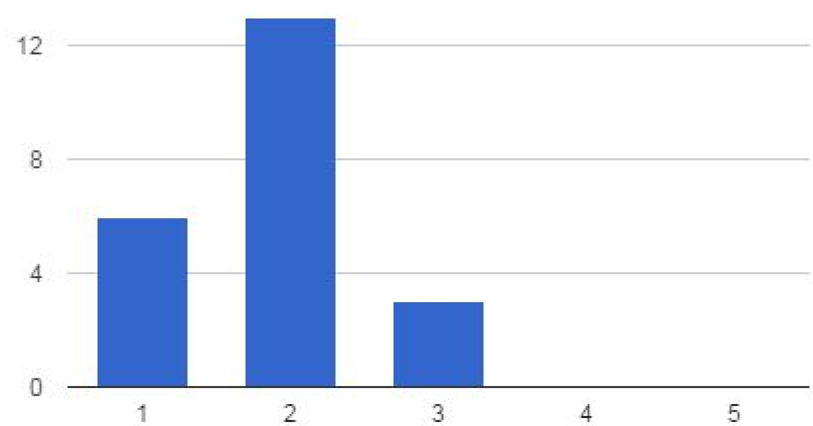

figure 1: How much help did you need while doing the open ISP experiments? (1: no help, 5: a lot of help)

Students were asked what they found difficult while doing the open ISP. A couple of students indicated they had trouble with knowing what they had to do exactly. These responses came in two variations. For instance: a student was unclear of what to do because “there was no clear manual provided”. Another student indicated: “it was hard to strictly execute our own research plan”. Most indication of difficulty came from students who said they didn’t know how to work the experimental set-ups because they had never seen it before.

When asked what they had learned from participating in the open ISP, students said they had learned how to work with the experimental set-ups, and that setting up your own research plan is a lot of work but if you have a good one you know better what to do and that creates a more relax experience. A student said: “A good preparation is chill. Another said:” A good preparation is half the work". Yet another said: "it is good to make your own plan and then put it into practice". A problem indicated by the students is that some had a sense of not knowing that what they were doing was the right thing to do. Others indicated that during the closed ISP it is clearer what is expected from the students

The students who participated in the open ISP were asked if they thought the open and closed ISP were: educational, time consuming, interesting, challenging and clear. The students answered with a five point likert scale for each of the characterising words. On this data a Wilcoxon Signed-Ranks data analysis was done.

	closed			open			Statistical analysis		
	avg	stdev	median	avg	stdev	median	Z	Sign. p	Comparison +/-
educational	3,13	0,757	3	3,36	0,953	3	-0,910	0,363	~
time consuming	2,52	0,898	2	3,32	0,894	3	-2,437	0,015	+
interesting	3,43	0,728	4	3,45	0,858	4	-0,061	0,951	~
challenging	2,52	0,947	2	3,14	0,941	3	-1,956	0,050	+
clear	4,09	0,793	4	3,00	1,024	3	-2,991	0,003	-

Table 9: How do the following characteristics apply to the open and closed ISP? Ranged from: 1, not at all, to 5, very much.

Table 9 shows that, when the closed ISP is compared to the open ISP, , a positive significant difference was seen on the characteristic time consuming (Z = -2.437, p=0,015) and challenging (Z = -1,956, p=0,050) while a significant negative difference was seen for the statement "clear" (Z = -2.991, p=0,003). There was no significant change on the statements "educational" (Z = -0.910, p=0,363) and "interesting" (Z = -0.61, p=0,951)

Lastly the students in the experimental group were asked how they they would rather see the ISP in the future and if they had any closing remarks. Half (52%) of the experimental group students indicated there should be a mix of open and closed experiments. A student said: "There should be a combination of both, so one can learn from both aspects: a good preparation and gaining knowledge on the spot." While another said: "Both have advantages: Open is more challenging but it is less clear than the closed experiments." the rest of the students were equally divided between a fully open ISP and an ISP with just closed experiments. Arguments for a totally open ISP were: "Two open experiments would be ideal. It really makes you think about the experiment" and "Just open, one learns more from it and it makes you think about the [research] process". Arguments given for a totally closed ISP were: "I thought the making of a research plan and rapport were boring. I immediately didn't feel like it anymore while I quite like doing experiments" and "It is better to learn a bit about a lot [of different concepts] than a lot about one"

5 DISCUSSION

One of the main goals of this study was to look for enhanced conceptual learning after doing a discovery based ISP than a very guided ISP experiment. The pre and post test results show no significant stronger increase in conceptual learning. The larger medium effect size on the average test score increase of the experimental group compared to the control group are not powerful because of the small sample size (N=42).
These results were probably mediated by the small sample size, the fact that the results of the participating schools were pooled and the fact that the pre and posttest were measurements of a large number of concepts that a student may encounter within the topic of ionising radiation. Next these factors and how they could have affected the results will be discussed.

Small sample size
Despite my efforts to gather a larger sample size the sample size that was eventually gathered was still small. The number of subjects in the experimental group were similar than that of the experimental group of Blasse's study. In this study however there was a control group which was not present in Blasse's study. With this small sample no significant difference in pre and post test grade could be indicated and the power of the effect size statements were also limited.

Pooled results
In the quantitative analysis of the pre and post test all the participants of all four schools were pooled. This was done to increase the sample size and to increase the odds of finding a significant result. This however diminished the ability to distinguish the pre and post test results between different approaches by teachers. It is possible the results of students from schools with a more closed and less discovery type approach mediated the results of the students from schools with a more guided discovery approach.

Concept in tests and experiments
The 23 experiments in the ISP and the ten of those that have been adapted to be the open ISP are all mainly focussed on a limited number of ionising radiation concepts. This means that during the ISP students will not be exposed to all the concepts contained in the entire ISP. This means that if there is an effect of the ISP (open or closed) on the conceptual knowledge of one of these concepts, the effect will be small on the total conceptual framework of ionising radiation. No concept independent analysis was done because the data collected per concept were very limited.
Because the pre and post test try to cover this entire framework, the effects on the test results of doing one open ISP experiments and maybe two more closed experiments will be inherently small. This fact will have made it hard for any researcher to find a significant effect on these test scores because the actual effects on concept knowledge will diluted by all the other unchanged concept knowledge tested in the pre and post test.

Preparation and feedback

The first two research questions were about the experiences of students and teachers with regard to the open and closed ISP. Although only a qualitative analysis was done on the results of the questionnaire and recorded interactions between students and teachers, the results show that when an ISP is structured as a guided discovery activity the students need a better preparation before and more thoughtful guidance during the ISP. The results show that well prepared students had a basic understanding of the important concepts, they knew the scientific aim and didactical purpose of the ISP which is in line with previous studies by Hart et al. (2000) and Deacon and Hajek (2010).

Time consuming

The students on average indicated that the open ISP was more time consuming however in the questionnaires some students indicated that this extra time in preparation saved time during the ISP itself. This is supported by statements of the teacher who indicated that while they had spent more time in preparation and during feedback moments, the students took less time with the actual experiment during the ISP than expected.

Guided discovery

The last research question tried to clarify what indications to enhance the conceptual learning as a result of the ISP were present in the literature. Three main goals were formulated that should increase the effectiveness of the ISP.

- It is important that the teacher and students are well prepared for the ISP including a good introduction to or repetition of the concepts that are needed to do the experiments. During the experiments additional information needed by the students should be available when needed.
- It is important for the students to know what the aim and the purpose of the activity are. The aim is the practical end of the research while the purpose is the broader didactical purpose of the activity.
- To achieve higher learning it is important that the students get feedback from teachers and/or experts and that they are made to think, predict, explain, observe and reflect so they can, if needed, modify their misconceptions.

6 RECOMMENDATIONS

Recommendations for follow up studies

- A follow up study should gather a larger sample size. With a large sample of students and more schools a better comparison can be made between different approaches by school and other confounders such as subject grade, math subjects(A and B) and sex.
- A follow up study should test the intended conceptual gains of each separate experiment. This can be done by giving students pre and post tests that are connected to the experiments they did. So a student doing an experiment on half life should be asked multiple questions on half life. This way the direct effects on concept knowledge can be measured undiluted.
- When recording conversations and student questions with a voice recorder always make sure they are turned off before one goes to the bathroom.

Recommendation for the ISP

- The Informations sheets of the open ISP experiments seem to be sufficient. They give adequate information and ask guiding questions. The researcher would advise to increase the number of available open ISP experiments so that an entire class can choose to do an open experiment. To make sure that all students learn something about all concepts embedded in the ISP an expert method activity could be suggested to schools so that students can exchange their findings with other students.
- An active role for the teacher is required prior to and during the ISP.
  - Basic concepts need to be clear to students in advance
  - The scientific aim and didactical purpose of the experiment need to be clear
  - It should be clear to the students how the experimental set ups look like and operate
  - This could be done using a database or even short youtube clips
  - Valuable feedback on research plan and during ISP that maintains the openness of the experiment is required

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8 APPENDICES

8.1 Appendix A Fill out worksheet example of closed ISP

Universiteit Utrecht

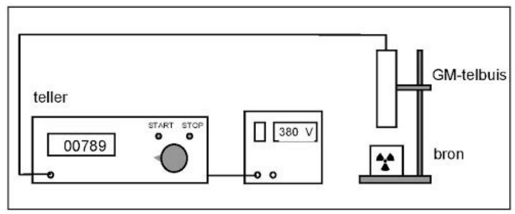
Faculteit Bètawetenschappen
Ioniserende Stralen Practicum

Experiment 6
Geiger-Müller telbuis

Naam:
………………………………………………

Doel

Bepalen van de werkspanning en van het tel-rendement van een Geiger-Müller telbuis.



Opstelling

De opstelling bestaat uit een Geiger-Müller telbuis met pulsenteller en een bron met strontium-90 (^{90}Sr). De telbuis is aangesloten op een variabele hoogspanningsbron.

Lees eerst de inleiding op pg. 8 van het oranje boekje ISP Experimenten over de werking van een GM-telbuis. Zie ook het informatieblad op de ISP website: www.fisme.science.uu.nl/isp > leerlingen > achter-grondinformatie > Geiger-Müller telbuis.
Dit experiment bestaat uit twee delen – bepalen van de *werkspanning* en van het *telrendement* van een GM-telbuis – met beide een onderdeel *metingen* en een onderdeel *uitwerking*.

Deel 1: Werkspanning

Metingen

1 Haal het deksel van de bron, en zet de bron in de opstelling onder de telbuis.

2 Zet de hoogspanning op 0. Draai de *time-interval knop* op de stand *off*. Start de teller en maak de hoogspanning geleidelijk groter tot de teller met een constante snelheid begint te tellen. Lees de spanning waarbij dit gebeurt af op de voltmeter.

3 Stel nu de hoogspanning in op een waarde die 50 V lager is dan wat je net hebt afgelezen. Dit is het nulpunt voor je metingen.

4 Stel de *time-interval knop* in op 10 s. Meet de intensiteit *I* van de straling (in pulsen per 10 s) als functie van de hoogspanning *U* (in V). Laat deze hoogspanning oplopen in stappen van 50 V. Noteer de meetresultaten in de tabel hieronder. **Let op**: De spanning over de telbuis mag niet groter worden dan **850 V**.

U (V)											
I (pulsen/10s)											

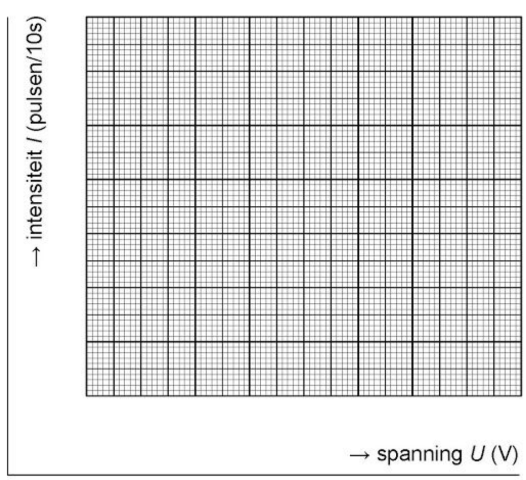
5 Haal de bron na het uitvoeren van de metingen uit de opstelling en doe het deksel er weer op.

Uitwerking

1 Maak hiernaast een grafiek van je meet-resultaten.

2 Verklaar de vorm van de getekende grafiek:
- Waarom telt de GM-telbuis niet bij lage waarden van de spanning?
- Waarom begint de gemeten intensiteit bij hoge waarden van de spanning weer op te lopen?

………………………………………………
………………………………………………
………………………………………………
………………………………………………
………………………………………………
………………………………………………
………………………………………………



In de bij opdracht 1 getekende grafiek zie je een spanningsgebied waarin de gemeten intensiteit vrijwel constant is. Dit gedeelte noemen we het *werkspanningsgebied* van de GM-telbuis.

3 Bepaal uit de getekende grafiek het werkspanningsgebied. Kies daarna in dit gebied een goede waarde van de werkspanning.

Werkspanningsgebied: ……… tot ……… V

Gekozen werkspanning: ……… V

Deel 2: Telrendement

Metingen

1 Haal het deksel van de bron, en zet de bron weer in de opstelling onder de telbuis.

2 Stel de buis in op de gekozen werkspanning. Meet vier keer de intensiteit *I* van de straling (in pulsen per 10 s) en bereken de gemiddelde intensiteit I_{gem} (in pulsen per 10 s). Noteer de resultaten in de tabel hieronder.

I (pulsen/10s)					I_{gem} (pulsen/10s)	

3 Haal de bron na het uitvoeren van de metingen uit de opstelling en doe het deksel er weer op.

Uitwerking

Door het verval van instabiele atoomkernen zendt de radioactieve bron per seconde een bepaald aantal deeltjes uit. Dit noemen we de activiteit *A* van de bron.

1 Leg uit waarom slechts een klein deel van deze uitgezonden deeltjes in de telbuis terecht komt.

………

………

Van de uitgezonden deeltjes die wél in de telbuis terecht komen, wordt vervolgens slechts een deel gedetecteerd. Het telrendement *η* van de GM-telbuis geeft aan welk deel dat is. In een formule:

$$\eta_{telbuis} = \frac{\text{aantal gedetecteerde deeltjes}}{\text{aantal invallende deeltjes}} \times 100\%$$

Hierbij gaat het natuurlijk wel om de aantallen gedetecteerde en invallende deeltjes in dezelfde tijdsduur, bijvoorbeeld 1 s. Het aantal per seconde gedetecteerde deeltjes is eenvoudig te berekenen uit de hierboven uitgevoerde metingen. Blijft over het aantal per seconde invallende deeltjes. Dat aantal wordt bepaald door de activiteit van de bron en de zogenaamde 'geometrie' van de tel-opstelling.

2 Bereken het aantal per seconde op de telbuis invallende deeltjes door de volgende regels aan te vullen.

- De beginactiviteit A_0 van de bron was 185 kBq. De bron is inmiddels zo'n 25 jaar oud. Het ^{90}Sr in de bron heeft een halveringstijd van 28 jaar.

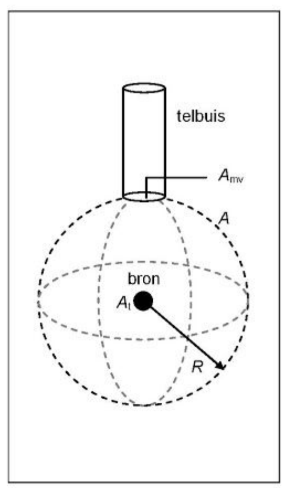
De huidige activiteit A_t van de bron is dan ……… kBq.
Aanwijzing: Voor de activiteit A_t geldt: $A_t = A_0 \cdot (\frac{1}{2})^{t/t_{1/2}}$

- De afstand *R* tussen de bron en het meetvenster van de telbuis is 5 cm. De bron zendt in alle richtingen straling uit, die zich dan over een denkbeeldige bol met een straal van 5 cm verspreidt.

Het oppervlak *A* van deze bol is dus ……… cm^2.
Aanwijzing: Voor het oppervlak *A* van een bol geldt $A = 4\pi \cdot R^2$.

- Het meetvenster van de telbuis bevindt zich op dit boloppervlak. Dit meetvenster heeft een oppervlak A_{mv} van 1,54 cm^2.

Het aantal per seconde op het meetvenster invallende deeltjes is dus ………
Aanwijzing: Gebruik voor je berekening de huidige activiteit A_t van de bron, het oppervlak *A* van de bol en het oppervlak A_{mv} van het meetvenster.



3 Bereken nu het rendement van de GM-telbuis.

$\eta_{telbuis}$ = ………. %

8.2 Appendix B Pre test

Universiteit Utrecht

Faculteit Bètawetenschappen
Freudenthal Instituut voor Didactiek van Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Voor-toets

Leeg laten, in te vullen door onderzoeker

LL-Code	
Datum	

Eerste letter van je voornaam:………..	gemiddelde voor natuurkunde:….. (vraag dit aan je leraar)
School: ……………………………………………………….	HAVO-4 / HAVO-5 / VWO-4 / VWO-5 / VWO-6
Geboortedatum: ……/……./………. (dd/mm/jjjj)	M / V

Deze korte vragenlijst is onderdeel van het onderzoek naar een meer open variant van het Ioniserende Straling practicum(ISP). Het zijn 10 vragen en het duurt ongeveer 15 minuten om het in te vullen. Je mag een BINAS en rekenmachine gebruiken.

Je krijgt hier geen punt voor maar we willen je toch vragen om de lijst zo goed mogelijk in te vullen. Lees elke vraag goed door en geef een <u>korte</u> toelichting op je antwoord.

Omcirkel het Juiste antwoord

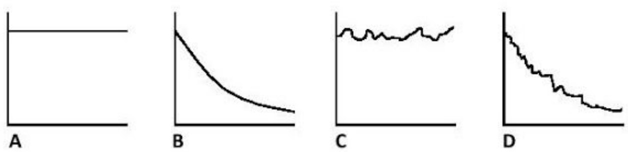
1. $^{134}_{55}Cs$ heeft een halveringstijd van 2 jaar. Na hoeveel jaar is er nog maar 12,5% van de originele activiteit over?
   - **A.** 2,25 jaar Toelichting:
   - **B.** 3,0 jaar
   - **C.** 6,0 jaar
   - **D.** 8,0 jaar

2. In een kluis op de zolder van een oud universiteitsgebouw in Utrecht werd een radioactieve $^{90}_{38}Sr$ (halveringstijd = 28,7 jaar)bron gevonden. De gemeten activiteit in september 2012 was 2,38 Bq. De kluis was voor het laatst geopend in september 1938. Wat was de activiteit van de radioactieve bron in 1938?
   - **A.** $4{,}8 \cdot 10^{-1}\ Bq$ Toelichting:
   - **B.** $1{,}4 \cdot 10^{1}\ Bq$
   - **C.** $6{,}7 \cdot 10^{1}\ Bq$
   - **D.** $8{,}2 \cdot 10^{-1}\ Bq$

3. Geef aan welke stellingen waar zijn:
   1. Als er op t=0 twee instabiele kernen zijn en op t=4s nog maar één, is de halveringstijd 4 seconden
   2. Als er op t=0 een activiteit is van 100Bq en op t=30s nog maar 25Bq is de halveringtijd 15 seconden

   - **A.** Stelling **1** en **2** zijn allebei waar Toelichting:
   - **B.** Stelling **1** en **2** zijn allebei niet waar
   - **C.** Alleen stelling **1** is waar
   - **D.** Alleen stelling **2** is waar

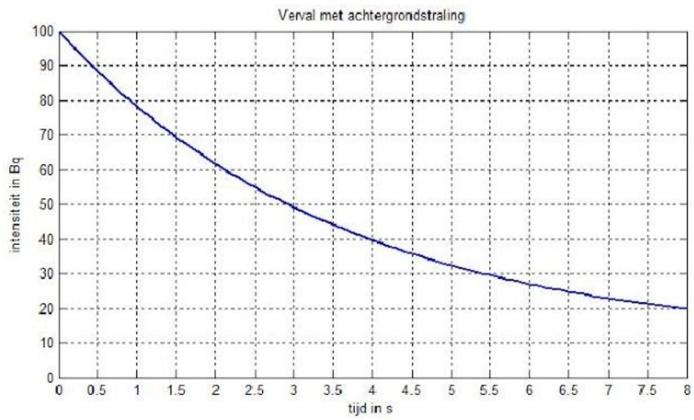
4. Welke van de volgende uitspraken over dracht en halveringsdikte zijn juist? Omcirkel die. Let op: het kan zijn dat méér dan één uitspraak juist is.
   A De dracht van β-straling in een materiaal is de afstand waarop de helft van de invallende straling is geabsorbeerd.
   B De dracht van β -straling in een materiaal is de afstand waarop alle invallende straling is geabsorbeerd.
   C De halveringsdikte van een materiaal voor β -straling is de afstand waarop de helft van de invallende straling is geabsorbeerd.
   D De dracht van γ-straling in een materiaal is de afstand waarop de helft van de invallende straling is geabsorbeerd.
   E De dracht van γ-straling in een materiaal is de afstand waarop alle invallende straling is geabsorbeerd.
   F De halveringsdikte van een materiaal voor γ-straling is de afstand waarop de helft van de invallende straling is geabsorbeerd.
   G Geen van deze uitspraken is juist.
5. Twee bundels γ-straling vallen in op twee verschillende platen A en B. De intensiteit van de invallende γ-straling op plaat B is tweemaal zo groot als die van A. De dikte van plaat A is twee halveringsdiktes, de dikte van plaat B is vier halveringsdiktes.
   De intensiteit van de doorgelaten γ-straling bij plaat A is, vergeleken met de intensiteit van de doorgelaten γ-straling bij plaat B
   A kleiner. Toelichting:
   B tweemaal zo klein.
   C even groot.
   D tweemaal zo groot.
   E viermaal zo groot.
   F groter.
   G Er is onvoldoende informatie om deze vraag te beantwoorden.
6. De 'snelheid' waarmee de activiteit van een radioactieve bron in de loop van de tijd afneemt, hangt af van de halveringstijd. Hieronder zie je een aantal vervaldiagrammen met een opnametijd van 30 seconden.



   a: Welk diagram geeft de activiteit van de bron met een halveringstijd van enkele jaren het best weer? Antwoord met uitleg: ......
   b: Welk diagram geeft de activiteit van de bron met een halveringstijd van 15 seconden het best weer? Antwoord met uitleg: ......
7. Bij het meten van de activiteit van een bron corrigeer je altijd voor achtergrondstraling. Wat zijn bronnen van achtergrondstraling? Meerdere antwoorden zijn mogelijk.
   a. Het menselijk lichaam
   b. Kosmische straling uit het heelal
   c. Bouwmaterialen
   d. Bodem en woonomgeving
   e. Fall-out van ontplofte atoombommen en ongelukken in Tjernobyl en Fukushima
   f. Geen van de hierboven genoemde dingen

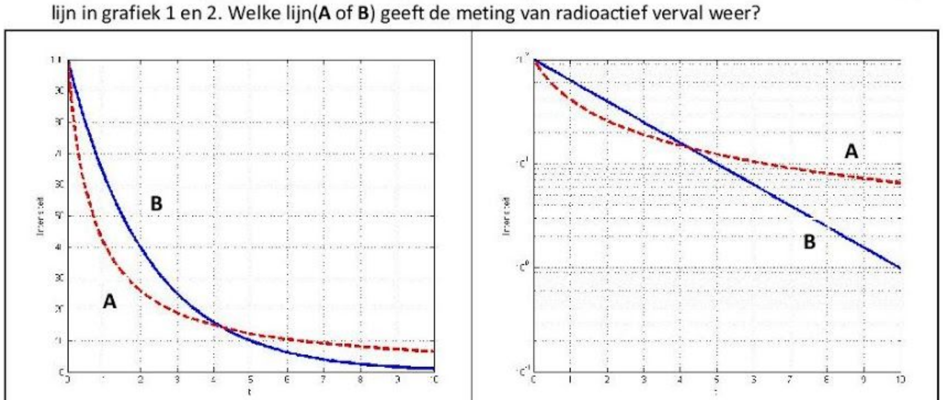
8. Waar moet je aan denken als je achtergrondstraling meet? Meerdere antwoorden zijn mogelijk.
    a. De bron met de straling die je wilt meten moet afgedekt zijn
    b. De bron met de straling die je wilt meten moet ver verwijderd zijn van de opstelling
    c. De Geiger-Mueller buis moet naar de grond gericht zijn om Radon gas uit de grond te meten
    d. De Geiger-Mueller buis moet naar de lucht gericht zijn om kosmische straling te meten
    e. De Geiger-Mueller buis moet al in de opstelling zitten zoals je gaat meten
    f. Je kunt het beste 1 keer kort, voor 2 seconden, meten
    g. Je kunt het beste 3 keer D lang, voor 10 seconden, meten

9. Om de halveringstijd van een bron te meten wordt een meting gedaan van de intensiteit. Hieronder staat de meting weergegeven in een grafiek. Deze is niet gecorrigeerd voor achtergrondstraling. Er heerst een achtergrondstraling van 10Bq. Wat is de halveringstijd van de bron?



Antwoord met toelichting:

10. Bij een meting is de activiteit van een bron gemeten. De meetwaarden zijn weergegeven in twee grafieken. Een normale grafiek en een enkel logaritmische grafiek. Hier onder staan die twee grafieken met in elk twee lijnen. De rode(A) lijn in grafiek 1 en 2 zijn van de zelfde meting net zoals de blauwe(B) lijn in grafiek 1 en 2. Welke lijn(**A** of **B**) geeft de meting van radioactief verval weer?



1. Normaal grafiek papier
2. Logaritmisch grafiek papier

Antwoord met toelichting:

8.3 Appendix C Post test

Universiteit Utrecht

Faculteit Bètawetenschappen
Freudenthal Instituut voor Didactiek van Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Na-toets

Leeg laten, in te vullen door onderzoeker

LL-Code	
Datum	

Eerste letter van je voornaam:………..	
Geboortedatum: …../……./………. (dd/mm/jjjj)	School: ……………………………………………………….

Deze korte vragenlijst is onderdeel van het onderzoek naar een meer open variant van het Ioniserende Straling Practicum(ISP). Het zijn 10 vragen en het duurt ongeveer 15 minuten om het in te vullen. Je mag een BINAS en rekenmachine gebruiken.

Je krijgt hier geen punt voor maar we willen je toch vragen om de lijst zo goed mogelijk in te vullen. Lees elke vraag goed door en geef een korte toelichting op je antwoord.

Omcirkel het Juiste antwoord

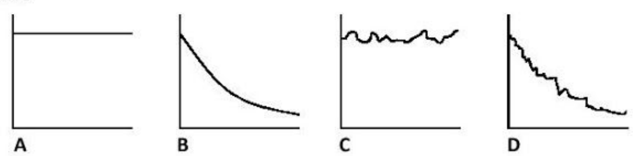
1. $^{134}_{55}Cs$ heeft een halveringstijd van 2 jaar. Na hoeveel jaar is er nog maar 7,25% van de originele activiteit over?
   - **A.** 3,00 jaar Toelichting:
   - **B.** 4,00 jaar
   - **C.** 6,00 jaar
   - **D.** 8,00 jaar

2. In een kluis op de zolder van een oud universiteitsgebouw in Utrecht werd een radioactieve $^{137}_{55}Cs$ (halveringstijd = 30,2 jaar)bron gevonden. De gemeten activiteit in september 2012 was 18,6 Bq. De kluis was voor het laatst geopend in september 1938. Wat was de activiteit van de radioactieve bron in 1938?
   - **A.** $4{,}83 \cdot 10^1\ Bq$ Toelichting:
   - **B.** $1{,}56 \cdot 10^2\ Bq$
   - **C.** $3{,}65 \cdot 10^1\ Bq$
   - **D.** $1{,}02 \cdot 10^2\ Bq$

3. Geef aan welke stellingen waar zijn:
   1. Als er op t=0 een activiteit is van 100Bq en op t=30s nog maar 25Bq is de halveringstijd 15 seconden
   2. Als er op t=0 twee instabiele deeltjes zijn en op t=4s nog maar één, is de halveringstijd 4 seconden

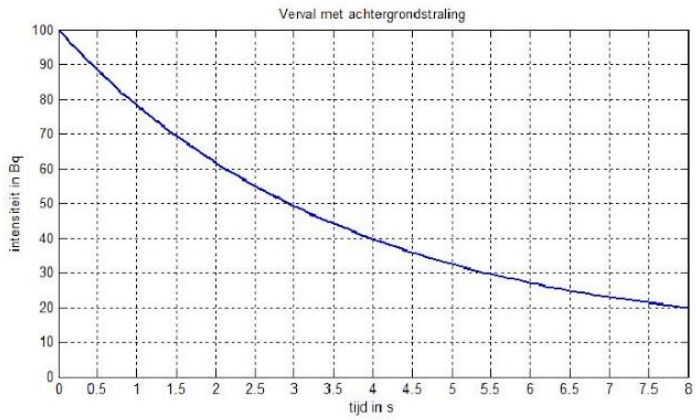
   - **A.** Stelling **1** en **2** zijn allebei waar Toelichting:
   - **B.** Stelling **1** en **2** zijn allebei niet waar
   - **C.** Alleen stelling **1** is waar
   - **D.** Alleen stelling **2** is waar

4. Welke van de volgende uitspraken over dracht en halveringsdikte zijn juist? Omcirkel die. Let op: het kan zijn dat méér dan één uitspraak juist is.
   A De dracht van γ-straling in een materiaal is de afstand waarop de helft van de invallende straling is geabsorbeerd.
   B De dracht van γ-straling in een materiaal is de afstand waarop alle invallende straling is geabsorbeerd.
   C De halveringsdikte van een materiaal voor γ-straling is de afstand waarop de helft van de invallende straling is geabsorbeerd.
   D De dracht van β-straling in een materiaal is de afstand waarop de helft van de invallende straling is geabsorbeerd.
   E De dracht van β -straling in een materiaal is de afstand waarop alle invallende straling is geabsorbeerd.
   F De halveringsdikte van een materiaal voor β -straling is de afstand waarop de helft van de invallende straling is geabsorbeerd.
   G Geen van deze uitspraken is juist.
5. Twee bundels γ-straling vallen in op twee verschillende platen A en B. De intensiteit van de invallende γ-straling op plaat B is tweemaal zo klein als die van A. De halveringsdikte van het materiaal van plaat A voor γ-straling is tweemaal zo groot als die van B. De dikte van plaat A is twee halveringsdiktes, de dikte van plaat B is drie halveringsdiktes.
   De intensiteit van de doorgelaten γ-straling bij plaat A is, vergeleken met de intensiteit van de doorgelaten γ-straling bij plaat B
   A tweemaal zo groot. Toelichting:
   B viermaal zo groot.
   C tweemaal zo klein.
   D viermaal zo klein
   E even groot.
   F Er is onvoldoende informatie om deze vraag te beantwoorden.
6. De 'snelheid' waarmee de activiteit van een radioactieve bron in de loop van de tijd afneemt, hangt af van de halveringstijd. Hieronder zie je een aantal vervaldiagrammen met een opnametijd van 30 seconden.



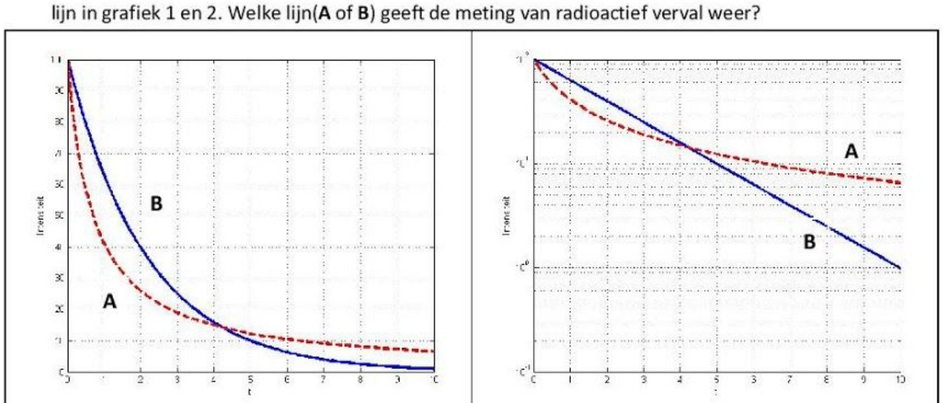
   a: Welk diagram geeft de activiteit van de bron met een halveringstijd van enkele jaren het best weer? Antwoord met uitleg: ……
   b: Welk diagram geeft de activiteit van de bron met een halveringstijd van 15 seconden het best weer? Antwoord met uitleg: ……
7. Bij het meten van de activiteit van een bron corrigeer je altijd voor achtergrondstraling. Wat zijn bronnen van achtergrondstraling? Meerdere antwoorden zijn mogelijk.
   a. Bodem en woonomgeving
   b. Fall-out van ontplofte atoombommen en ongelukken in Tjernobyl en Fukushima
   c. Het menselijk lichaam
   d. Kosmische straling uit het heelal
   e. Bouwmaterialen
   f. Geen van de hierboven genoemde dingen

8. Waar moet je aan denken als je achtergrondstraling meet? Meerdere antwoorden zijn mogelijk.
    a. De Geiger-Mueller buis moet al in de opstelling zitten zoals je gaat meten
    b. De Geiger-Mueller buis moet naar de grond gericht zijn om Radon gas uit de grond te meten
    c. De Geiger-Mueller buis moet naar de lucht gericht zijn om kosmische straling te meten
    d. Je kunt het beste 1 keer kort, voor 2 seconden, meten
    e. Je kunt het beste 3 keer lang, voor 10 seconden, meten
    f. De bron met de straling die je wilt meten moet ver verwijderd zijn van de opstelling
    g. De bron met de straling die je wilt meten moet afgedekt zijn
9. Om de halveringstijd van een bron te meten wordt een meting gedaan van de intensiteit. Hieronder staat de meting weergegeven in een grafiek. Deze is niet gecorrigeerd voor achtergrondstraling. Er heerst een achtergrondstraling van 10Bq. Wat is de halveringstijd van de bron?



Antwoord met toelichting:

10. Bij een meting is de activiteit van een bron gemeten. De meetwaarden zijn weergegeven in twee grafieken. Een normale grafiek en een enkel logaritmische grafiek. Hier onder staan die twee grafieken met in elk twee lijnen. De rode(A) lijn in grafiek 1 en 2 zijn van de zelfde meting net zoals de blauwe(B) lijn in grafiek 1 en 2. Welke lijn(**A** of **B**) geeft de meting van radioactief verval weer?



1. Normaal grafiek papier
2. Logaritmisch grafiek papier

Antwoord met uitleg:

8.4 Appendix D Teacher questionnaires

Universiteit Utrecht

Faculteit Bètaw etenschappen
Freudenthal Instituut voor Didactiek van
Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Vragenlijst-A Docenten

Leeg laten, in te vullen door onderzoeker

D-Code	
Datum	

Eerste letter van uw voornaam:………..	TOA / Docent 1ste graad natuurkunde / Docent 2de graad natuurkunde
School: ………………………………………………	

A. Voorafgaand aan de werkplanbespreking	**Kleur het bolletje in als het antwoord op u van toepassing is**
A.1. Hebt u al eerder deelgenomen aan het ISP?	0 Nee, Nooit 0 1-2 keer 0 3-5 keer 0 Vaker
A.2. Hoeveel experimenten voerden uw leerlingen toen uit?	… Experimenten in … klokuren
A.3. Hoe telde het ISP toen mee?	0 Als handelingsdeel 0 Als cijfer 0 Niet 0 Anders, namelijk..
A.4. Wat vind u van de manier waarop het practicum tot nu toe gegeven wordt? (Gesloten variant)	Totaal niet … Heel erg Leerzaam 0 0 0 0 0 Tijdrovend 0 0 0 0 0 Interessant 0 0 0 0 0 Uitdagend 0 0 0 0 0 Duidelijk 0 0 0 0 0
A.5.Met welke klas(sen) doet u mee aan het onderzoek naar de open variant?	0 4-HAVO 0 5-HAVO 0 4-VWO 0 5-VWO 0 6-VWO
A.6. Wat verwacht u van de open variant van het practicum?	Totaal niet … Heel erg Leerzaam 0 0 0 0 0 Tijdrovend 0 0 0 0 0 Interessant 0 0 0 0 0 Uitdagend 0 0 0 0 0 Duidelijk 0 0 0 0 0
A.7. Hoe veel groepjes van uw klas doen mee aan de open variant?	…………….. groepjes
A.8. Hoeveel werkplanbesprekingen gaat u doen per groepje?	…………….. besprekingen
A.9. Bekijkt u de werkplannen van de leerlingen al voor het gesprek?	0 Ja 0 Nee
A.10. Maakt u gebruik van de aanwijzingen per experiment (te vinden op het lerarengedeelte van de ISP website) bij het bespreken van het werkplan?	0 Ja 0 Nee
A.11. Vond u de aanwijzingen per experiment behulpzaam?	Totaal niet … Heel erg 0 0 0 0 0
A.12. Hoeveel tijd hebt u zelf in totaal besteed aan de voorbereiding van de werkplanbesprekingen?	0 niet voorbereid 0 minder dan een half uur 0 tussen een half uur en één uur 0 tussen de één en twee uur 0 meer dan twee uur

Universiteit Utrecht

Faculteit Bètaw etenschappen
Freudenthal Instituut voor Didactiek van
Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Vragenlijst-B Docenten

Leeg laten, in te vullen door onderzoeker

D-Code	
Datum	

Eerste letter van uw voornaam:………..	School: ………………………………………………………
Leerling 1 (voorletter – geb.datum)	………-…………………………………………………
Leerling 2 (voorletter – geb.datum)	………-…………………………………………………

Dit deel van de vragenlijst graag na elke bespreking afzonderlijk invullen, dus per tweetal.

B. Na de werkplanbespreking	**Kleur het bolletje in als het antwoord op u van toepassing is**					
B.1. Moest er nog veel veranderen aan het werkplan van de leerlingen?	Helemaal niks				Bijna alles	
		0	0	0	0	0
B.2. Hebben de leerlingen gedacht aan:		Helemaal niet				Goed aan gedacht
	Veiligheid	0	0	0	0	0
	Achtergrond-straling	0	0	0	0	0
	Meetonzekerheid	0	0	0	0	0
	Verwerking meetgegevenes	0	0	0	0	0
B.3. Wat viel u verder op?						
B.4. Hoe lang duurde deze werkplanbespreking?						

Universiteit Utrecht

Faculteit Bètaw etenschappen
Freudenthal Instituut voor Didactiek van
Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Vragenlijst-C Docenten

Leeg laten, in te vullen door onderzoeker

D-Code	
Datum	

Eerste letter van uw voornaam:………..	School: ………………………………………………………

Deze vragenlijst mag u invullen na het ISP practicum en gaat over uw algehele ervaring tijdens het ISP

C. Na het ISP practicum	**Kleur het bolletje in als het antwoord op u van toepassing is**
C.1. Hebt u het gevoel dat de leerlingen goed voorbereid het open ISP ingingen?	Niet voorbereid … Goed voorbereid 0 0 0 0 0
C.2. Heeft u de leerlingen die de open variant deden veel moeten helpen tijdens het practicum?	Geen hulp … Heel Veel hulp 0 0 0 0 0
C.3. Met wat moest u hun zoal helpen?	0 Functionele problemen met de opstelling 0 Leerlingen snapte de opstelling niet 0 Uitleggen van natuurkundig principe(dracht, activiteit, etc) 0 Veiligheid 0 Algemene verdwaaldheid ("wat nu?') 0 Anders, namelijk…
C.4. Duurden de open experimenten langer of korter dan verwacht?	Veel Korter … Als verwacht … Veel langer 0 0 0 0 0
C.5. Waarom denkt u dat het langer/korter duurde?	

Universiteit Utrecht

Faculteit Bètaw etenschappen
Freudenthal Instituut voor Didactiek van Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Vragenlijst-D Docenten

Leeg laten, in te vullen door onderzoeker

D-Code	
Datum	

Eerste letter van uw voornaam:...........	School: ....

D. Na de verslaglegging	**Kleur het bolletje in als het antwoord op u van toepassing is**					
D.1. Hoeveel tijd hebt u gemiddeld per verslag besteed aan het nakijken van de open variant verslagen?						
D.2. Wat vond u achteraf van de open variant van het practicum?		Totaal niet				Heel erg
	Leerzaam	0	0	0	0	0
	Tijdrovend	0	0	0	0	0
	Interessant	0	0	0	0	0
	Uitdagend	0	0	0	0	0
	Duidelijk	0	0	0	0	0
D.3. Heeft u opmerkingen of suggesties voor verbetering? Daarbij kunt u denken aan het werkblad voor de leerlingen, de docentenhandleiding, etc.						

8.5 Appendix E Student questionnaires

Universiteit Utrecht

Faculteit Bètaw etenschappen
Freudenthal Instituut voor Didactiek van Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Vragenlijst-A Leerlingen

Leeg laten, in te vullen door onderzoeker

LL-Code	
Datum	

Eerste letter van je voornaam:………..	M / V
School: ………………………………………………………	HAVO-4 / HAVO-5 / VWO-4 / VWO-5 / VWO-6
Geboortedatum: …../……./………. (dd/mm/jjjj)	Profiel: NT / NG / NT+NG

A. Voorafgaand aan de werkplanbespreking	**Kleur het bolletje in als het antwoord op jou van toepassing is**
A.1. Welk open experiment ga je doen?	
A.2. Heb je die zelf uitgekozen of heeft de docent jullie ingedeeld?	0 Zelf Uitgekozen 0 Ingedeeld door leraar
A.3. Is radioactiviteit/ioniserende straling al behandeld in de les?	0 Ja, alles behandeld 0 We zijn ermee bezig 0 Nee
A.4. Omcirkel de begrippen waarover je in de les hebt geleerd.	0 Halveringstijd 0 Halveringsdikte 0 α, β, ϒ, straling 0 Achtergrondstraling 0 Dosis 0 Intensiteit 0 Dracht 0 Activiteit
A.5. Hoe vaak heb je al een werkplan moeten schrijven? (Bij biologie, scheikunde en natuurkunde samen)	0 Nooit 0 1-3 keer 0 3-7 keer 0 Vaker
A.6. Hoe vaak heb je al een meetverslag moeten schrijven? (Bij biologie, scheikunde en natuurkunde samen)	0 Nooit 0 1-3 keer 0 3-7 keer 0 Vaker
A.7. Hoeveel tijd hebben jij en je partner in totaal besteed aan het schrijven van jullie werkplan?	0 Minder dan tien minuten 0 Tussen tien minuten en een half uur 0 Tussen een half uur en één uur 0 Tussen één en twee uur 0 Langer dan twee uur
A.8. Wat vond je moeilijk bij het opstellen van een werkplan?	
A.9. Begrijp je wat je gaat onderzoeken?	
A.10. Wat heb je geleerd bij het maken van je werkplan?	

Universiteit Utrecht

Faculteit Bètaw etenschappen
Freudenthal Instituut voor Didactiek van Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Vragenlijst-B Leerlingen

Leeg laten, in te vullen door onderzoeker

LL-Code	
Datum	

Eerste letter van je voornaam:………..
School: ………………………………………………
Geboortedatum: …../……./………. (dd/mm/jjjj)

B. Na de werkplanbespreking	**Kleur het bolletje in als het antwoord op jou van toepassing is**
B.1. Moeten jullie nog veel veranderen aan jullie werkplan?	0 Niets 0 Een klein beetje 0 Redelijk veel 0 Bijna alles
B.2. Aan welke onderdelen moeten jullie nog iets veranderen?	0 Onderzoeksvraag 0 Hypothese 0 Meetplan
B.3. Aan welke van de volgende onderwerpen moeten jullie nog iets veranderen?	0 Veiligheid 0 Achtergrondstraling 0 Meetonzekerheid 0 Verwerking meetgegevens 0 n.v.t
B.4. Wat heb je geleerd bij de bespreking van je werkplan?	
B.5. Hoe lang duurde de bespreking ongeveer?	0 Minder dan vijf minuten 0 Tussen vijf minuten en de tien minuten 0 Tussen de tien en de twintig minuten 0 Meer dan twintig minuten

Universiteit Utrecht

Faculteit Bètaw etenschappen
Freudenthal Instituut voor Didactiek van Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Vragenlijst-C Leerlingen

Leeg laten, in te vullen door onderzoeker

LL-Code	
Datum	

Eerste letter van je voornaam:………..
School: …………………………………………………
Geboortedatum: …../……./………. (dd/mm/jjjj)

C. Na de practicumsessie	Kleur het bolletje in als het antwoord op jou van toepassing is
C.1. Welke gesloten experimenten heb je gedaan?	
C.2. Had je al gesloten experimenten gedaan voor je met het open experiment begon? Zo ja, welke?	0 Nee 0 Ja, experiment …
C.3. Wat vond je moeilijk bij het uitvoeren van de gesloten experimenten?	
C.4. Wat vond je moeilijk bij het uitvoeren van het open experiment (aan de hand van je eigen werkplan)?	
C.5. Hoeveel hulp hadden jullie nodig bij het uitvoeren van het open experiment?	Geen hulp — Heel Veel hulp 0 0 0 0 0
C.6. Waar hadden jullie zoal hulp bij nodig?	
C.7. Wat heb je geleerd bij het uitvoeren van de gesloten experimenten?	
C.8. Wat heb je geleerd van het uitvoeren van het open experiment?	

Universiteit Utrecht

Faculteit Bètaw etenschappen
Freudenthal Instituut voor Didactiek van
Wiskunde en Natuurwetenschappen
Ioniserende Stralen Practicum

Vragenlijst-D Leerlingen

Leeg laten, in te vullen door onderzoeker

LL-Code	
Datum	

Eerste letter van je voornaam:………..
School: …………………………………………………
Geboortedatum: …../……./………. (dd/mm/jjjj)

D. Na de verslaglegging	**Kleur het bolletje in als het antwoord op jou van toepassing is**
D.1. Hoe lang waren jullie bezig met het uitwerken van de meetresultaten van het open experiment en het schrijven van het verslag?	
D.2. Hoelang was je bezig met het verwerken van de resultaten van de gesloten proeven?	0 Minder dan een half uur 0 Tussen een half en een heel uur 0 Tussen de een en twee uur 0 Meer dan twee uur
D.3. Hoe moeilijk vond je de verwerking van de resultaten van het open experiment?	Heel Makkelijk … Heel Moeilijk 0 0 0 0 0
D.4. Had je het idee dat je genoeg voorkennis had voor het open experiment? Zo nee, licht toe wat je miste.	0 Ja 0 Nee, Ik miste...
D.5. Wat vond je moeilijk bij het verwerken van je gegevens van je open experiment en het schrijven van je verslag?	
D.6. Wat vond je moeilijk bij het verwerken van de gegevens van de gesloten experimenten die je hebt gedaan?	
D.7. Wat heb je geleerd door de gesloten proeven die je hebt uitgevoerd?	
D.8. Wat heb je geleerd door het doen van het open experiment?	
D.9. Wat vond je van de gesloten variant van het practicum?	Totaal niet … Heel erg Leerzaam 0 0 0 0 0 Tijdrovend 0 0 0 0 0 Interessant 0 0 0 0 0 Uitdagend 0 0 0 0 0 Duidelijk 0 0 0 0 0
	Ga verder op de volgende pagina

D.10. Wat vond je van de open variant van het practicum?		Totaal niet				Heel erg
	Leerzaam	0	0	0	0	0
	Tijdrovend	0	0	0	0	0
	Interessant	0	0	0	0	0
	Uitdagend	0	0	0	0	0
	Duidelijk	0	0	0	0	0
D.11. Hoe zou jij het practicum het liefste zien? Alleen maar open proeven, alleen gesloten of een mix daartussen? En waarom?						
D.12. Heb je nog opmerkingen of suggesties voor verbetering met betrekking tot de open variant?						

8.6 Appendix F transcribed recordings cited in this paper.

There are to many to add them to this paper. They can be found using this link:

https://drive.google.com/folderview?id=0B_Y0sAzHzPuOOGFnYzJQUExKY0k&usp=sharing&tid=0B_Y0sAzHzPuOMnQ0UDBUNVN3MVU