Enhancing students' conceptual understanding by an inquiry-based physics practical

A quasi-experimental comparative study between a Direct Instruction and Inquiry-Based Learning approach

Research Project FI-MSECR30

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Abstract

In order to support the proliferation of scientific literacy, inquiry-based learning (IBL) proves to be an important tool so that students tap into their scientific knowledge to ask scientific questions (Gormally et al., 2009). This study investigated the effect of an IBL approach of a physics practical on students' conceptual understanding of radiation in the context ionizing radiation. A mixed method, quasi-experimental study design was used in which 146 students (10th and 11th grade of higher general secondary and pre-university education) performed either a direct instruction (DI) or IBL version of an experiment. Conceptual understanding was measured using pretest and posttest questionnaires specific for each experiment in the practical, and students' confidence in their answers was measured using a Likert scare for each question. Qualitative data were gathered in three focus groups with a total of 24 students. Results showed that the conceptual understanding in terms of test scores increased for both the DI and IBL approach, with the IBL approach increasing the most. The difference between these two increases was, however, not significant. The confidence scores for the IBL approach was found to be significantly higher compared to the DI approach. In the focus groups students reported that they felt supported by several elements of the IBL approach, namely the instructional video, worksheet layout, and example questions. IBL students explicitly reported on their perceived active participation and on performing "real" research during the experiments. These findings were absent in the utterances of the DI students. The results of this study suggest that the IBL approach of a physics practical does not directly benefit conceptual understanding compared to a DI approach. However, the IBL practical is perceived as being more activating and authentic. Implications and limitations are discussed.

Keywords: Conceptual understanding, inquiry-based learning, ionizing radiation, constructivist learning theory, direct instruction

Introduction

Scientific literacy is the ability to engage science-related issues, and with the ideas of science, as a reflective citizen in the general public (OECD, 2017). A scientifically literate person is willing and able to engage in reasoned discourse about science and technology, requiring the competences to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically. New generations of students will most probably be confronted with ongoing so-called socio-scientific issues, meaning controversial, socially relevant, real-world problems that are informed by science (Sadler et al., 2007), which will impact them and the people around them. Getting students prepared to understand and deal with socio-scientific issues is therefore at the core of science education (Osborne, 2007). The students need factual knowledge as a basis but should also be educated towards becoming scientifically literate members of society. They will be part of a community where these issues are spoken of daily.

One major issue is global warming. Overwhelming scientific consensus has it that human influences have warmed the atmosphere, ocean, and land, at a rate unprecedented in at least the last 2000 years (IPCC, 2021). This climate change is considered to be a result of greenhouse gas emissions from human activities, mainly the burning of fossil fuels. This not only produces high amounts of greenhouse gasses but is also a major source of airborne fine particulates, a key contributor to global mortality and disease (Vohra et al., 2021). Among the safest and least polluting alternative ways of producing energy are hydropower, wind, solar and nuclear energy (Markandya & Wilkinson, 2007; Pehl et al., 2017). Nevertheless, a long-neglected option, i.e., nuclear fission, actually is the most efficient energy source available to the world, both in energy density and in land use (Brook & Bradshaw, 2014). Producing energy using nuclear fission does, however, raise serious concerns regarding safety, radioactive waste storage, and nuclear non-proliferation (Grape et al., 2014). Nuclear energy has thus become an example of a socio-scientific issue, resulting in controversial discussions in many regions of the world (Jho et al., 2014).

Countries in Europe such as France and Finland are already dependent on their nuclear reactors for most of their electricity production. For France the reactors produce as much as 70% of their energy consumption (Statista, 2020), while Finland is also on its way to producing 60% of their total energy consumption using nuclear energy (World Nuclear Association, 2022). In order to be able to effectively gauge the complex issues around nuclear fission energy production, secondary school students need enough skills to deal with these socio-scientific issues in their adulthood.

It is thus essential that secondary school students acquire some general understanding on radiation physics and related safety issues (Jho et al., 2014). A practical approach can be effective in providing experiences that make information comprehensible, and to integrate students' knowledge of physics, making that knowledge easier to recall and apply (White, 1979). In the Netherlands, a practical offered nationwide to schools is the so-called Ionization Radiation Practical ("ioniserende stralen practicum" or ISP), acquainting some 20000 students yearly with different aspects of radioactivity. This practical has been taught for 50 years (Utrecht University, 2021) and consists of 24 stand-alone experiments covering the topics such as half-life, absorption, X-rays, and various others, for upper secondary school students (grades 10-12). This practical is usually taught using a 'cookbook', direct instruction (DI) style, students being guided through the experiment by simple, step-by-step worksheets.

However, inquiry-based learning (IBL) approaches to the same practical have been adopted over the years, with students drawing on their scientific knowledge to ask scientific questions. It has been shown that an IBL approach can have positive effects on students learning and increase their conceptual understanding of science concepts (Furtak et al., 2012; Minner et al., 2010). On the other hand, IBL is often criticized for not offering students enough support compared to DI approaches and depending on the implementations of IBL, negative impacts on learning have also been observed (Furtak et al., 2012; Kirschner et al., 2010). Therefore, development of conceptual understanding in IBL and DI situations remains an important subject for study.

This study intends to determine whether there is a difference in development of conceptual understanding between two variants of the ISP (Utrecht Universiteit, 2021): a direct instruction version with step-by-step instructions and maximum guidance versus an inquiry-based version, where the same experimental setup is provided, but where student formulate their own research question and devise a plan to answer this question using the provided setup. Earlier research on the differences in conceptual understanding when comparing IBL against DI for the ISP concluded that there were no significant differences (Verburg, 2018). On the basis of these results, the IBL version of the practical has since been revised several times between 2018 – 2021 to increase the amount of support that students experience. It is therefore of interest to determine whether current version of the practical results in an increase of conceptual understanding, compared to the DI version of the practical. The research question will be the following:

> What are the differences in conceptual understanding when comparing inquiry-based and direct instruction approaches for a secondary-school radiation physics practical?

This research question is divided into two sub-questions:

1. What are the differences in gains of conceptual understanding between direct instruction and inquiry-based approaches in a physics practical?
2. What do students report on the way in which elements of the inquiry-based approach support them in their learning process?

A mixed-methods, quasi-experimental approach will be used. The answer to the first, quantitative, sub-question will not result in a possible mechanism of the way that both approaches support concept development. The second, qualitative, sub-question is important for two reasons; (1) it provides clues for the mechanism for students' concept development, and (2) it may thus complement the first question, even if there are no significant differences between the two groups.

Hypothesis

As discussed earlier, guided inquiry-based learning elements are among the highest predictor of an increase in learning outcome (Furtak et al., 2012). As the current revision of the IBL version of this practical is found to be more towards guided IBL (Van Asseldonk, 2018), it is hypothesized that there is an increase in the specific learning outcome of conceptual understanding scores, when compared to the more teacher-centered DI version of the practical. When there is an increase in conceptual understanding scores, it is also hypothesized this becomes apparent in the focus group interviews.

Theoretical background

First, the process of constructive learning will be discussed, followed by an overview of the fundamentals of inquiry-based learning and direct instruction teaching approaches. Next, the model by which science through inquiry supports students in developing understanding is presented. This is followed and concluded by a comparison of the gains in conceptual understanding when looking at inquiry-based learning and direct instruction approaches.

The process of constructive learning

In traditional instruction design theories, the students' learning activities are under external control, directing how learners should behave to realize the objectives and transfer of knowledge from external source to the learner (Vermunt, 1998). In contrast, cognitive constructivist such as Jean Piaget and William Perry argue that learning is not passive knowledge-consuming and externally directed process, but rather an active, constructive, and self-directed process (Piaget & Elkind, 1968). The learner builds up internal knowledge representations that form a personal interpretation of their learning experiences. As knowledge is actively constructed, learning becomes a process of active discovery, the instructor providing the necessary recourses and guidance for students as they attempt to absorb new knowledge and modify their intellectual framework to accommodate new or changed concepts. Whereas the cognitivists would advise the use of systematic repetition of examples and concepts, and the memorization of facts, constructivists place greater importance on strategies that help students to actively assimilate new material (Wadsworth, 1996).

Building on the ideas of constructivism, researchers such as Lev Vygotsky (1978) argue that all cognitive functions originate in social interactions, implicating that learning does not comprise solely the assimilation and accommodation of new knowledge, but is rather a process by which learners adapt to a knowledge community. He argued that cognitive structures are essentially socially constructed or co-constructed. Vygotsky thus extends the ideas of Piaget with the concept that learning is essentially a collaborative process. Vygotsky also introduces the so-called *zone of proximal development* (ZPD) which is "the distance between what children can do by themselves and the next learning that they can be helped to achieve with competent assistance" (Raymond, 2000, p. 176). This then becomes the foundation for scaffolding, which is a teaching strategy that provides individualized support based on the learner's ZPD (Chang, Sung, & Chen, 2002). A *more knowledgeable other* provides support or scaffolds to facilitate the learner's learning and helps them to build upon their prior knowledge and internalize the new information (Van der Stuyf, 2002).

To summarize, social constructivist theories describe that learning is an active process which feels authentic to them. Students are supported in their learning by scaffolding – either from a more knowledgeable other, or teaching materials – and this all happens in a social context. These learning theories are also the fundamentals of inquiry-based learning.

Inquiry-Based learning and Direct Instruction

Direct instruction (DI) is a teacher-centered form of learning, where the teacher takes the instructional decisions and has the full responsibility for the learning process (Carnine, 2000). It is characterized by face-to-face instruction, learning new concepts by demonstration and by structured and repeated practice with guidance from the teacher (Ebbens, 2013).

A contrast of this teacher-centered approach is Inquiry-based learning (IBL), a more student-centered way of learning. Instead of information being conveyed by the teacher using presentations or worksheets, students learn by investigation, asking questions, collecting data and providing evidence and answers (Capps & Crawford, 2017). IBL follows the scientific approach to give answers to questions. Although critics have stated that a minimally guided approach will not give students enough structure to help them learn important concepts and procedures in science (Kirschner et al., 2010; Mayer, 2004), the more teacher-guided form has been shown to be very effective for learning science (Furtak et al., 2012). In this approach, IBL is not always fully student-led, but can rather be placed on a continuum of guidance, between teacher-led direct instruction and student-led discovery learning.

The model of developing understanding through inquiry

The model by which students gain understanding through inquiry is thoroughly described by Harlen (2013). For students, process of inquiry-based learning begins by trying to make sense of a phenomenon, or to try and answer a question about why something behaves in certain way. The initial exploration then reveals possible explanations as previous ideas are recalled ("I've seen something like this before, when..." "I think it has to do with…"). Several ideas from previous experiences might be relevant and these ideas are explored through discussion where one possible explanation or hypothesis is stated to be explored. Students then proceed to see how useful the chosen idea is by making a prediction based on the hypothesis, as only those ideas that can predict are useful. To test the prediction, data about the phenomenon is gathered and analyzed, whereafter the outcome is used as evidence to be compared with the predicted results. It is possible that more than one prediction and investigation is conducted as more than one prediction is desirable. From the results a provisional conclusion can be drawn about the initial idea(s). When the conclusion proves to be a good explanation then the existing idea is not only confirmed but also becomes more powerful because it can explain a whole range of phenomena (Harlen et al., 2010). Even when the idea does not seem to work and students must try another one (from the alternative ideas in Figure 1), the experience has helped them to refine the idea and knowing that is doesn't fit is thus also useful. This process of building understanding through collecting evidence for testing possible explanations and testing the ideas behind them in a scientific manner is described as learning through scientific inquiry (Figure 1). When more questions are raised as students gain more experience repeating this cycle of processes (Figure 1) leads to broad ideas that apply to a range of different objects and situation. Principles and concepts of new material cannot be directly transmitted to learners, they must be gradually constructed through the learners' own thinking.

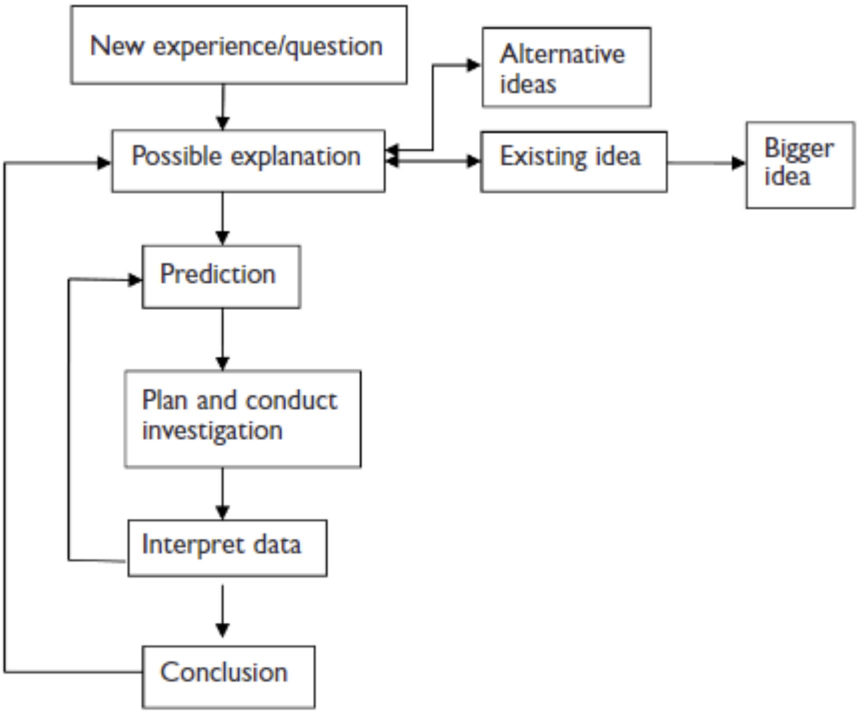


Figure 1. Schematic model of the processing cycle that students follow during the process of "science through inquiry". (Harlen, 2013, p. 16)

This model presents a view on how smaller ideas are progressively developed into bigger ideas. It is important to start from the ideas that students already have, as just putting these ideas aside students will still hold onto them because these are the ones they worked out themselves and still make sense to them (Harlen, 2013). Through science inquiry, they are given a chance to see for themselves which ideas are consistent with found evidence.

Comparing conceptual understanding between direct instruction and inquiry-based learning

One of the important objectives of science education is the enhancement of learners' scientific literacy, including the conceptual understanding (American Association for the Advancement of Science, 1993). How effective students can solve problems depends on their domain knowledge, skills, and attitudes. Their conceptual understanding is often regarded as a prime research issue in science learning evaluation (Eylon & Linn, 1988).

It has been shown that learning outcomes for IBL largely depend on the elements of IBL that are implemented (Furtak et al., 2012). As discussed earlier, one of these elements is the amount of guidance (teacher-guided inquiry vs. student-guided inquiry), while other elements that effect learning outcomes are the various domains of inquiry that are involved. These domains are described by Furtak (2012) as; procedural, epistemic, conceptual, and social (Table 1)

Table 1. Domains of inquiry and general activities that describe the various domains (adapted from Furtak et al., 2012).

Domain of inquiry	**Activities that describe the domain**
Procedural	Asking scientifically oriented questions Experimental design Representing data Hands-on experience
Epistemic	Drawing conclusions based on evidence Generating and revising theories
Conceptual	Drawing on/ connecting to prior knowledge Eliciting students' ideas and/or mental models
Social	Participating in class discussion Presentation Working collaboratively

The learning outcome is then strongly dependent on the amount of guidance that is given by the teacher in the inquiry process and the domains of inquiry that are involved in the lessons (Furtak et al., 2012). Although student-guided inquiry has been found to lead to improved learning outcomes when compared to traditional teacher-centered education, most notable increases of learning outcomes are found when the inquiry is teacher-guided.

It has been shown that the largest effect sizes on learning outcomes – including conceptual understanding – are achieved when the epistemic domain, as well as a combination of the procedural, epistemic and social domain are addressed (Furtak et al., 2012). Inquiry-based approaches adopting the procedural and epistemic domain for a physics course have also been linked to an increase in student achievement and conceptual understanding when compared to more direct instruction approaches (Arafah et al., 2020; Njoroge et al., 2014).

Guidance and inquiry domains present in the ISP

Looking at the inquiry-based experiments of the ionization practical, multiple teacher-guided inquiry elements can be found, such as introductory videos and a step-by-step guide to inquiry (Appendix B). Domains of inquiry that are most prominent are the procedural and epistemic domain, as e.g. students have to design the experiment and draw their conclusions based on gathered evidence. This means that the IBL-version of the ISP can be regarded as a teacher-guided inquiry activity with a focus on the procedural and epistemic domains of inquiry.

Methodology

A mixed-methods, semi-experimental approach is used to study the effects of inquiry-based learning on the degree of conceptual understanding of upper secondary school students for a radiation physics practical. A qualitative approach is used to research the conceptual understanding scores, while a qualitative approach in the form of focus group interviews is used to research what students report on the way the approaches supported their concept development and/or learning.

Context and participants

This research focused on the physics practical called the Ionization Radiation Practical (ISP, 'Ioniserende Stralen Practicum' in Dutch). This practical, given since 1972, is given to 15 – 18 year old higher general secondary education (HAVO) and pre-university education (VWO) students (grade 10 – 12). The main goal of the practical is to give these students hands-on experience in dealing with radioactive materials, which would otherwise remain an abstract topic.

Originally, the ISP adopted a DI approach, where students follow practical execution steps and answer the questions in 'cookbook' worksheets. This changed after the Institute for Curriculum Development (SLO; 'Stichting Leerplan Ontwikkeling' in Dutch) called for a lesson approach which would be more focused on the input of students (Hulsbeek et al., 1999). Starting from 2011, 11 of the 24 different experiments given in the IRP can be performed either using the DI version or the IBL version, the choice being up to the teacher. The experimental setups provided to the students are identical in both versions, but the worksheets accompanying the set-ups are very different. In the DI approach students are provided with research questions and step-by-step instructions on how to take measurements using the specific set-up and how to analyze the obtained results. The IBL approach, on the other hand, requires students to formulate their own research question, devise a plan to answer this question using the given set-up, and execute this plan themselves. The IBL version has been updated regularly, to include instructional videos at the start of the experiment to introduce the goal and main topics of inquiry, prompts being added to the worksheets, reminding students of what to include and what direction to think in when in doubt (Appendix B).

This research was performed at three schools throughout the Netherlands which the mobile lab would visit (Table 2). A completely random sample selection was not possible, as the selection of schools is dependent on the schools that offer themselves for the DI or IBL version. Whether students are randomly assigned DI or IBL versions of the experiment is also up to the teacher, and not fully up to the researcher, meaning the groups will most likely never be truly random.

Table 2, Information of schools that participated in the data collection.

City	Province	School type	Number of students	Class(es)	Approach
Schiedam	Zuid Holland	Urban	46	VWO	DI
Alphen aan den Rijn	Zuid Holland	Urban	55	VWO	IBL
Noordwijkerhout	Zuid Holland	Urban	45	HAVO and VWO	IBL

Study design

In this study, students conducting the IBL version of the experiment are regarded as the experimental group, while students conducting the DI version are regarded as the control group, pre- and posttest samples being dependent. Figure 2 gives an overview of the design. The qualitative data was collected using semi-structured focus group interviews with groups of students either conducting the DI or IBL approach.

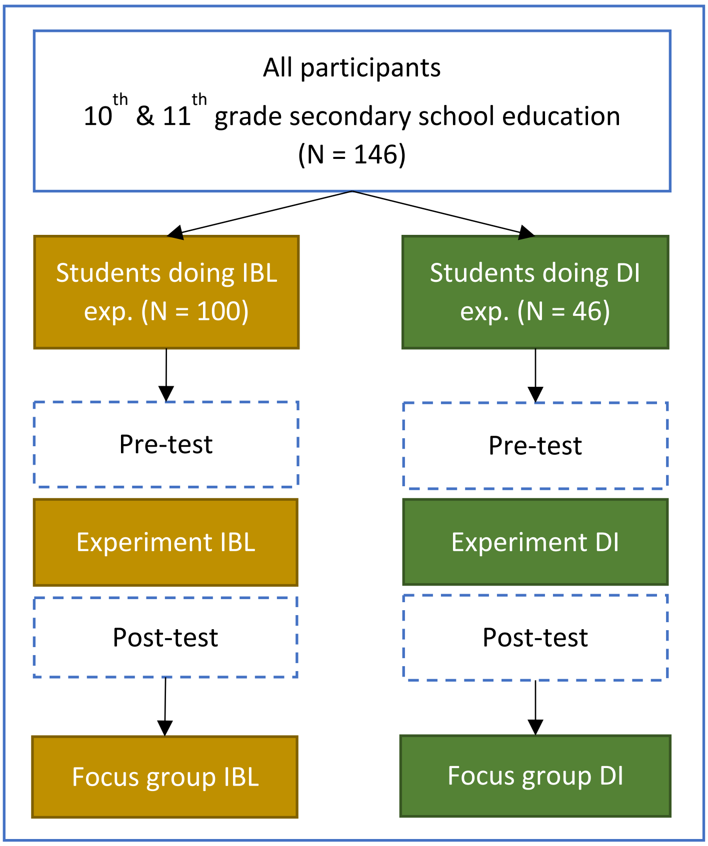


Figure 2. Flow diagram of the study design.

Instruments

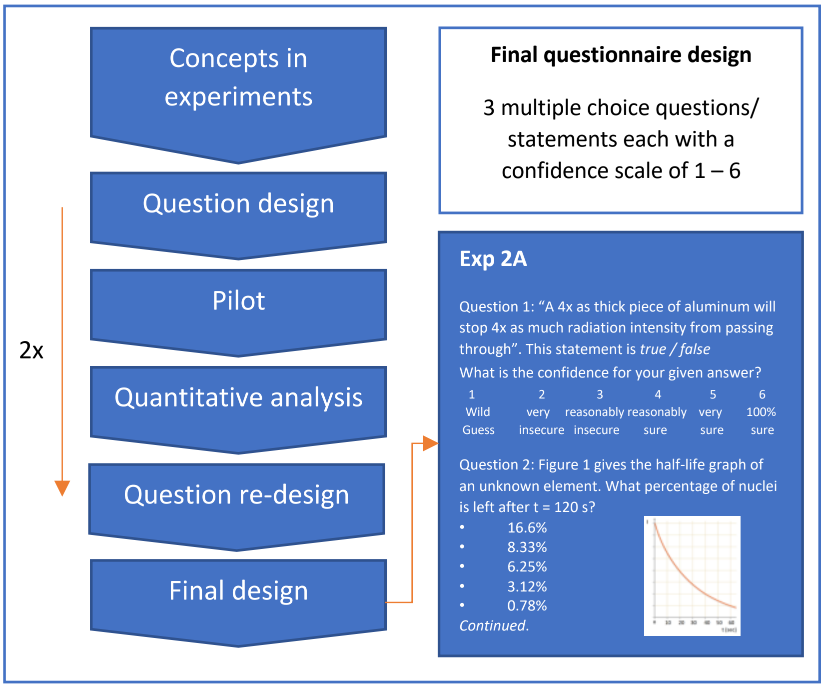
Experiment specific pre- and posttest questionnaire design

Several domains of physics have seen the development of conceptual tests, e.g., the Force Concept Inventory (FCI) (Hestenes et al., 1992) and the Brief Electricity and Magnetism Assessment (BEMA) (Ding et al., 2006). For radiation, no such standardized test is available, hence questionnaires for this study needed to be designed from scratch.

Figure 3 gives the design process for these questionnaires. The FCI and BEMA were analyzed in terms of categorization, item difficulty, and forms of questioning, so that these design guidelines can be used for the development of the radiation concept tests. In view of the limited time available for students to conduct the experiments and the fact they were asked to fill in the questionnaire twice, pre- and posttest questionnaires needed to be very short. A multiple-choice approach was chosen, focusing on concepts specific to a certain experiment. For each experiment received a specific pre- and posttest was designed. To gain insights into students' thinking, confidence ratings were added after each question (Caleon & Subramaniam, 2010), with a Likert scale from "wild guess" to "very confident".

The questions were designed by the researcher and discussed with an expert in the field of physics education before each piloting. The first question design was examined using a pilot test, in which 47 students participated (11th and 12th grade HAVO and VWO). Answers were quantitatively analyzed using a correction model. Questions that were either too easy or too difficult were re-designed or replaced with questions that were answered correctly around 50% of the time. Correct average scores per question (75%+) were unwanted, as this could lead to high pre-test scores, where little to no increases in test scores could be measured (Verburg, 2018). After the first redesign, the redesigned questions were piloted a second time, in which 176 students participated (11th grade). This process was repeated a second time, and the same criteria was used to redesign questions before constructing the final question design (Figure 3).

One of the constructed pre- and posttests can be found in Appendix C. Both pre- and posttest questionnaires consist of 3 multiple choice questions, each with a 6-point Likert scale (*Wild guess* to *100% certain*).



Final questionnaire design

3 multiple choice questions/ statements each with a confidence scale of 1 – 6

Exp 2A

Question 1: "A 4x as thick piece of aluminum will stop 4x as much radiation intensity from passing through". This statement is *true / false*

What is the confidence for your given answer?

1	2	3	4	5	6
Wild Guess	very insecure	reasonably insecure	reasonably sure	very sure	100% sure

Question 2: Figure 1 gives the half-life graph of an unknown element. What percentage of nuclei is left after t = 120 s?

- 16.6%
- 8.33%
- 6.25%
- 3.12%
- 0.78%

Continued.

Figure 3. Flowchart for the design of the pre- and posttest questionnaires.

Focus groups

To get a qualitative understanding of the ways in which students felt supported in their concept development and learning, semi-structured focus group interviews were conducted. Focus groups are often used so that researchers can explore the participants' perceptions, attitudes, feelings, ideas, etc., and encourage group interactions. They usually consist of small groups of 4 – 12 people, who meet with the researcher to discuss a selected topic in a non-threatening environment (Wilson, 1997). The students' answers and discussion amongst them allowed for conjectures about the reasons behind the quantitative results. As there were no interview guidelines available in literature for this specific goal, guidelines were developed using 5 cognitive and social constructivism core concepts on learning namely, authenticity, scaffolding, active/passive learning, social interaction, and the zone of proximal development (Figure 4). The interviews consisted of 5 questions, one for each of the selected constructivism concepts (appendix D). To aid students at the start of the interview and prevent them from overanalyzing or drawing to themselves, 'thinking aloud' hints were given to students at the start of the interview (Saul, 1998).

The interview guidelines and questions can be found in Appendix D.

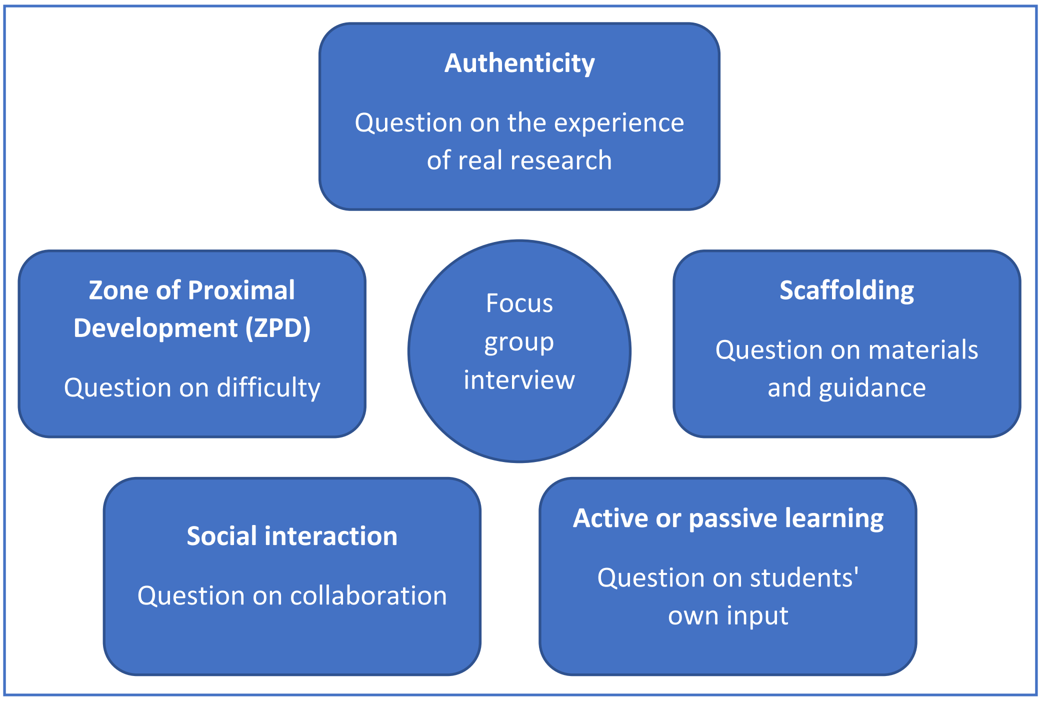


Figure 4. Concepts of cognitive and social constructivism used as guidelines for the focus group interviews

Procedure

To determine to what extent IBL elements were implemented in the IBL worksheets, Capps and Crawford’s (2017) framework (see Appendix A) can be used. This matrix can be used to determine whether implemented elements are either student or teacher-initiated and uses numerical scores from 1 to 4 to describe who initiates aspects of the inquiry process. 1 being the most teacher-initiated and 4 being the most student-initiated. Previous versions of the IBL worksheets resulted in an average score of about 3, meaning that the inquiry-based approach could be categorized as guided inquiry-based learning (Van Asseldonk, 2018). As recent changes to the IRP include the inclusion of an introductory video, and reminders/ hints in the worksheets, the core initiation of learning tasks themselves remained unchanged.

Students work in dyads or trios during the experiments. All groups receive oral instruction about the safety by one of the ISP staff members and procedural instructions by the researcher prior to the experiments. Next, students can work on both the experiments for around 90 minutes, including pre-test and post-test questionnaires. As all experiments are stalled out, when possible, groups that finish one experiment can immediately switch to the next. When groups would finish both experiments early, they must either until the end of the session or are free to go, which is up to the teacher to decide. From observations it also became apparent that it is quite normal for students to conduct one IBL and one DI version of the experiments, even when the school opted for one of both versions.

Even though the environments and instructions were generalized between the two approaches as much as possible, practical differences between them remained. Classes which performed the direct instruction experiments either did two or three in the session, one of which had to finalize their worksheets only after all measurement sections were completed. The classes performing the inquiry-based experiments did either one inquiry-based followed by one direct instruction experiment or just one inquiry-based experiment. This means that even though the pre-and posttest were focused on the first experiment, their schedule for the practical was different, with different time constraints. Students generally spend more time on the IBL version of the practical, as this includes preparation, discussion, and conclusion. Depending on the teacher, some students were also forced to complete at least two experiments, which can influence the amount of time the student feels he/she has available and lead to unwanted pressure or mistakes.

A total of 3 focus group interviews were conducted: 2 for an IBL class (experimental group) and 1 for a DI class (control group). This means that an interview was collected from every participating school. Multiple interviews were used to assess if the themes that emerge in one group are found in multiple groups as well, using a codebook (Table 3). In these classes 12 – 15 students were randomly approached and asked to cooperate in interviews after finalizing the experiments, whereafter 6 – 8 students would remain based on their available time after class and willingness to cooperate.

Informed consent

Involved students were asked for written and vocal consent regarding the recording of the interview and the usage of the data, and students could choose to opt out of the interviews at any given moment.

Table 3. Codebook used for the focus group interviews

Category	**Description**	**Typical Quote +**	**Typical quote -**
Scaffolding procedure	Quotes regarding the procedural scaffolding as provided e.g. by the worksheet and teacher guidance	“They were good and clear, for example next to the conclusion [on the worksheet] there were two questions you could answer.”	“Well because it was not particularly clear what you had to answer.”
Scaffolding non-salient tasks	Quotes regarding the procedural scaffolding as provided e.g. by the set-up manual and the knowledge clips	“After the video it was relatively easy to understand.”	“The video I could not quite understand, but after you, [the teacher], explained how the set-up worked we could just get started on our own.”
ZPD level of challenge	Quotes regarding the level of challenge students experience from e.g. the worksheet and practical execution. Too easy or too difficult is regarded as negative.	“But I did not think it was too easy or anything, if you would make it more difficult in this short amount of time, it would take much longer to complete.”	“Some of them I just could not understand, and it is frustrating if you cannot understand it.”
Social interaction	Quotes regarding the social interaction of students e.g. by working in pairs	“It is also nice to have participation from someone else, not only your own.”	… No quotes found. Typical could be “I did not enjoy working in pairs”
Authentic research	Quotes regarding the feeling of authenticity, meaning the feeling of doing “real” research, like a “real” researcher.	“No I understand, but that does mean it is research.”	“No, because you did not state the hypothesis or anything, you just follow the steps which means that it doesn’t feel like you are doing actual research.”
Active learning	Quotes regarding whether learning activities were described as active or passive.	“At the end, yes. You still have to do the practical, it is not done for you, you have to do the whole research, write down all the results.”	“Well no, it was all pretty much worked out already, you just had to calculate the results using a formula.”

Data analysis

Quantitative data

Quantitative analysis was conducted in SPSS. A one-way ANOVA could be used to assess whether the students' pre- and posttest score differences were equal between the DI and IBL approach. To determine if the increase (or decrease) of confidence scores was different between the DI and IBL approach, a one-way ANOVA was used to assess the data. This means that the Likert-scale data was assumed to have even spacing, so that it could be treated as interval data. The independent variable was experimental approach (DI versus IBL), and dependent variables were either difference in pre- and posttest scores and difference in pre- and posttest confidence. Effect sizes were determined using eta-squared (η^2). Before using ANOVA, two assumptions were checked: the posttest needs to be approximately normally distributed and there needs to be homogeneity of variances.

The posttest scores, and posttest confidence scores were not all normally distributed as indicated by a Shapiro-Wilks test for the posttest scores for both approaches ($p < 0.001$), and posttest confidence scores of the IBL approach ($p = 0.031$). A discussion of these assumptions can be found in Appendix E. Q-Q plots were visually analyzed to investigate whether deviations from normality were important (Figure 5 and 6).

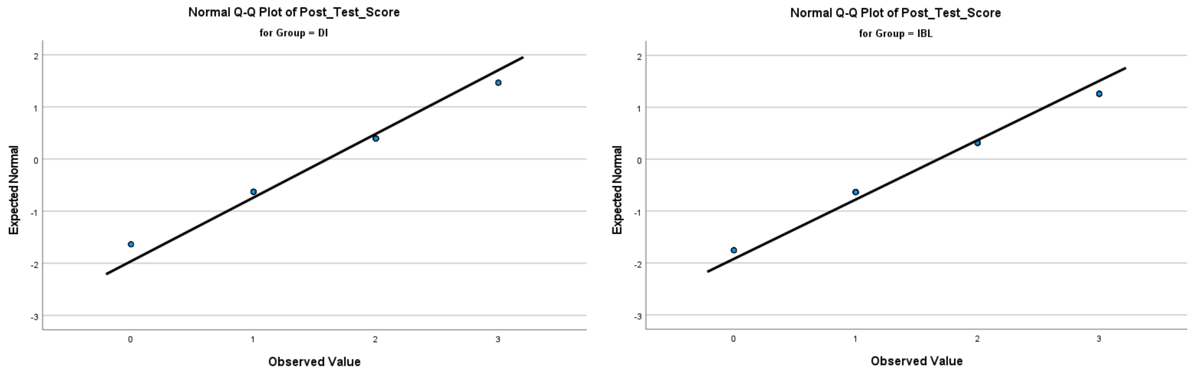


Figure 5. Q-Q plots for posttest scores for the DI and IBL approach of the practical.

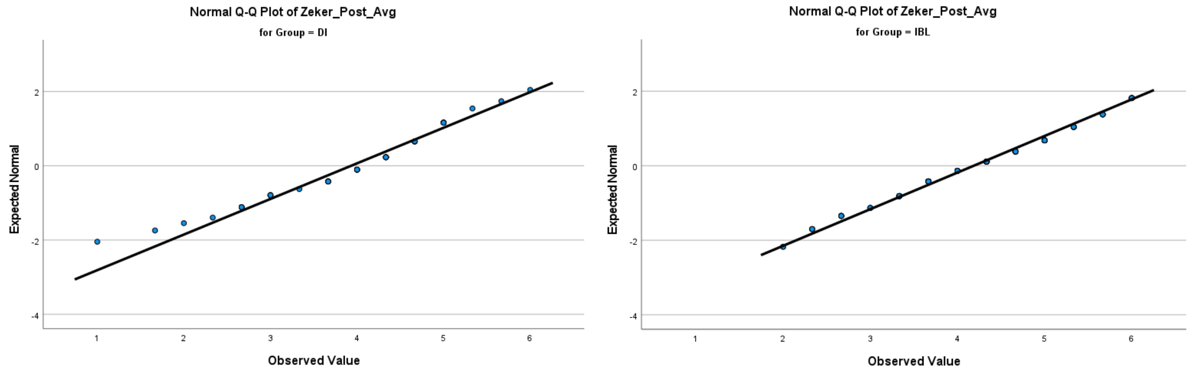


Figure 6. Q-Q plots for the posttest confidence scores for the DI and IBL approach of the practical.

From the Q-Q plots it is apparent that no large deviations from a normal distribution are observed.

Posttest scores and posttest confidence scores did meet the assumption of homogeneity of variances, as indicated by a Levene's test (p = 0.054 and 0.048, respectively). A discussion of these assumptions can also be found in Appendix E.

As the groups are unequal in sample size, this has implications for the statistical power and assumption of equal variance. An unequal sample can affect the robustness of the equal variance assumption, but as long as the variances stay equal this does not dramatically affect the statistical power or Type I error rates (Rusticus & Lovato, 2019). A general loss of power does occur, as equal-sized groups maximize the statistical power, and the power is based on the smallest sample size. Having a larger sample size for one of the groups thus does not hurt the power of the analysis (Wickens & Keppel, 2004).

On the basis of these analyses, it was decided to perform a one-way ANOVA in order to study possible differences in learning outcome in terms of test scores and confidence of students' answers. As an extra descriptive statistic, a Wilcoxon signed rank test could be used to assess whether the students' pre- and posttest scores and confidence within each group were equal. This test is more sensitive when compared to a Student *t*-test, and the preferred test for nonparametric data (Scheff, 2016).

Qualitative data

The interviews were transcribed, and a code book was developed around six key concepts of learning as described by cognitive and social constructivism: *authenticity*, *scaffolding*, *active/passive learning*, *social interaction*, and *the zone of proximal development*. Each of these categories was further coded for either positive or negative affect. The complete code book can be found in Appendix X. 36 quotes were coded by both coders, resulting in 35 agreements for the categories (Cohen's Kappa 0.966) and 34 agreements for the positive/negative association (Cohen's Kappa 0.880). This means the agreement is almost perfect (Cohen, 1960).

Results

First, the differences in gains of conceptual understanding between the DI and IBL approach will be presented in terms of test scores and confidence scores. The results of the focus group interviews will be represented by a distribution of the codes, and quotes that represent each category.

Test scores

Table 4 shows the descriptive statistics for the pre- and posttest scores. Mean pre- and posttest concept test scores are visually displayed in Figure 7. Both approaches seemed to result in increasing test scores with the increase being greater for the IBL approach compared to the DI approach.

A Wilcoxon signed-rank test indicated that the difference between pre- and posttest scores were statistically significant for the IBL approach, $T = 582$, $z = 2.487$, $p = 0.013$, but not significant for the DI approach, $T = 90$, $z = 0.728$, $p = 0.467$. A one-way ANOVA could be used to assess whether the students' increase in pre- and posttest scores were equal between the DI and IBL approach. The test revealed that this difference was in fact nonsignificant, $F(1, 146) = 1.485$, $p = 0.225$, $\eta^2 = 0.010$.

In conclusion, in both approaches seemed the average test scores increased. This increase was found to be significant in the IBL approach, but not for the DI approach. The differences in this increase of test scores between the DI and IBL approach of the practical were not significant.

Table 4. Descriptive statistics for the pre- and posttest scores

Approach	Test	*N*	*M*	*SD*
DI	Pre	46	1.54	0.86
	Post	46	1.61	0.83
IBL	Pre	100	1.48	0.89
	Post	100	1.68	0.88

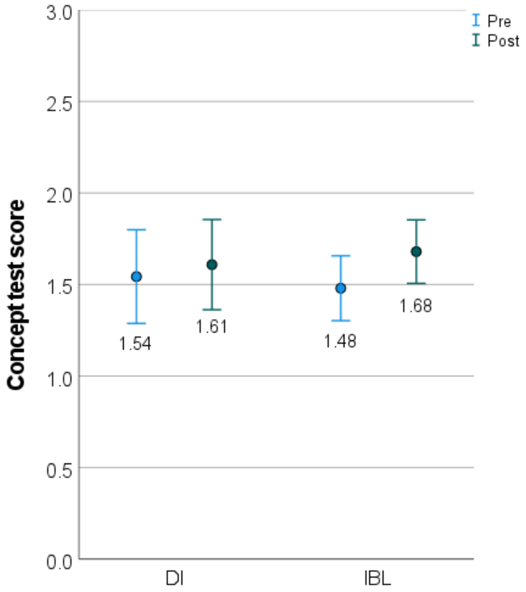


Figure 7. Mean pre- and posttest scores for the concept tests (3 items) for the DI and IBL experiments. Error bars represent the 95% confidence intervals for the means.

Confidence

The confidence score descriptive statistics are shown in Table 5 and mean pre- and posttest average confidence scores are visualized in Figure 8. Students' confidence scores increased for both approaches, but the increase was larger for the IBL approach than for the DI approach. On average, students conducting the DI experiments had a higher confidence in their answers (M = 3.93) than before (M = 3.25). A Wilcoxon signed-rank test indicated that this difference was statistically significant, T = 660, z = -5.186, $p < 0.001$. Students conducting the IBL experiments also had a higher confidence in their answers (M = 4.19) than before (M = 3.20). A one-way ANOVA could be used to assess whether the students' increase in pre- and posttest confidence scores were equal between the DI and IBL approach. The test revealed that this difference was in fact significant, F (1, 146) = 3.893, p = 0.050, η^2 = 0.026, which implied that there is a difference in the confidence score increase between the DI and IBL approach of the practical, favoring the IBL version.

In conclusion, the students' increase in confidence in their answers was significantly different within their experimental approach and gains were also significantly different between the DI and IBL approaches.

Table 5. Descriptive statistics for the confidence subscale.

Approach	Test	*N*	*M*	*SD*
DI	Pre	46	3.25	0.97
	Post	46	3.93	1.04
IBL	Pre	100	3.20	1.07
	Post	100	4.19	1.02

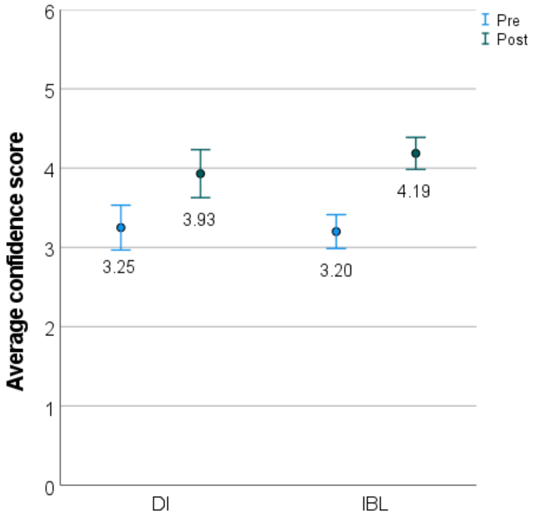


Figure 8. Mean pre- and posttest confidence scores for the concept tests (3 items) for the DI and IBL experiments. Error bars represent the 95% confidence intervals for the means.

Focus groups

The results of the focus group interviews will be presented in general with comments on the larger observations, whereafter each concept of learning will be presented in more detail with quotes from the interviews.

The distribution of the codes for the concepts of learning on two levels (positive – negative) for the DI and IBL approach are displayed in Figure 9.

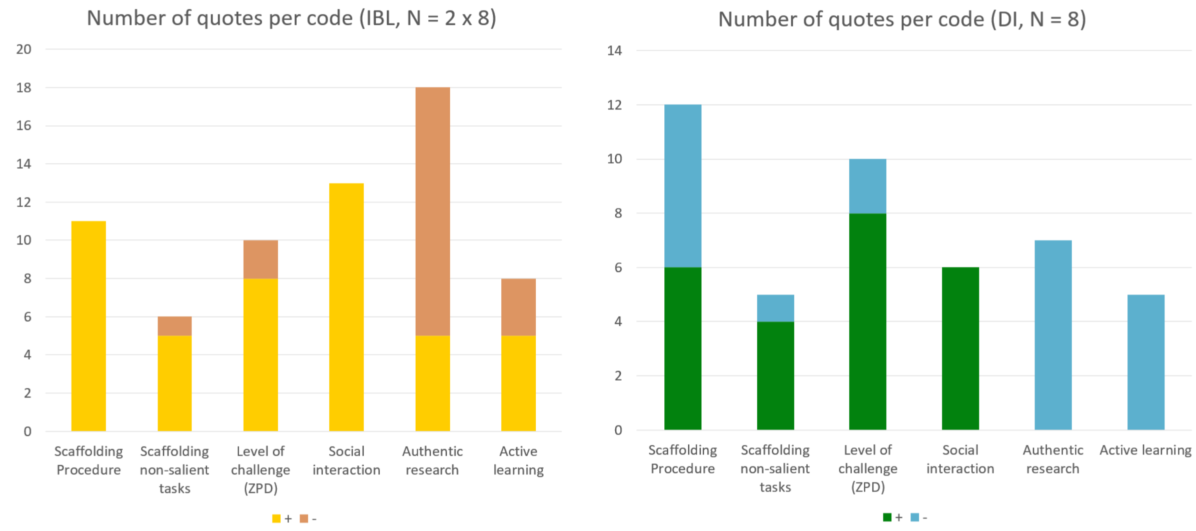


Figure 9. Distribution of codes for the focus group interview.

The results presented in Figure 9 provide an image of the students' perception on these different concepts of learning. A few key components of the results will be presented here. For the IBL approach, students are strictly positive about the scaffolding offered in the procedure, while the results for the DI approach are mixed. The social interaction is positive for both approaches. A few positive comments are made for the authenticity of research, but most of them are negative for the IBL approach and strictly negative for the DI approach. Students mention they were positively active in their learning more times than negative in the IBL approach, while the comments were strictly negative for the DI approach.

The results from the analysis of the transcripts can be narrowed down to 3 parts where student appear to experience differences. Students felt more supported by the scaffolding provided by the worksheet while performing the IBL approach of the practical. Moreover, students felt more active in their involvement in the practical of the IBL approach. Students also felt like they were doing more "real" research in the IBL approach.

Scaffolding in the procedure

There are no negative comments on the scaffolding of procedural tasks for the IBL approach, compared to comments that are split between positive and negative for the DI approach. Students report the procedure as given in the DI worksheets to be vague on several occasions:

> *Student M1: I found the calculations, especially just to understand the question, quite difficult. The questions were somewhat complicated, while the calculations in the question were not difficult at all. I thought it was more reading comprehension than physics.*

> *Student M2: Some questions I just didn't understand, then it's frustrating when I can’t answer them.*

Here it seems student M1 refers to difficulty in understanding the questions of the DI approach, while feeling competent enough to answer them. Some students did feel supported by the worksheets:

> *Student M3: Oh yeah, I liked that [the way the worksheet was set up], especially because it was a nice introduction to those practical’s, instead of getting all complicated things thrown at your head, you could learn from this in a constructive way.*

Students conducting the IBL approach did not give negative comments on the guidance in the worksheets or the worksheets in general. Students felt supported by the different worksheets, but also mention that the teacher stepped in to supported before they could get to work independently:

> *Student F1: [The worksheets] they were good and clear, for example next to the conclusion [on the worksheet] there were two questions you could answer to help you.”*
>
> *Student F2: The video I could not quite understand, but after you, [the teacher], explained how the set-up worked, we could just get started on our own.*

This scaffolding by the teacher is not mentioned in the DI approach.

Scaffolding in non-salient tasks

When asked about the support they received from material provided besides the worksheets or individual support from the teacher, students from the different approaches are equally positive/ negative about the support they received but mention different materials. The students who followed the DI approach mentioned the way in which the pracftical setup was set up in general:

> *Student M2: Everything was really clear, everything had red and yellow stickers [to know which buttons you have to press], but I did not really used the extra information outside of the worksheets. I thought it was a bit unnecessary, you could use it as an introduction but not really during the experiment.*
>
> *Student F1: Oh, in one of the two experiments I found that extra information helpful. I did not know how to use a logarithmic graph paper anymore so it was nice to see that it was included.*
>
> *Student F2: Overall the practical set-up was just really clear.*

Students in IBL group seem to agree as well but mention different supports. In both IBL approach interviews, students mention the video as support material:

> *Student F3: The video was really useful.*
>
> *Student F4: Yes after the video it was relatively easy to understand.*
>
> *Student F5: The combination of the worksheets and the video made it really clear. In the video it was explained what you had to do, and the worksheet was nice as support.*
>
> *Student M5: With the inclusion of the video I found it the easiest to do.*

Level of challenge (ZPD)

Regarding the level of challenge, when asked about the difficulty of the practical, students in the DI group mentioned they thought the difficulty was right in the middle:

> *Student M1: There were no difficult questions in there per se, more just vague questions which made it more difficult, but I think on average I was quite pleased with the difficulty. I would find this easier to do than a physics exam.*

There were no comments from students who mentioned the difficulty being either very high or very low. The same is true for the IBL approach, and a couple of students mentioned that they had expected not to be able to understand the experiment:

> *Student F4: More personally, but I really did not think I would understand what was going on.*
>
> *Student F5: Yes, I thought it would be very difficult.*

Social interaction

For both the IBL and DI approach, students spoke positively about the social interaction during the experiment, agreeing that working in pairs was more beneficial compared to working individually. There was no distinct difference between the IBL and DI approach.

> *Student F5: [in the IBL approach] when you're working together you are more sure you are doing it correctly. If I had to do it alone, it would seem more complicated to me.*
>
> *Student M4: I agree, I liked working in pairs more than individually, it would be more boring otherwise.*

Students who conducted the DI experiments reacted in the same manner, even when they are not that fond of working in pairs in general:

> *Student M1: Working together is just more relaxing, and it makes it more fun.*
>
> *Student M2: Personally, I don't like working together that much, but with experiments like this there are more things you need to pay attention to. You cannot just write stuff down and do whatever you want, you need to talk about it with your partner about what you are doing or what you are going to write down.*

Authentic research

Students in the IBL group gave mixed comments on whether they were doing real research. At one instance, a discussion would arise between four students on whether the IBL approach of the experiment would count as 'real research':

> *Student F4: I don't think so, as what you are researching is already known, you are doing it more for yourself, because you don't know it yourself. At the end everything you are doing here has already been done before so it doesn't feel like real research*
>
> *Student M4: I agree, it is not actual research, you're not doing something new.*
>
> *Student M5: Well, I don't fully agree, as your final research project [during your exam year] is often also something that has been researched already.*
>
> *Students F4: Yes, but I don't think that is real research either, it.*
>
> *Students F5: It is more like research for yourself, not like research for physics.*
>
> *Students M5: Well yes but that does mean it is research.*

> *Students F5: I don't know, I still see it as more of an assignment instead of research.*

Students of the DI group all agreed on the fact that they did not feel like they were doing 'actual research' when asked to give their opinion:

> *Student F6: No, because you did not state the hypothesis or anything, you just follow the steps which means that it does not feel like you are doing actual research.*

Active learning

When students conducting the IBL practical were asked whether they felt like they had to do a lot on their own, students responded both positively, and negatively for the IBL approach:

> *Student M5: Yes in the end I think so, because you just have to do the practical yourself, it is not done for you completely, you have to do the entire research, write down all the results…*
>
> *Student F5: Well, no, it was all fairly worked out, and then you just had to present the results with a calculation.*

On the other hand, when students conducting the DI experiment were asked the same question, all quotes from students were found to be quite negative:

> *Student M1: Well, it would be nice if you could assemble certain things yourself, now it was much like everything was done for you and all you have to do is turn it on.*

Conclusion

The aim of this study was to investigate the effect of an inquiry-based learning approach on students' conceptual understanding of physics, compared to the original direct instruction approach. To investigate this topic, two sub-questions were created:

1. What are the differences in gains of conceptual understanding between direct instruction and inquiry-based approaches in a physics practical?
2. What do students report on the way in which elements of the inquiry-based approach support them in their learning process?

To answer the first sub-question, a quasi-experimental study design with 148 participating upper secondary school students was employed. As assessed by pre- and posttest scores between the IBL and DI approaches of the experiments, the results showed that there was an increase in conceptual understanding for both approaches. The increase in test scores for the IBL version was larger than the DI version, but the difference between the two groups was not found to be statistically significant. The results do indicate that the students might be learning more in the IBL approach of the practical compared to the DI approach. The associated confidence with which these questions were answered also increased for both versions of the practical as assessed by pre- and posttest confidence scores. The increase in confidence was found to be higher for the IBL version, and the difference in increase between the two versions of the experiment was found to be statistically significant. What can be concluded is that the students conducting the IBL approach are answering questions with more confidence, and with a significantly higher score, indicating better learning overall. What should be considered is that students get more time to conduct the experiment during the IBL approach, as this includes preparation, conclusion, and discussion, which is not included in the DI approach. As a result, students simply spend more time with the experiment in the IBL approach, which could be a reason for the increase in the results.

The second sub-question aimed to describe possible mechanisms to explain differences in conceptual understanding and confidence. Focus group interviews were conducted at each of the three participating schools: one interview for the DI approach and two for the IBL approach. The interviews were designed around concepts of constructivist learning theory, as to identify in which ways learning takes place, and transcripts were analyzed in the same manner. It appears that notable differences can be found in three concepts: scaffolding, active/passive learning, and authenticity. Students feel more supported by the scaffolding present in IBL approach of the practical. From the data this seems to be mainly due to the usage of an introductory video, and the way the worksheet was organized using guiding questions. In contrast, students mention to be frustrated by some of the questions present in the DI worksheet, due to their perceived difficulty or irrelevance. These questions are not present in the IBL version of the worksheets. Furthermore, from the data it seems students feel like they have a more active participation in the IBL approach, compared to the DI approach. Students also felt like they were doing more "real" research in the IBL approach. The general increase in test scores and confidence for both the IBL and DI version of the experiments could thus attributed to the positive ways in which students experience the social interaction.

The main research question was: What are the differences in conceptual understanding when comparing inquiry-based and direct instruction for a secondary-school radiation physics practical?

This research found that the gains of students' conceptual understanding were higher for the IBL approach, when comparing the IBL approach to the DI approach of the practical. The results did however not differ significantly. Both groups showed a significant improvement in conceptual understanding. This means that both the DI and IBL approach are succeeding in their goal to increase student understanding of ionizing radiation. The confidence scores when answering questions increased for both groups, but more for the students in the IBL group compared to the DI group. In previous research on the Ionization Radiation Practical, van Asseldonk (2018) concluded that when comparing the DI and IBL approach on the level of motivation, students experience more autonomy during the IBL approach. This could be one of the reasons to explain the increase in confidence. This study add even more context to these results, as students describe the feeling they had a more active participation in the IBL approach, which can be linked to an increase in autonomy.

Discussion

Limitations

The findings of this study are subject to several methodological limitations. One of these is the use of experiment specific concept tests as a measure for conceptual understanding. The design of the questionnaires might align better with the fixed experimental design of the DI approach. As discussed in the Methodology section, students in the IBL approach are free to pursue their own research question and design their experiment to answer it. It is possible that the research question a group answers does not help them to better answer the questionnaire. In addition, the practical supervisor checks the workplan and research question of each IBL group of students before they are allowed to start their experiment. In most cases, however, students are guided towards the same research question when they have difficulties, which means that a smaller portion of students should face this problem.

Furthermore, assignment of participants to the either the DI or IBL approach was done quasi-randomly as discussed in the Methodology section. It is possible that bias is introduced by this quasi-random participant assignment could affect the pretest test scores and confidence scores as e.g., a teacher might opt to use the IBL approach for a higher achieving class of students. In addition, as discussed in the Methodology section, the number of participants in the control group was relatively limited compared to the experimental group (48 versus 100). The lower number of participants for the control group was a result of sub-optimal scheduling. Within the relatively short time window of the data collection, there were simply less schools that opted for the DI approach, as opposed to the IBL approach. Although the total number of participants is still quite high for a statistical analysis, the statistical power of the analysis is dependent on the smallest group. Increasing the control group to 100 students would increase the power of the analysis and lower the 95% confidence interval of the DI group. The levels of education were also different between the control group and experiment group; the control group consisted of 10th and 11th grade higher general secondary education and pre-university education classes, while the experiment group consisted only of 11th grade pre-university education classes.

For qualitative data collection, 3 focus groups were used: one for the DI approach and two for the IBL approach. As 3 – 6 focus group interviews are advised by Onwuegbuzie et al. (2009), combined with the fact that there was repetition between the two IBL groups, it is possible that theoretical saturation of topics and comments might have been met. Another factor that should be considered is that during the qualitative analysis of the Likert scale data, it was assumed the scales could be used as interval data. This assumes that the distribution between the Likert scale points is even, which is not proven. The power of the analysis leaves something to be desired and this power could be increased by changing the scale from 6 points to 11 (Wu & Leung, 2017).

The results of this study should, however, not be understated. Compared to previous research revolving around the ISP, this research was the first to compare conceptual understanding on a quantitative scale with a reasonable number of participants for both group, where previous research was mostly focused on motivation and autonomy. The design and redesign of experiment-specific pre- and posttests also lay a great foundation for future studies revolving around conceptual understanding within the ISP. It is with no doubt that more adjustments to the IBL and even the DI approach of this practical will be made, all for the better. The tools presented here will always be helpful when researchers are curious of the results of these adjustments.

Implications

Altogether, this study has found that the inquiry-based and direct instruction approach implemented in the ISP increase the conceptual understanding of students, but the increase of the approaches did not differ significantly. Although these findings do not directly confirm the stated hypothesis, these results fit the data presented by Furtak (2012), as although the increase in conceptual understanding does not significantly increase between the DI and IBL approach, some studies examined by Furtak concluded the same. As discussed in the Theoretical background, the amount of guidance is an important factor that determines the learning outcome. I speculate that the recent additions of instructional videos to increase the guidance, can still not compete with direct guidance from a teacher, face-to-face. What is also true is that the amount of guidance a teacher can give changes with every group that conducts the practical. The number of teachers that are present in the room changes, the availability of the expert changes, and depending on the time of day their effort can also change. These factors contribute to the fact that results of studies on IBL vs DI fluctuate.

Future research

These results direct future research towards investigating whether quantitative differences in conceptual understanding between the DI and IBL approach present themselves under circumstances different than presented in this research. A good starting point for this research could be by addressing the limitations stated in the previous section, such as increasing the amount of data that is collected, polishing the research instruments by adding questions specific to each practical setup. It is possible to develop other questions with which conceptual understanding can be presented, i.e. questions that require students to answers with explanations instead of multiple-choice answers. One of the interesting ways to then evaluate the answers is using Comparative Judgement, where experts quickly evaluate the conceptual understanding of students, as opposed to using rubrics (Bisson et al., 2016). Furthermore, changing the Likert scale from 6 point to 11 as mentioned in the limitations section, or switching it out for a continuous measurement scale would lead to an increase in statistical power (Allen & Seaman, 2007).

It would also be interesting to explore why students feel more confident in answering concept test questions for the IBL approach. Underlying factors which influence these decisions could be explored so that possible mechanisms for this increase in confidence can be presented.

This study has demonstrated that inquiry-based learning as implemented in an ionization radiation physics practical in itself is not enough to significantly increase conceptual understanding when compared to a direct instruction approach. Both approaches seem to increase conceptual understanding, but the IBL approach seems to more advantages besides measuring conceptual understanding. Students felt supported by the materials provided in the IBL approach, they took a more active role in their learning, and previous studies noted in increase in their motivation (Van Asseldonk, 2018). In my own opinion, these factors contribute to a positive trend revolving the IBL approach of this practical, while also indicating that the comparison of DI and IBL approaches in general is one that depends on factors we might not even be aware of, and continues to need design improvements.

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Appendix A: Inquiry dimension matrix

Reprinted from Capps & Crawford (2017).

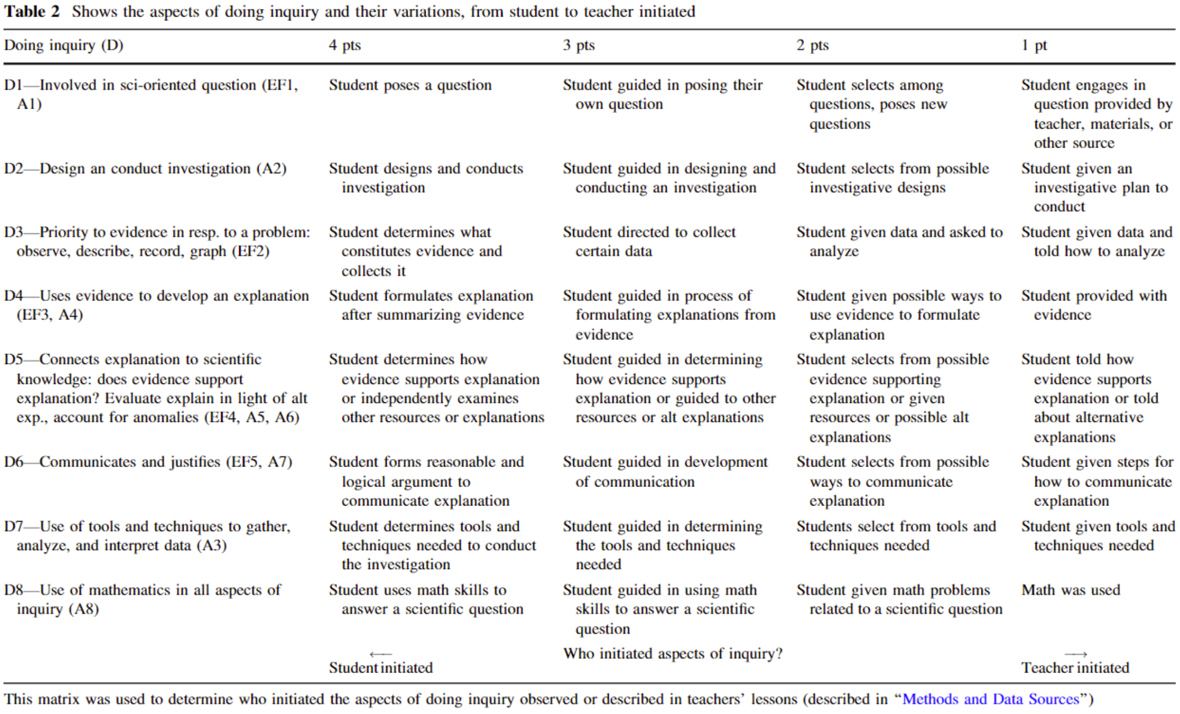


Table 2 Shows the aspects of doing inquiry and their variations, from student to teacher initiated

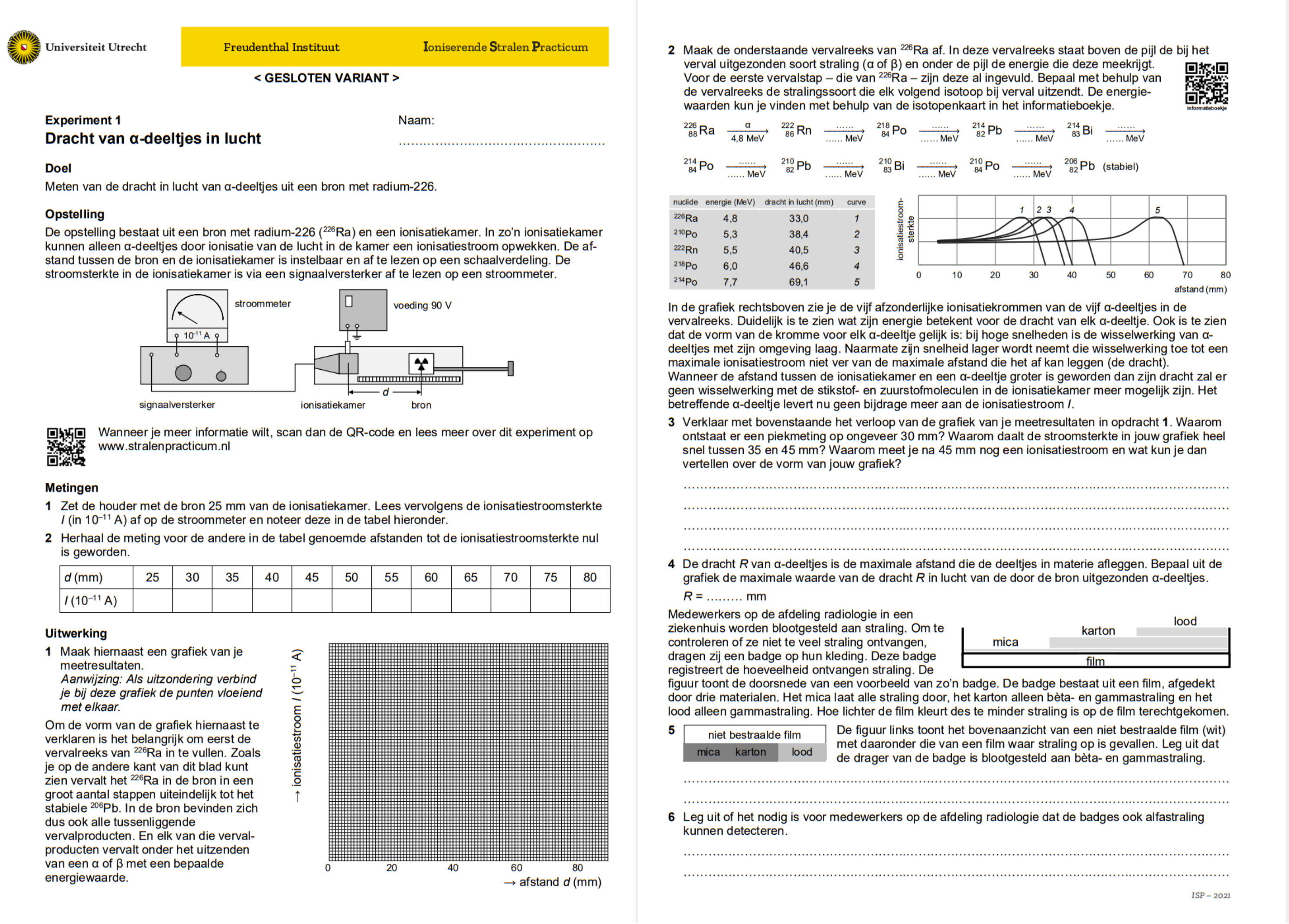
Doing inquiry (D)	4 pts	3 pts	2 pts	1 pt
D1—Involved in sci-oriented question (EF1, A1)	Student poses a question	Student guided in posing their own question	Student selects among questions, poses new questions	Student engages in question provided by teacher, materials, or other source
D2—Design an conduct investigation (A2)	Student designs and conducts investigation	Student guided in designing and conducting an investigation	Student selects from possible investigative designs	Student given an investigative plan to conduct
D3—Priority to evidence in resp. to a problem: observe, describe, record, graph (EF2)	Student determines what constitutes evidence and collects it	Student directed to collect certain data	Student given data and asked to analyze	Student given data and told how to analyze
D4—Uses evidence to develop an explanation (EF3, A4)	Student formulates explanation after summarizing evidence	Student guided in process of formulating explanations from evidence	Student given possible ways to use evidence to formulate explanation	Student provided with evidence
D5—Connects explanation to scientific knowledge: does evidence support explanation? Evaluate explain in light of alt exp., account for anomalies (EF4, A5, A6)	Student determines how evidence supports explanation or independently examines other resources or explanations	Student guided in determining how evidence supports explanation or guided to other resources or alt explanations	Student selects from possible evidence supporting explanation or given resources or possible alt explanations	Student told how evidence supports explanation or told about alternative explanations
D6—Communicates and justifies (EF5, A7)	Student forms reasonable and logical argument to communicate explanation	Student guided in development of communication	Student selects from possible ways to communicate explanation	Student given steps for how to communicate explanation
D7—Use of tools and techniques to gather, analyze, and interpret data (A3)	Student determines tools and techniques needed to conduct the investigation	Student guided in determining the tools and techniques needed	Students select from tools and techniques needed	Student given tools and techniques needed
D8—Use of mathematics in all aspects of inquiry (A8)	Student uses math skills to answer a scientific question	Student guided in using math skills to answer a scientific question	Student given math problems related to a scientific question	Math was used
	⟵ Student initiated	Who initiated aspects of inquiry?		⟶ Teacher initiated

This matrix was used to determine who initiated the aspects of doing inquiry observed or described in teachers' lessons (described in "Methods and Data Sources")

Appendix B

Ionizing Radiation Practical worksheets

Typical Ionizing Radiation Practical worksheets are set up as displayed in Figure B1, and Figure B2.



Universiteit Utrecht

Freudenthal Instituut   Ioniserende Stralen Practicum

< GESLOTEN VARIANT >

Experiment 1

Dracht van α-deeltjes in lucht

Naam: ………………………………………

Doel

Meten van de dracht in lucht van α-deeltjes uit een bron met radium-226.

Opstelling

De opstelling bestaat uit een bron met radium-226 (^{226}Ra) en een ionisatiekamer. In zo'n ionisatiekamer kunnen alleen α-deeltjes door ionisatie van de lucht in de kamer een ionisatiestroom opwekken. De afstand tussen de bron en de ionisatiekamer is instelbaar en af te lezen op een schaalverdeling. De stroomsterkte in de ionisatiekamer is via een signaalversterker af te lezen op een stroommeter.

Wanneer je meer informatie wilt, scan dan de QR-code en lees meer over dit experiment op www.stralenpracticum.nl

Metingen

1 Zet de houder met de bron 25 mm van de ionisatiekamer. Lees vervolgens de ionisatiestroomsterkte I (in 10^{-11} A) af op de stroommeter en noteer deze in de tabel hieronder.

2 Herhaal de meting voor de andere in de tabel genoemde afstanden tot de ionisatiestroomsterkte nul is geworden.

d (mm)	25	30	35	40	45	50	55	60	65	70	75	80
I (10^{-11} A)												

Uitwerking

1 Maak hiernaast een grafiek van je meetresultaten.
Aanwijzing: Als uitzondering verbind je bij deze grafiek de punten vloeiend met elkaar.

Om de vorm van de grafiek hiernaast te verklaren is het belangrijk om eerst de vervalreeks van ^{226}Ra in te vullen. Zoals je op de andere kant van dit blad kunt zien vervalt het ^{226}Ra in de bron in een groot aantal stappen uiteindelijk tot het stabiele ^{206}Pb. In de bron bevinden zich dus ook alle tussenliggende vervalproducten. En elk van die vervalproducten vervalt onder het uitzenden van een α of β met een bepaalde energiewaarde.

2 Maak de onderstaande vervalreeks van ^{226}Ra af. In deze vervalreeks staat boven de pijl de bij het verval uitgezonden soort straling (α of β) en onder de pijl de energie die deze meekrijgt. Voor de eerste vervalstap – die van ^{226}Ra – zijn deze al ingevuld. Bepaal met behulp van de vervalreeks de stralingssoort die elk volgend isotoop bij verval uitzendt. De energiewaarden kun je vinden met behulp van de isotopenkaart in het informatieboekje.

$$^{226}_{88}\text{Ra} \xrightarrow[4{,}8\text{ MeV}]{\alpha} {}^{222}_{86}\text{Rn} \xrightarrow[\text{...... MeV}]{\text{......}} {}^{218}_{84}\text{Po} \xrightarrow[\text{...... MeV}]{\text{......}} {}^{214}_{82}\text{Pb} \xrightarrow[\text{...... MeV}]{\text{......}} {}^{214}_{83}\text{Bi} \xrightarrow[\text{...... MeV}]{\text{......}}$$

$$^{214}_{84}\text{Po} \xrightarrow[\text{...... MeV}]{\text{......}} {}^{210}_{82}\text{Pb} \xrightarrow[\text{...... MeV}]{\text{......}} {}^{210}_{83}\text{Bi} \xrightarrow[\text{...... MeV}]{\text{......}} {}^{210}_{84}\text{Po} \xrightarrow[\text{...... MeV}]{\text{......}} {}^{206}_{82}\text{Pb} \text{ (stabiel)}$$

nuclide	energie (MeV)	dracht in lucht (mm)	curve
^{226}Ra	4,8	33,0	*1*
^{210}Po	5,3	38,4	*2*
^{222}Rn	5,5	40,5	*3*
^{218}Po	6,0	46,6	*4*
^{214}Po	7,7	69,1	*5*

In de grafiek rechtsboven zie je de vijf afzonderlijke ionisatiekrommen van de vijf α-deeltjes in de vervalreeks. Duidelijk is te zien wat zijn energie betekent voor de dracht van elk α-deeltje. Ook is te zien dat de vorm van de kromme voor elk α-deeltje gelijk is: bij hoge snelheden is de wisselwerking van α-deeltjes met zijn omgeving laag. Naarmate zijn snelheid lager wordt neemt die wisselwerking toe tot een maximale ionisatiestroom niet ver van de maximale afstand die het af kan leggen (de dracht). Wanneer de afstand tussen de ionisatiekamer en een α-deeltje groter is geworden dan zijn dracht zal er geen wisselwerking met de stikstof- en zuurstofmoleculen in de ionisatiekamer meer mogelijk zijn. Het betreffende α-deeltje levert nu geen bijdrage meer aan de ionisatiestroom I.

3 Verklaar met bovenstaande het verloop van de grafiek van je meetresultaten in opdracht **1**. Waarom ontstaat er een piekmeting op ongeveer 30 mm? Waarom daalt de stroomsterkte in jouw grafiek heel snel tussen 35 en 45 mm? Waarom meet je na 45 mm nog een ionisatiestroom en wat kun je dan vertellen over de vorm van jouw grafiek?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

4 De dracht R van α-deeltjes is de maximale afstand die de deeltjes in materie afleggen. Bepaal uit de grafiek de maximale waarde van de dracht R in lucht van de door de bron uitgezonden α-deeltjes.

R = ……… mm

Medewerkers op de afdeling radiologie in een ziekenhuis worden blootgesteld aan straling. Om te controleren of ze niet te veel straling ontvangen, dragen zij een badge op hun kleding. Deze badge registreert de hoeveelheid ontvangen straling. De figuur toont de doorsnede van een voorbeeld van zo'n badge. De badge bestaat uit een film, afgedekt door drie materialen. Het mica laat alle straling door, het karton alleen bèta- en gammastraling en het lood alleen gammastraling. Hoe lichter de film kleurt des te minder straling is op de film terechtgekomen.

5 De figuur links toont het bovenaanzicht van een niet bestraalde film (wit) met daaronder die van een film waar straling op is gevallen. Leg uit dat de drager van de badge is blootgesteld aan bèta- en gammastraling.

……………………………………………………………………………………………

……………………………………………………………………………………………

6 Leg uit of het nodig is voor medewerkers op de afdeling radiologie dat de badges ook alfastraling kunnen detecteren.

……………………………………………………………………………………………

……………………………………………………………………………………………

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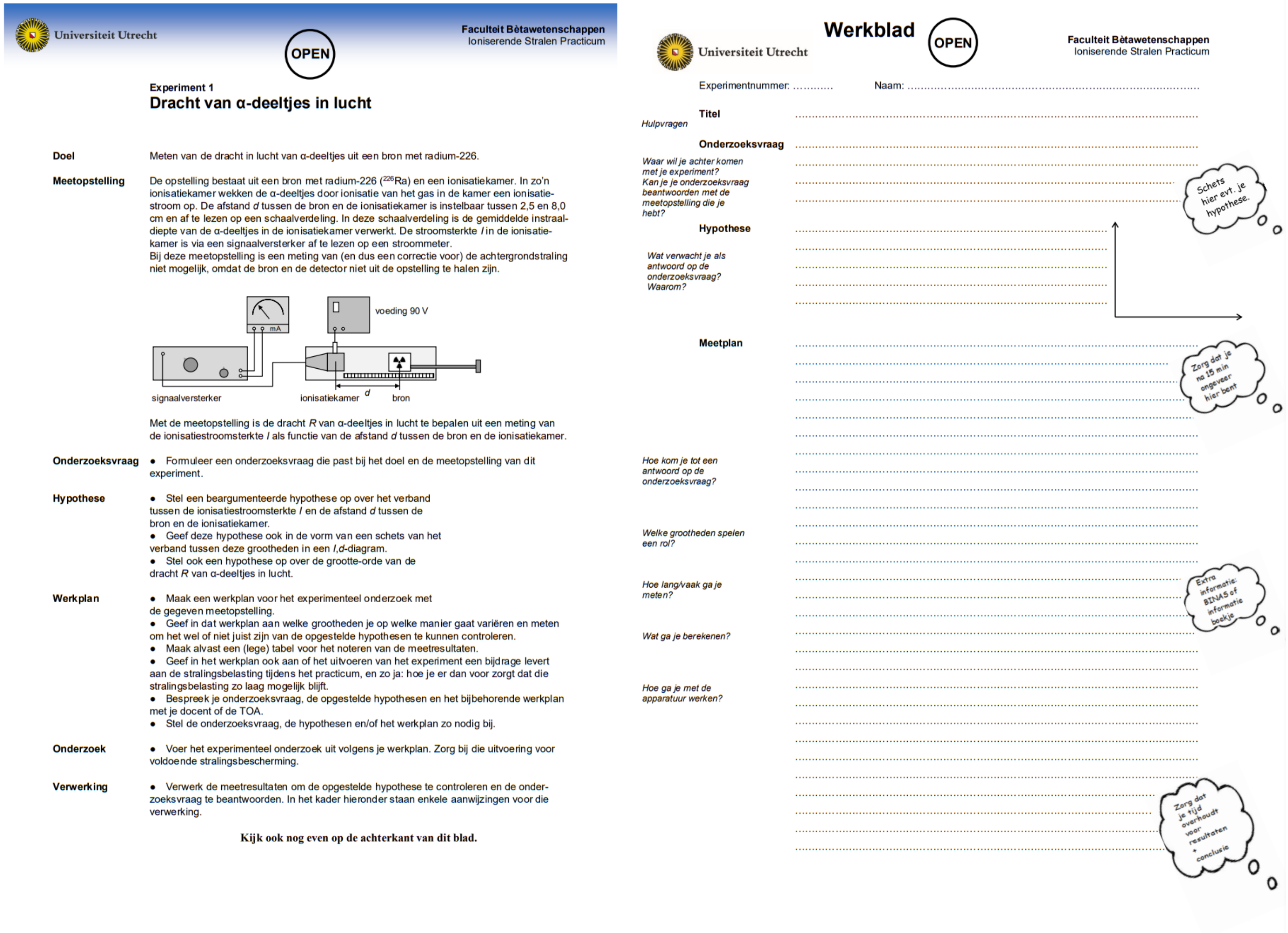
Figure B1. Direct instruction approach worksheets of experiment 1.



Universiteit Utrecht

OPEN

Faculteit Bètawetenschappen
Ioniserende Stralen Practicum

Experiment 1

Dracht van α-deeltjes in lucht

Doel Meten van de dracht in lucht van α-deeltjes uit een bron met radium-226.

Meetopstelling De opstelling bestaat uit een bron met radium-226 (^{226}Ra) en een ionisatiekamer. In zo'n ionisatiekamer wekken de α-deeltjes door ionisatie van het gas in de kamer een ionisatiestroom op. De afstand *d* tussen de bron en de ionisatiekamer is instelbaar tussen 2,5 en 8,0 cm en af te lezen op een schaalverdeling. In deze schaalverdeling is de gemiddelde instraaldiepte van de α-deeltjes in de ionisatiekamer verwerkt. De stroomsterkte *I* in de ionisatiekamer is via een signaalversterker af te lezen op een stroommeter.
Bij deze meetopstelling is een meting van (en dus een correctie voor) de achtergrondstraling niet mogelijk, omdat de bron en de detector niet uit de opstelling te halen zijn.

Met de meetopstelling is de dracht *R* van α-deeltjes in lucht te bepalen uit een meting van de ionisatiestroomsterkte *I* als functie van de afstand *d* tussen de bron en de ionisatiekamer.

Onderzoeksvraag
- Formuleer een onderzoeksvraag die past bij het doel en de meetopstelling van dit experiment.

Hypothese
- Stel een beargumenteerde hypothese op over het verband tussen de ionisatiestroomsterkte *I* en de afstand *d* tussen de bron en de ionisatiekamer.
- Geef deze hypothese ook in de vorm van een schets van het verband tussen deze grootheden in een *I*,*d*-diagram.
- Stel ook een hypothese op over de grootte-orde van de dracht *R* van α-deeltjes in lucht.

Werkplan
- Maak een werkplan voor het experimenteel onderzoek met de gegeven meetopstelling.
- Geef in dat werkplan aan welke grootheden je op welke manier gaat variëren en meten om het wel of niet juist zijn van de opgestelde hypothesen te kunnen controleren.
- Maak alvast een (lege) tabel voor het noteren van de meetresultaten.
- Geef in het werkplan ook aan of het uitvoeren van het experiment een bijdrage levert aan de stralingsbelasting tijdens het practicum, en zo ja: hoe je er dan voor zorgt dat die stralingsbelasting zo laag mogelijk blijft.
- Bespreek je onderzoeksvraag, de opgestelde hypothesen en het bijbehorende werkplan met je docent of de TOA.
- Stel de onderzoeksvraag, de hypothesen en/of het werkplan zo nodig bij.

Onderzoek
- Voer het experimenteel onderzoek uit volgens je werkplan. Zorg bij die uitvoering voor voldoende stralingsbescherming.

Verwerking
- Verwerk de meetresultaten om de opgestelde hypothese te controleren en de onderzoeksvraag te beantwoorden. In het kader hieronder staan enkele aanwijzingen voor die verwerking.

Kijk ook nog even op de achterkant van dit blad.

Universiteit Utrecht

Werkblad OPEN

Faculteit Bètawetenschappen
Ioniserende Stralen Practicum

Experimentnummer: .... Naam: ....

Hulpvragen

Titel ....

Onderzoeksvraag ....

Waar wil je achter komen met je experiment? Kan je je onderzoeksvraag beantwoorden met de meetopstelling die je hebt?

Hypothese ....

Wat verwacht je als antwoord op de onderzoeksvraag? Waarom?

Meetplan ....

Hoe kom je tot een antwoord op de onderzoeksvraag?

Welke grootheden spelen een rol?

Hoe lang/vaak ga je meten?

Wat ga je berekenen?

Hoe ga je met de apparatuur werken?

Figure B2. Inquiry-based leraning approach worksheets of experiment 1.

Appendix C

Questionnaires

A typical experiment specific pre- and posttest questionnaire design.

Informatie over het onderzoek

Dit onderzoek wordt uitgevoerd door Jurrian Zandbergen, master-student aan de Utrecht Universiteit. Het doel van het onderzoek is om de kennis van studenten over straling te meten, vóór en ná hun practicum. Data uit dit onderzoek is anoniem, en de data zal ook niet terug te traceren zijn naar jou.

Om de data vóór en ná het experiment aan elkaar te kunnen koppelen, heb je een unieke code nodig, namelijk de laatste 4 cijfers van je telefoonnummer. Ook is de klas, bijvoorbeeld H5 of V6 nodig om de data aan het juiste niveau te kunnen koppelen. Je mag te allen tijde beslissen om niet meer mee te werken aan dit onderzoek.

Door dit hokje aan te vinken en de enquête in te vullen geef je aan dat je hiermee akkoord gaat.

☐

De laatste 4-cijfers van mijn telefoonnummer (mijn unieke code) zijn ______________

Klas (bijv. H5 of V6) __________

Mocht je vragen of klachten hebben over de privacy van dit onderzoek kun je contact opnemen met functionaris gegevensbescherming van de Universiteit Utrecht via privacy@uu.nl

Exp. 2A en 2B

Opdrachten

1. Radioactieve kernen die ioniserende straling uitzenden kunnen de lucht ioniseren. Wanneer er een spanning wordt aangelegd, kan er een stroom gemeten worden; de ionisatiestroom. **Stelling**: “Deze ionisatiestroom volgt de wet van Ohm.”

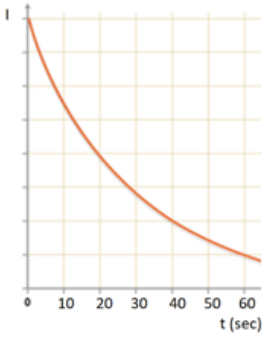
   Deze stelling is *juist / onjuist*. Omcirkel het juiste antwoord.

   Omcirkel hier hoe zeker je bent van je antwoord op vraag 1

1	2	3	4	5	6
Wilde gok	Erg onzeker	Redelijk onzeker	Redelijk zeker	Erg zeker	100% zeker

2. Veel radioactieve kernen zenden een α-deeltje uit die de lucht ioniseert. Hierdoor kan de lucht stroom geleiden die gemeten kan worden. Deze stroom wordt de ionisatiestroomsterkte genoemd. Vlak voor de meting wordt een bepaalde hoeveelheid onbekende radioactieve kernen in de meetkamer gespoten. In het figuur hieronder staat de ionisatiestroomsterkte-tijd grafiek weergegeven van deze meting.

Beredeneer met behulp van de figuur hoeveel procent van de oorspronkelijke radioactieve kernen nog over is op t = 120 sec. Omcirkel het juiste antwoord. Er is maar 1 antwoord juist.

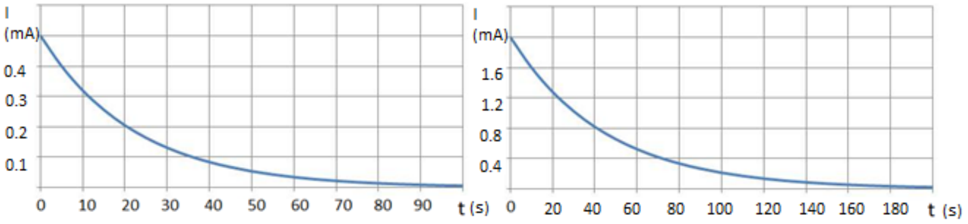


- ○ 16.6 %
- ○ 8.33 %
- ○ 6.25 %
- ○ 4.17 %
- ○ 3.12 %
- ○ 1.56 %
- ○ 0.78 %
- ○ 0.39 %

Omcirkel hier hoe zeker je bent van je antwoord op vraag 2

1	2	3	4	5	6
Wilde gok	Erg onzeker	Redelijk onzeker	Redelijk zeker	Erg zeker	100% zeker

3. In het figuur hieronder staan twee mogelijke ionisatiestroomsterkte-tijd grafieken weergegeven van **twee** onbekende stoffen. Wanneer deze stoffen vervallen, zenden ze een α-deeltje uit, die de lucht ioniseert.



Hieronder staan enkele beweringen over deze metingen, waarin de **linker** en **rechter** meting met elkaar worden vergeleken. We houden hierbij geen rekening met de verval producten en de meetopstelling is gelijk. Omcirkel de juiste bewering. Er is maar 1 antwoord juist. Je hoeft niets in je Binas op te zoeken voor deze vraag.

- ○ In de **linker** meting zijn in het begin meer radioactieve kernen aanwezig
- ○ In de **linker** meting is de halveringstijd groter
- ○ In de **linker** meting zijn er meer kernen aanwezig én is de halveringstijd kleiner
- ○ In de **rechter** meting zijn in het begin meer radioactieve kernen aanwezig
- ○ In de **rechter** meting is de halveringstijd kleiner
- ○ In de **rechter** meting zijn in het begin meer radioactieve kernen aanwezig én is de halveringstijd kleiner
- ○ Je hebt te weinig informatie om hier een uitspraak over te doen

Omcirkel hier hoe zeker je bent van je antwoord op vraag 3

1	2	3	4	5	6
Wilde gok	Erg onzeker	Redelijk onzeker	Redelijk zeker	Erg zeker	100% zeker

Appendix D

Focus group interview core questions and guidelines

Introduction

- Fill in consent forms, I need to record this because it might be useful for my research, but it needs to be official and follow specific guidelines.
- Start recording.
- Opening with consent.
- What part are we talking about (DI or IBL), think back to the first experiment of today.
- Talk about whatever comes to your mind, all information is useful, there are no wrong answers, these won't be shared with anyone so feel free to answer how you like.
- We will talk about the experiment which you made a test one

5 questions from constructivist theories:

1. ZPD → Did you think this practical was easy or difficult? Why? Can you give an example? What were things you found easy, and what were thing you found hard?
2. Scaffolding → Were the materials you were given useful, during the execution of the practical? (Worksheet, introduction video, etc.). Why? Why not?
3. Social interaction → Was it nice to do this practical together with your neighbor? Why? Can you give an example?
4. Active or passive learning → Did you have the feeling you had to do a lot yourself during this practical? Can you give an example? Why? Why not?
5. Authenticity → Did you feel like you were doing real research during this practical? Did you feel like a real researcher? Why? Why not? Can you give an example of this?

Appendix E

Assumptions for one-way ANOVA

The and posttest scores for correct answers and the confidence scores should meet the two assumptions in order to determine if there are differences between the mean scores of the direct instruction and inquiry-based approach. These three assumptions are:

1. The pre- and posttest scores should be approximately normally distributed.
2. The variances of the pre- and posttest scores should be equal for both experimental approaches.

Test scores

Both pretest scores for the DI and IBL group were not normally distributed as indicated by a Shapiro-Wilk test, $W = 0.843$, $p < 0.001$, and $W = 0.878$, $p < 0.001$, respectively. Both posttest scores for the DI and IBL group were not normally distributed as indicated by a Shapiro-Wilk test, $W = 0.867$, $p < 0.001$, and $W = 0.866$, $p < 0.001$, respectively. A Levene's test showed that the variances for the gain of test scores were equal, F (1, 146) = 3.782, $p = 0.054$

Confidence scores

Both pretest confidence scores for the DI and IBL group were normally distributed as indicated by a Shapiro-Wilk test, $W = 0.964$, $p = 0.146$, and $W = 0.979$, $p = 0.109$, respectively. Posttest confidence scores were normally distributed for the DI group but not for the IBL group as indicated by a Shapiro-Wilk test, $W = 0.960$, $p = 0.099$ and $W = 0.972$, $p = 0.031$, respectively. A Levene's test showed that the variances for the gain of confidence scores were approximately equal, F (1, 146) = 3.992, $p = 0.048$