A qualitative and free-choice approach on the influence of an inquiry-based learning practical on intrinsic motivation

Maaike Blekman

Utrecht University, Freudental Institute

Abstract

Studies have found a decline in intrinsic motivation (IM) for science of students in secondary education. There are indications that the educational approach could prevent the decline. Inquiry based learning could be a solution to this problem by raising the basic psychological needs for intrinsic motivation: perceived competence, autonomy and relatedness. Therefore, this study investigates the influence of an inquiry-based learning (IBL) practical on intrinsic motivation opposed to a direct instruction (DI) practical, in the context of a national radiation practical (ISP). With a semi-experimental qualitative approach intrinsic motivation and the support of its basic psychological needs are determined from 16 students of secondary education (age 16-18). This is conducted using a task which measures free-choice behaviour, interviews and focus groups. When observing the free-choice behaviour, there are indications that IM was positively influenced by IBL. However, this is not quantitatively measured. Opposed to what was expected, it is found that the perceived level of competence was not sufficiently supported by IBL opposed to DI for all students. IBL was a ‘fun challenge’, but was also too difficult. DI provided more support, but was also too easy. Nonetheless, participants experienced a positive perceived level of autonomy with IBL and not with DI. The perceived level of relatedness could not be determined. In conclusion, IBL met the competence and autonomy needs for some students. However, it needs alteration to provide more guidance to support competence in all students, and therefore foster intrinsic motivation.

Repeatedly, studies have found a decline in intrinsic motivation for science of students in secondary education over time (Gottfried, Marcoulides, Gottfried, & Oliver, 2009; Potvin & Hasni, 2014). Intrinsic motivation is engagement in a behaviour purely out of interest and enjoyment of the activity itself (Lepper, Corpus, & Iyengar, 2005). Higher intrinsic motivation is associated with a greater chance of completing education, more interest in pursuing a science career and higher performance (Cerasoli, Nicklin, & Ford, 2014; Lavigne, Vallerand, & Miquelon, 2007). This is important as there is a shortage of scientists in Europe and not enough students choose a university education direction which leads to a scientific career (Gago et al., 2005). So, it is important to prevent the intrinsic motivation of students to decline.
The decline in intrinsic motivation appears to be caused by changes in the classroom environment from the end of primary and during secondary education (Vedder-Weiss & Fortus, 2011, 2012), rather than being inevitable during this age. Furthermore, the decline was not present when the three basic psychological needs for intrinsic motivation (competence, autonomy and relatedness) are supported during education (Gnambs & Hanfstingl, 2016). Thus, to prevent intrinsic motivation to decline, secondary education should foster the intrinsic motivation of students. This is also of importance as Dutch pupils decide upon their study direction during secondary school. With a low intrinsic motivation for science, students will have less interest in pursuing a science career (Lavigne et al., 2007). One of the possible solutions to this problem is inquiry-based learning (IBL).

Research suggests that Inquiry-based learning (IBL) has the potential to enhance intrinsic motivation towards the subject (Potvin & Hasni, 2014; Saunders-Stewart, Gyles, & Shore, 2012). Inquiry-based learning is a more authentic way of learning science, as it follows the scientific inquiry. This is a more student-centred way of learning, opposed to, for example, direct instruction (DI) which is very teacher directed. As students have more influence on what they do, what the difficulty is and have possibility to collaborate, IBL could support the basic psychological needs for intrinsic motivation (Loukomies et al., 2013; Vaino, Holbrook, & Rannikmäe, 2012). However, although Loukomies *et al.* (2013) theorizes this positive effect, the satisfaction of these needs is not always found in practice (Loukomies et al., 2013; Van Asseldonk, 2019). For example, in the research of Van Asseldonk (2019) the perceived level of competence was not sufficiently supported by IBL. Thus, it is needed to find out more about the mechanism if and how IBL influences these basic psychological needs.

Also, additional research is needed to confirm the positive effect of IBL on intrinsic motivation (Potvin & Hasni, 2014). Firstly, more knowledge is needed regarding different educational contexts (Saunders-Stewart et al., 2012). For example, there is not a large body of research conducted on IBL and intrinsic motivation in practical's, which suit the inquiry nature of IBL very well. Secondly, the current body of research is mainly based on questionnaire measurements of the Intrinsic Motivation Inventory (IMI: McAuley, Duncan, & Tammen, 1989). Wentzel & Miele (2016) state measurements of intrinsic motivation with traditional self-reports should be triangulated with additional measurements. More specifically, Potvin and Hasni (2014) state that viewing free-choice behaviour, for example students choosing to watch an extra video on the subject matter, could provide different results than declared perceptions in self-reports. Concepts or research can be declared to be interesting, but without being an actual joy to participate in.

Additionally, Vallerand (1997) states it is important to find 'the why of behaviour' instead of solely measuring outcomes, such as affective reactions (i.e. in self-reports) and behaviour in itself. Because, extrinsic motivation could also interfere with these outcomes. For example, one can choose to participate in an extra assignment out of intrinsic motivation, but one can also feel an extrinsic need to know more about the subject because of a subsequent test on the subject matter. Therefore, additional measurements of intrinsic motivation using a free-choice and observing the consequential behaviour, followed by interviews regarding this behaviour, is needed for methodological triangulation.

The above mentioned topics that need further clarification will be investigated in this study in the context of the Ionizing Radiation Practical (ISP). There is some previous research conducted on the effect of this IBL practical on intrinsic motivation (Nooijen, 2017; Van Asseldonk, 2019; Verburg, 2018). However, these investigations mainly use the IMI to determine the intrinsic motivation between large groups of students. Thus, this research aims to triangulate these measurements, using free-choice behaviour in terms of a specific follow-up task, to investigate the influence of IBL on intrinsic motivation opposed to a direct instruction (DI) practical. Also, as there are indications that not all basic psychological needs are supported in the IBL practical (Van Asseldonk, 2019), the current research aims to clarify if and how the characteristics of IBL are supportive of these basic psychological needs. Thus, the research questions will be:

> What is the influence of an inquiry-based ISP practical on the intrinsic motivation of learners in secondary education?

The sub questions are:

1. To what extent does the version of the practical, IBL versus DI influence the free-choice behaviour (for a specific follow up task)?
2. To what extent is the observed free-choice behaviour (choice for a specific task) following the practical based upon intrinsic motivation?
3. To what extent are characteristics of IBL supportive of basic psychological needs (competence autonomy and relatedness)?

Theoretical Framework

Intrinsic Motivation in Self-determination Theory

The self-determination theory (SDT) of Ryan and Deci is a well-accepted theory on distinguishing different types of motivation, such as intrinsic motivation, and what influences them (Ryan & Deci, 2000b). The perceived locus of causality (in figure 1) is one important factor in characterizing the motivational type of a learner. The locus of causality is one's perception of where origin of engaging in an activity or behaviour lies. This locus can be internal when it is one's own choice to do something, but it can also be external when one is pressured by someone to do so. Thus, a behaviour, or motivational type, can be more self-determined (autonomous) or nonself-determined.

In this theory, intrinsic motivation is purely characterized by self-determined factors (regulatory processes in figure 1), such as enjoyment of the behaviour or interest. For example, one is playing a game out of enjoyment of participating, not to win a prize. In contrast, extrinsic motivation is stimulated by other, less autonomous regulatory processes. These external factors can be more self-determined in nature (figure 1), such as personal importance and conscious value of a certain behaviour. For example, one likes to have a room that is clean, rather than enjoying to clean the room. In contrast, extrinsic factors such as external rewards and punishments, e.g. a high salary or an angry teacher, are on the less autonomous side (Ryan & Deci, 2000b). The least self-determined motivation is amotivation, in which there is no regulation of the motivation.

The cognitive evaluation theory (CET) is a part of the SDT which aims to describe what factors influence intrinsic motivation. CET proposes that the basic psychological needs to foster intrinsic motivation are competence, autonomy and relatedness (CAR). Relatedness is feeling a sense of belongingness and connectedness to the persons, group, or culture disseminating a goal (Ryan & Deci, 2000a). A feeling of competence is supported when one feels efficacious to a goal, understands it and feels that the person has the right skills to succeed. This is promoted by optimal challenges, effective feedback, and freedom from demeaning evaluations. Lastly, one has a high level of perceived autonomy when the behaviour is self-determined. Ryan & Deci (2000a) state that for a high level of intrinsic motivation, both the needs for competence and autonomy need to be satisfied. Additionally, it is found that if extrinsic goals are present, intrinsic motivation can be undermined (E L Deci, Koestner, & Ryan, 1999). This makes the pursuit of intrinsic motivation over extrinsic motivation even more important.

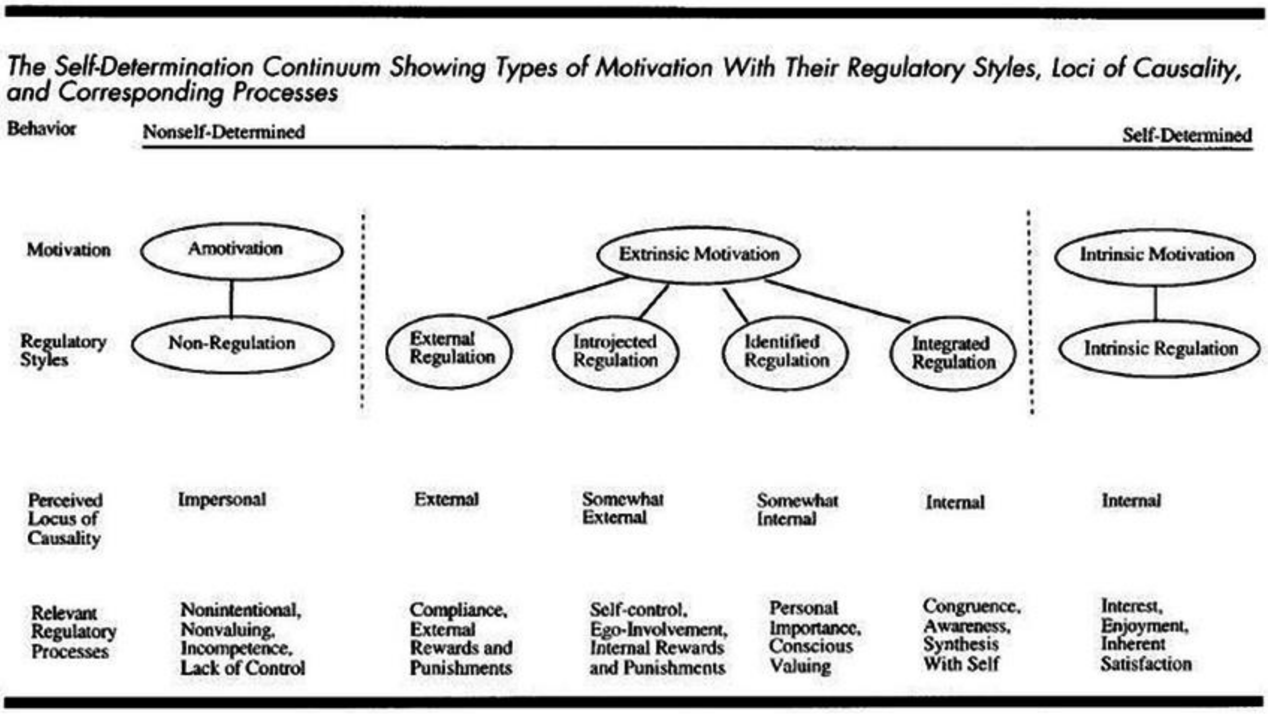


Figure 1. The motivation types of the self-determination theory. The different motivational types are influenced by the perceived locus of causality. (Reprinted from: Ryan & Deci, 2000b, p. 72)

Intrinsic Motivation and Free-choice Behavior

Intrinsic motivation is often evaluated through self-report questionnaires, such as the intrinsic motivation inventory (IMI, McAuley et al., 1989). These questionnaires have been designed to measure the self-reported level of intrinsic motivation. Also the level of perceived competence, autonomy and relatedness are included into the seven subscales of the IMI. However, as stated in the introduction, it is important to triangulate these measurements with using free-choice behaviour to fully accept that an intervention indeed increases the intrinsic motivation.

In various researches the free-choice behaviour, as a result of intrinsic motivation, is measured. Firstly, (Edward L. Deci, 1971) determined the effect of an extrinsic measure on intrinsic motivation. The activity in this investigation was playing with a puzzle in order to solve it. At first, the participants could play with it freely. Then, half of the participants gained money when they solved the puzzle. Afterwards, none of the participants gained money and the intrinsic motivation was determined. This was done by the researcher leaving the room with an unrelated excuse. It was concluded that the intrinsic motivation was present when the participants would continue to play the puzzles, when they did not need to, as the researcher was not there.

In a similar set-up, Lepper, Greene, and Nisbett (1973) investigated several interventions on intrinsic motivation. The task for the participants in this research was to draw. It was observed if primary pupils would choose to sit on a certain table on which they could pick up a marker and go drawing. When they were not sitting at this table or picking up the marker, they were considered not interested, and thus not intrinsically motivated.

Furthermore, in a descriptive and qualitative set-up of Lee and Brophy (1996), the type of motivation was evaluated through observations of class processes and unstructured interviews. They analysed upon different features of the motivational types. Intrinsic motivation was indicated by *'enthusiasm in learning science, self-initiation in task engagement without solicitation from the teacher, choice in* *academic activities among alternatives, interest or curiosity in learning beyond the lesson content, and engagement in tasks beyond the requirements or expectations of the classroom'* (Lee & Brophy, 1996, p. 309). These aspects are also important in the set-up of the free-choice behaviour test in the current research.

Additionally it is stated by Vallerand (1997) that the 'why of behaviour' really shows if intrinsic motivation is present, instead of extrinsic or a-motivation. Whereas, measuring solely the affective (e.g. measured through a questionnaire) and behavioural reactions (e.g. free-choice behaviour), outcomes of intrinsic motivation are measured instead of intrinsic motivation itself. For example, there are indications that more self-determined types of extrinsic motivation can also positively influence these affective and behavioural outcomes. Thus, when there is a behaviour, it does not necessarily mean that intrinsic motivation is the cause of this behaviour. Therefore the 'why of the behaviour' must be determined. This includes the general question "Why are you currently doing this activity?". Vallerand (1997) developed a scale which includes sample items which characterize the 'why of behaviour', in order to determine if the behaviour really depends on intrinsic over extrinsic or a-motivation (table 1)

Table 1
Sample items from each of the subscale of the situational motivation scale.

	"Why are you currently doing this activity?"
Intrinsic motivation	"Because it is interesting."
Identified regulation	"Because I have chosen to do it for my own good."
External regulation	"Because I am supposed to do it."
Amotivation	"I am doing the activity, but I am not sure if it is worth it."

Note. Reprinted from: Vallerand, 1997, p. 294.

Inquiry-Based Learning and Direct Instruction

Direct instruction is a teacher-directed form of learning. The teacher makes all the instructional decisions and has all the responsibility for the learning process (Carnine, 2000). It is characterised by face-to-face instruction, learning new concepts by demonstration and structured practise with guidance from the teacher (Ebbens & Ettekoven, 2013). It is mainly used in the education of basic concepts.

In contrast, inquiry-based learning (IBL) is a more student-centred way of learning. Using this teaching approach, the students learn by discovery, instead of the information being presented by the teacher or a worksheet. It helps students to investigate questions and use data as evidence to answer these questions (Capps & Crawford, 2013). Inquiry-based learning follows the scientific approach to problems. However, there are different levels of student-initiation in IBL.

Capps & Crawford (2013) developed a framework of characteristics to asses if the inquiry method is more student-initiated or teacher-initiated. When the teaching method has none of these characteristics, there is no inquiry, as with direct instruction. Such lessons are, for example, lectures and activity-based lessons. The eight inquiry characteristics of IBL are:

Students should…

1. be involved in science-oriented questions;
2. design and conduct an investigation;
3. determine what constitutes evidence and collect it
4. use this evidence to develop an explanation;
5. connect their explanation to scientific knowledge;
6. communicate and justify their explanation;
7. use tools and techniques to gather, analyse, and interpret data;

8. use mathematics in all aspects of inquiry.

The highest level of inquiry is authentic or open inquiry (Banchi & Bell, 2008; Capps & Crawford, 2013). The learner develops his own research question, design, procedure and results. This is more student-initiated and autonomous IBL. However, the role of the teacher is not passive. The teacher gives the learner guidance to determine if their design will work. The level of autonomy and inquiry is lower when one or more steps in this research is provided by the teacher, such as the research question, method and results. However, students can build competence and confidence when they are being guided through the inquiry (Kuhlthau, Maniotes, Caspari, & Alsop-Cotton, 2009). This guidance ranges from guided inquiry, where learners only know the problem, to structured and confirmation inquiry, where more steps are provided by the teacher (Banchi & Bell, 2008).

When viewing the characteristics of inquiry combined with the self-determination theory, several inquiry characteristics overlap with the basic psychological needs for intrinsic motivation, such as competence, autonomy and relatedness. Firstly, Asseldonk (2019), theorized that students determining their own research questions, design and evidence (aspect 1,2 and 3) has the potential to support their perceived autonomy. IBL is also known as a more autonomy supportive teaching strategy (Buchanan, Harlan, Bruce, & Edwards, 2016). Next, it is noted by Loukomies (2013) that collaboration and interaction in small groups (aspect 6) could give students the feeling that they are valued and respected (Niemiec & Ryan, 2009), which potentially could enhance relatedness. At last, the ownership of this learning process and therefore the possibility for the learner to choose a task fitting to their level of knowledge has the potential to enhance competence (Loukomies et al., 2013). It is also found that inquiry raises confidence and self-efficacy through autonomy and empowerment over the learning process (Saunders-Stewart et al., 2012).

The hypothesis of the current research therefore is that IBL indeed raises the three basic psychological needs (competence, autonomy and relatedness) in the way described above (subquestion 3 and main question). Furthermore, the support of these basic psychological needs leads to higher intrinsic motivation and therefore influences the free-choice behaviour of the students during a specific follow-up task, which determines intrinsic motivation (subquestions 1 and 2).

Methods

This study uses a semi-experimental, qualitative and free-choice approach. In order to answer the research question, intrinsic motivation and the support of the basic psychological needs (competence, autonomy and relatedness) are determined after participants do two different experiments (IBL and direct instruction) in a practical. This is done by determining choice of behaviour during an interview and the influence on the basic psychological needs during focus groups.

Setting

This research will be conducted in the context of the ‘Ionizing radiation practical’ (ISP). This is a practical of the University of Utrecht that was developed for secondary education students of age 16 to 18 (HAVO-5 and VWO-6, pre-university education) in the Netherlands. This practical consists of several different experiments on different subjects. The students work in groups of two. Schools can either come to the University to conduct this practical or invite the university to conduct it at school. This practical has existed for over 40 years and has 18.000 students participating every year.

The experiments during the practical are offered in two distinct approaches: DI and IBL. During the inquiry experiments the research question and the workplan is determined by the learners themselves. Prepared measurement equipment is provided for the learners and each equipment set-up accompanied by a worksheet with guiding questions (e.g. *What is your research question?*) and tips (see Appendix A1 and A2). It is therefore classified by previous thesis as ‘*guided inquiry*’ instead of fully ‘*open inquiry’* (Nooijen, 2017). This approach could in principle support students’ autonomy as well as competence, as the teacher is there to help the learner during the IBL process. In contrast, with the DI experiments, the learners answer only fixed questions in a worksheet (see Appendix A3). In this every step of the measurement is explained and tables to note the date are provided. They also use the equipment set-up, but don't investigate an research question of their own.

This practical has previously been investigated. In the master thesis of Verburg (2018), there was no difference found in conceptual understanding between the IBL and DI variant. Another study, Nooijen (2017), used the IMI to determine the intrinsic motivation of a relatively small sample of pupils (N=55) after conducting either the IBL or DI practical. It was found that the IBL version of the practical led to a significantly higher increase in intrinsic motivation of students than the DI one.

The current research uses the different experiments of the ISP practical. In total there over 20 experiments with different subjects and practical set-ups on ionizing radiation. Eight of those experiments are available in both an IBL (open) and DI (closed) version. The current research will compare these IBL and DI experiments of the national ISP practical.

Participants

The participants are non-random sampled from the schools taking part in the ISP practical. In collaboration with two schools, 16 students from four different classes (and teachers) participated in the investigation. There were four participants from each class and 2 classes from each school. All participants were between the age of 15-18 (grade 4 and 5). In the first part of the investigation (interviews) one participant of the total of 16 was excluded, as the recording failed initially. When repeating the answers quickly with recording, the participant contradicted itself and was therefore not reliable.

The selection of participants was not random. The schools participating were based upon willingness of cooperation. Also, the participants were selected upon subscription to a specific subset of experiments, which were determined by this investigation, and their willingness to participate in the research. The inclusion of participants was thus based on willingness, preference of experiment and possibly preference of the teacher for certain students. However, this research is aiming to elicit a mechanism rather than measuring an absolute effect. This mechanism could be the same for learners volunteering in a research as for learners who did not. To obtain diverse views upon the practical, not only views from participants from one specific class, data is collected from four different classes of two different schools with different characteristics regarding IBL practical's.

The two schools were both very different in characteristics. School A was an international school with mixed school-levels in one class. The teacher stated they were used to do IBL in other situations. The second school (school B) was a Dutch school with two pre-university (VWO) classes. These teachers stated they were less used to IBL practical's.

Data Collection

Participants of both schools conducted an inquiry-based learning (IBL) and direct instructional (DI) version of an experiment of the ISP practical in duo's (see figure 2), and two participants conducted the practical in a trio. Interviews were used to determine their behaviour and the reasons behind the observed behaviour (figure 2). This was followed by focus groups of all four participants from one class participating in the individual interviews, with a total of four focus groups. These were performed to determine the influence of the IBL and DI practical on competence, autonomy and relatedness.

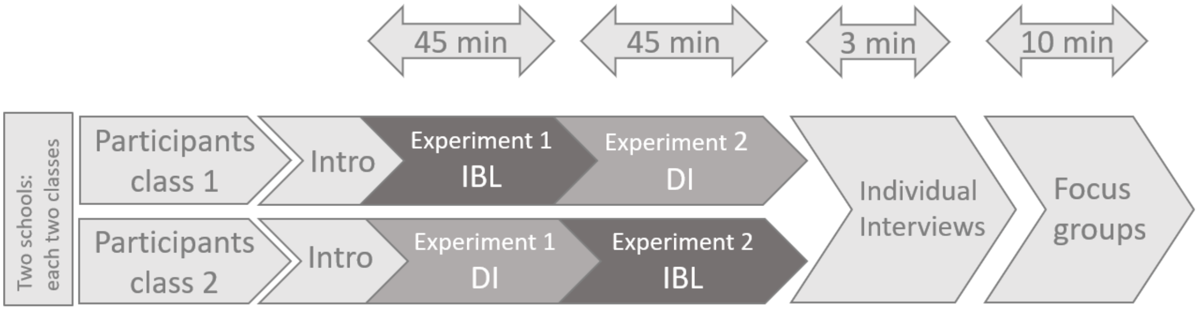


Figure 2. Scheme of the consecutive parts of the data collection. First the participants conduct an IBL and DI experiment during the ISP practical in duo's. Two classes perform the ISP practical in a different order. First, participants in the first class conducted an experiment (topic 1) in the inquiry-based learning (IBL) version, followed by a direct instructional (DI) experiment on topic 2. In the next class, this order of IBL and DI were switched. Directly after the practical, the results upon motivation were collected. First through individual interviews with the students, followed by focus groups.

ISP Practical

Two different experiments of the practical were performed by the participants. One experiment in the IBL approach and one in the DI approach. For practical reasons, the participants unfortunately could not conduct two experiments on the same subject. In practice, one duo conducted (for example) one IBL experiment on half-life and a DI experiment on absorption. However, not every experiment is the same in terms of difficulty and participants can have varying amounts of previous knowledge. Therefore, we chose to switch the approach (IBL or DI) with every topic between the participants (see class A and class B in figure 3). This is done to make sure the most interesting or difficult topic is not always with IBL or always with DI. Also, the order of the IBL and DI approach is alternated to prevent one approach being the most interesting most often as it was the first experiment.

In the experiments the following topics were used:

- 8 participants Half-life & Absorption (school A)
- 4 participants Half-life & Scattering (school B)
- 4 participants Distance & Absorption (school B)

Different Schools' Approach

This investigation is not a convenient sample, but the set-up is semi-experimental. The participants conducted a specific subset of experiments of the ISP-practical set-up by the researcher specifically for this investigation. However, the two schools participating in the ISP had a different approach to the conduction of the practical by their students. School A had minimal specific preparation before conducting the experiments. The participants only read the introduction and goal for every experiment. At the university they made the research plan and conducted the experiments. Not every participant had enough time to work out all the experiments at the end of the practical. In contrast, school B prepared the participants very thoroughly, especially with the IBL experiment. Before going to the university, the participants had one lesson to prepare for the practical, mainly to prepare the IBL experiment. They read the introduction for the DI experiment and determined a research question and plan for the IBL experiment during this lesson. Afterwards this plan was checked by the teacher. Also, these participants conducted an extra DI experiment before conducting the two experiments under investigation and had an additional 45 minutes at the end of the practical to work out all the experiments. Thus, overall school B invested more time in this practical. This was due to the fact that the grade for the worksheets (DI) and measurement report (IBL) of the practical was included in the national school exam (PTA). With school A only the practical skills, in context of the ISP practical, were tested for a grade afterwards. So, these were procedures determined by the teachers themselves, and not experimentally controlled. The implications of this are discussed in the discussion.

Individual Interviews

After conducting the practical, the intrinsic motivation of every student is measured separately by observing free-choice behaviour and a semi-structured individual interview. The free-choice task consists of choosing between watching two different videos on the two subjects of the conducted experiments (see figure 3). One video is about the subject of the practical with direct instruction, one on the practical with the guided IBL approach. This task aligns with one of the intrinsic motivation indicators of Lee & Brophy (1996): *Interest or curiosity in learning beyond the lesson content, engagement in tasks beyond the requirements or expectations of the classroom* and *choice in academic activities among alternatives*. The participant was told that the videos have the same duration so that a time preference is not influencing the outcome of the choice. The participant is asked in an interview which of the topics he/she chooses. After the individual interview the participant was allowed to actually watch this movie, so the movie would not influence the answers on the interview questions. Not every student was able to watch the video afterwards due to time and technical issues.

Figure 3. Video choice. Participants were asked to choose a video on the two topics of the experiments they conducted. It was made sure they would not be distracted by thumbnails of the video and they were told they take the same amount of time.

Additionally, some extra choices on intrinsic motivation were provided. One question is about which experiment the participant would tell their friends of family about (question based on MacLeod, Yang, & Xiang (2017). Another question is on which experiment the participant found the most interesting one, as this is can be an indication of intrinsic motivation for that experiment (Hassandra, Goudas, & Chroni, 2003). Instead of just observing the choice, the participants are also asked why they made a certain choice for an experiment (‘*why of behaviour’* of Vallerand, 1997) , in order to elucidate the motives for their behaviour.

The questions that were asked in the interview were for example; ‘*which video do you want to watch*?’, ‘*If you would tell about one of the two experiments to your friends or family, which one would that be?*’, and ‘*which experiment did you find most interesting*?’ (see Appendix B1 for a complete interview scheme and substantiation with previous research)

Table 2
Interview coding scheme.

Code	Specification	Example (I choose this because…)
Interest and enjoyment		
(Other not) interesting	Because of topic or in general	"I found (the topic of) this experiment more interesting (or: because of the topic)"
(Other not) interesting	Because of approach	"I found the approach of this experiment the most interesting (or: because of the approach)"
Fun	Because of topic or in general	"I found (the topic of) this experiment more fun (or: because of the topic)"
Fun	Because of approach	"I found the approach of this experiment the most fun (or: because of the approach)"
Better understanding		
Better understanding	Because of topic or in general	"I have a better understanding of this topic or experiment in general (i.e. math)"
Better understanding	Because of approach	"I have a better understanding (because) of the approach of this experiment"
More knowledge	-	"I have more knowledge on this experiment or topic"
Less understanding		
Less knowledge	-	"I have less knowledge on this experiment or topic"
Less previous knowledge	-	"In class the teacher has not taught about this experiment or topic so I know less about this"
Other topic too simple		"I think the other topic is too simple, so I choose this topic as it is more difficult."
Other		
Easier to understand for another	-	"This experiment is easier to understand for my friends or family when telling them about it"
Spend most time	-	"I spend the most time on this experiment"

Each interview was recorded and transcribed verbatim. This was followed by making an inventory of the behavioural choices and inductive coding of the reasons behind the choices according to the 'Inductive Category Formation' process model of (Mayring, 2014) which is based upon grounded theory. This coding scheme is visible in table 2. Then it is analysed if the choices are based upon intrinsic motivation, comparing the reasons to sample items from the 'the situational motivational scale' of Vallerand (1997).

Focus Group

After the individual interviews, focus groups consisting of four participants were conducted to determine the influence of the IBL and DI approach on the intrinsic motivation. The emphasis during these focus groups was on comparing the experimental approaches (IBL and DI), rather than on the experiments in general, which was the case in the individual interviews.

As in the investigation of Hassandra *et al.* (2003), which measured the factors influencing intrinsic motivation in physical education in separate interviews, questions are asked upon enjoyment, perceived competence and perceived autonomy. Additionally, questions on relatedness are asked as it is also one of the basic psychological needs for intrinsic motivation, besides autonomy and competence (Deci & Ryan, 2000a).

As in the group discussions conducted in Banfield and Wilkerson (2014) on intrinsic motivation, questions are used as conversation starters. This is done to avoid the conversation to take a biased direction. Questions that were asked are partly based on the previously approved methods of Banfield and Wilkerson (2014) and Hassandra *et al.* (2003) and modified to fit the context of this investigation.

Also the indications of intrinsic motivation of Lee & Brophy (1996) are used. Examples of the focus group questions are (see appendix B2 for a complete interview scheme with substantiation from previous research):

- Which approach did you enjoy most, and why?
- With which approach did you investigate what you wanted to investigate the most, and why?
- Imagine that you need to do another experiment after this, and you can choose which approach you work with. Both approaches take the same amount of time (half an hour) and you don't get a grade for it. You can choose the topic yourself, within the radiation practical. Which approach (step-by step plan [DI], or open [IBL]) would you choose, and why?

The focus groups were recorded, transcribed verbatim and coded deductively for positive or negative remarks upon perceived competence, autonomy and relatedness (table 3). These categories were chosen as these are the basic psychological needs for intrinsic motivation (Ryan and Deci, 2000a). Only full statements which indicate a positive or negative feature of one of the two approaches were coded, as it is intended to compare the two variants with each other. Thus, when an answer to an interview question only included 'IBL' or 'DI', this answer was not coded, as it was directly evoked by the interviewer. For example, when asked with which approach the participants '*have investigated what they wanted to investigate the most*' and the participant only says '*IBL*' this is not coded. These individual answers on the questions prompted by the interviewer are shown separately in the results.

Table 3
Focusgroup coding scheme.

Code	Description	Example
Competence		
Positive	One feel having enough skills to complete the DI/IBL version of the practical. However, it is not perceived as being too easy. The practical is an 'optimal challenge' (Ryan & Deci, 2000a)	"The DI/IBL variant was more of a fun challenge, instead of being too hard"
Negative	The experiment is perceived as being too difficult or easy. One has not the right skills for the practical.	"The DI/IBL experiment was too easy" or "I did not understand wat to do with the DI/IBL variant, so I did not like it"
Autonomy		
Positive	One feels ownership over the learning process during the DI/IBL experiment. They can think of and make decisions themselves.	"With the DI/IBL variant I liked deciding what you are going to do yourselves"
Negative	One feels that the behaviour during the DI/IBL experiment is not self-determined and one has not enough ownership over the learning process.	"I did not like the DI/IBL experiment because you had to follow the worksheet."
Relatedness		
Positive	One feels a sense of belongingness and connectedness to others while conducting the DI/IBL experiment.	"During the DI/IBL experiment the cooperation went well, but during the DI/IBL experiment it did not."
Negative	One feels not enough or a lower sense of belongingness and connectedness to others while conducting the DI/IBL experiment.	"Because of the DI/IBL variant the collaboration during the experiment did not go well"

Pilot

Before collection of the main results a pilot with two participants was conducted (for pilot questions see Appendix B3 and B4). This was done to test the experimental set-up, interview and focus group questions. Subsequently, the interview and focus group questions were altered, because with the pilot questions the mechanism (competence, autonomy and relatedness) behind the motivation was difficult to determine. The participants focussed too much on the experiments themselves (e.g. the topic) than on the different approach. The main change was that the participants are asked to compare the two approaches, instead of general questions about the experiments. Also, both interview and focus group schemes were optimized by adding additional questions and changing wording.

Interrater Reliability

To increase internal reliability, the coding of both interviews and focus groups were also coded by a second coder with knowledge on intrinsic motivation. Subsequently, the Cohen's Kappa's were calculated (see Appendix C). In the individual interviews there were 38 items coded with 12 codes in total (Appendix C1). The Cohen's Kappa for the interrater reliability ranged from substantial to almost perfect (ranging between 0,65-1) with a mean of 0,82 (Landis & Koch, 1977). In the focus groups there were 45 items coded in 12 codes (Appendix C2). Three of the initial codes were excluded, as no results were found (positive IBL-relatedness, negative IBL-relatedness and negative DI-relatedness). The Cohen's Kappa for the interrater reliability of the focus group codes is almost perfect (ranging between 0.84-1), with a mean of 0.92 (Landis & Koch, 1977).

Results

Interviews

The individual participants chose of which experiment (with an IBL or a DI approach) they wanted to watch a video. This question was followed by asking about which experiment they would tell their friends or family and which topic was most interesting. Here the numbers of choices and the frequency of codes about the why of this free-choice behaviour is reported (table 4).

Table 4
The number of participants (n) choosing the IBL or DI experiment during the individual interviews.

Choice	DI (n)	IBL (n)
Video	5	10
Tell a friend	7	8
Most interesting	5	8 (2 n.c.*)
Alignment between 'video' and 'interesting' choice	5	*8 (2 n.c.*)*

Note. A total of 15 participants was included in these results, as one participant was excluded. Two participants did not choose one approach as most interesting (one both one neither) after choosing the IBL video. These were not counted (n.c.).

Choices.

More than twice as much participants chose to watch a video about the IBL experiment than the DI experiment. The same number of participants wanted to tell their friends or family about the IBL and the DI experiment. Three participants switched from watching an IBL experiment video to the DI experiment for the friend's choice. The reason for their choice was that they had more knowledge on the DI experiment. One participant understood the equipment better, another because she had finished it in time, but the third one specifically because she understood the experiment better because of the DI approach.

Almost the same number of participants who chose a video of the IBL or DI approach, also chose the approach as most interesting. However, two participants, who initially chose to watch the movie of the IBL experiment, were not counted. One found none of the experiments interesting, and one found both interesting. That all other choices stayed with same experiment is an indication that interest and the choice for the video relate to each other. The qualitative data on the reasons, in the following section, also shows that interest is a main determining factor for the movie choice.

Reasons.
There are several categories of reasons behind the different choices for the video, ‘tell a friend’ and ‘most interesting’ (see table 5). For the video and the ‘tell a friend’ choice all the reasons were collected. However, for the ‘interest’ choice a ‘why?’ was not explicitly asked three times, because the reason for it being interesting was already mentioned during the conversation. The interviewer therefore had the tendency not to stick to the interview scheme. Additionally, one time the reason was asked, but the answer was evoked by the interviewer (participant P7). This result was thus excluded. The categories shown are summarized from the 12 codes used, for the purpose of readability and relevance.

Table 5.
Difference between IBL and DI concerning the why of choosing to watch a video and additional choices. These are shown in two separate columns.

Reasons for choices of experiment		Choice IBL		Choice DI	
Overall category	Because of:	Video	All	Video	All
Interest and enjoyment[1]	Topic or in general	✓	✓	✓	✓
	Approach	✓	✓		
Better understanding[2]	Topic or in general	✓	✓	✓	✓
	Approach		✓		✓
Less understanding[3]	Less (previous) knowledge	✓	✓		✓
	Other topic too simple		✓	✓	✓
Other	Spend most time				
	Easier to understand for another		✓		✓

Note. *Included codes: 1. Fun (topic, approach), Interesting (topic, approach), 2. better understanding (topic, approach), Less knowledge, 3. less knowledge, less previous knowledge, other topic too simple*

The most prevalent reasons behind the video choice were interest or enjoyment (fun). In total eleven participants mentioned at least interest or fun among their reasons for the choice (additional reason was often having ‘more knowledge’). The other four participants chose the video because the other topic was too simple (one participant) or they had less knowledge on the video topic of their choice (two participants). Also, one participant did not give a reason, even when prompted to do so.

When participants were asked which practical was most interesting and which practical they would tell to their friends, participants also gave other reasons (category ‘other’ in table 5). For example, they thought one of the experiments being easier to understand when telling their friends. Also, a reason was having spent more time on the IBL variant, as there was more preparation for that experiment.

Intrinsic motivation behind the reasons.
When viewing the situational motivational scale of Vallerand (1997), the reasons ‘*interest and enjoyment*’ behind free-choice behaviour are based on intrinsic motivation. However, ‘*less understanding*’ could be based on a form of extrinsic motivation (identified regulation) as one could have made this choice ‘*for their own good’* (Vallerand, 1997). One can find that he or she needs more knowledge or has a test upon the subject and wants to know more about it.

Similarly, the code '*better understanding'* could depend on extrinsic motivation, but also on intrinsic motivation. When one finds the experiment more interesting because of better understanding, this could indicate more intrinsic motivation based upon a higher perceived competence. If choosing to watch a video, or finding an experiment the most interesting it can be concluded this is indeed the case. However, with the '*tell a friend or family'* choice, the reason of '*better understanding*' could also be less internal, as this choice can be externally influenced. It can depend on the external pressure to be able to explain the experiment sufficiently when telling a friend or family about it. For example: "*Participant: [I would tell them] about the scattering, because we did the closed [DI] version with that and thus I understood it better, at once. Interviewer: Okay, Okay, yes. So you understand it better and thus it is easier?. Participant: Yes, than it is easier to tell."* In conclusion, as there is personal importance to be able to explain the experiment sufficiently, this choice could be motivated by identified regulation.

Having spent the most time and the experiment being easier for others as a reason for telling friends or family about an experiment, is not based upon intrinsic motivation. Having spent the most time, was based upon that one school scheduled more preparation time for the IBL variant. Something being easier for others is an external motivation for the choice. These reasons do not relate to with doing the activity out of interest or enjoyment of the activity itself, which indicates intrinsic motivation.

The influence of the approach.
More interest in the experiment because of the topic or in general can be unrelated to the nature of the approach (DI or IBL). It could also be based on external factors such as previous knowledge, preference or experience with this topic. For example, one participant said: *"Because half-life [experiment] has more math, and that is a bit boring, and absorption is more interesting, because it penetrates materials."*

However, a distinct finding in the reasons is that only the IBL approach is mentioned as being the reason of the experiment being interesting, whereas the DI approach is not mentioned in this respect (see table 2). In total four participants mention the IBL approach in this way. For three of these participants it was a reason for one of their choices for the IBL approach. Additionally, one participant chose the DI experiment as most interesting, because of the topic and previous knowledge, but she found the IBL approach the most fun. These findings are an indication that interest and enjoyment, and thus intrinsic motivation, is specifically promoted by the IBL version of this practical.

Also '*better understanding'* because of the approach was mentioned for both DI and IBL. When asked which experiment was more interesting, two participants chose the IBL experiment because of better understanding due to this approach (table 5). This could indicate more IM for the IBL experiment, as mentioned in the previous heading, because they are more interested. In contrast, when asked which experiment he would tell to his friends or family, one participant chose the DI experiment because of a better understanding of the experiment due to the approach, so it would this be easier to explain to his friends. In this case there is personal importance to be able to explain the experiment sufficiently. As reasoned in the previous heading, it is possible that the locus of causality to choose the DI experiment is more external, as with identified regulation, instead of being based upon intrinsic motivation.

Focus groups

In the focus groups, discussion starting questions were asked. The statements in the conversation were coded for positive or negative comments on competence, autonomy and relatedness. No results were found for the codes positive IBL-relatedness, negative IBL-relatedness and negative DI-relatedness. After the coding, also the individual answers on the discussion starting questions are described.

Results of the number of participants in each code (competence, autonomy and relatedness) are reported in figure 4.

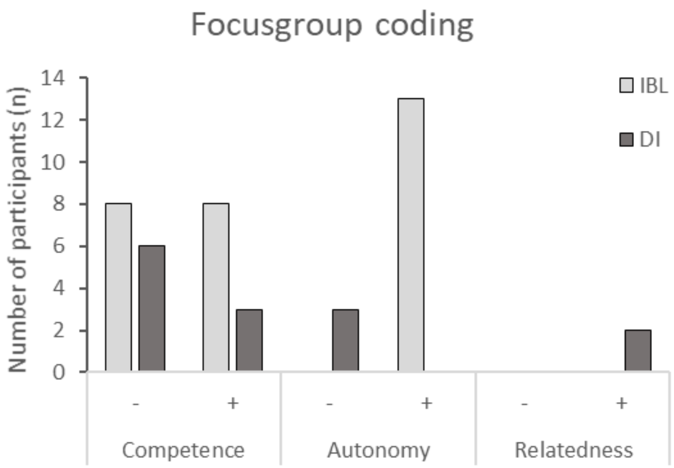


Figure 3. Coding of the focus groups. Amounts of participants having one more positive (+) or negative (-) statements in each category (competence, autonomy and relatedness), while comparing the two approaches IBL and DI of the ISP practical.

Relatedness.

In figure 4 there is a high amount of codes for competence and autonomy, but not for relatedness. For relatedness students often did not experience any difference. This is logical as the groups and the teachers, and thus the people to relate to, remained the same with both approaches. The statements that are there were based upon the DI practical being easier, and thus easier to work together. However, this is strongly related to competence.

Autonomy.

Main findings:

1. In the IBL approach participants liked to do, decide and think of it themselves, for example:
    a. "*I feel like the more you get to do it yourself, the more you are like in control of the experiments, the more fun it is.*"
    b. "*You find it out yourself. You are looking for something you want to look for that way you find out more*"
2. In the DI approach participants did not like the procedure was a fixed set of steps, for example:
    a. "*when it is kind of given to you, you have to follow the formula and follow the booklet, it gets more boring and therefore less engaging*"
3. In the DI approach, participants did not like that there were a lot of mandatory questions, for example:
    a. *"Well you do all kinds of things, and you had to make a new graph out of that and you had to determine that again and you had to do that again, and that went a bit far*"

Striking about figure 3 is that a high amount (thirteen) of the participants mentioned positive autonomy for the IBL approach, opposed to none for the DI one. The DI variant is only mentioned as negative in autonomy (by three participants), while the IBL variant is not. With the IBL variant participants stated that that they liked that they could do it, decide it, think of it themselves and take more initiative during the experiment. In the DI variant, participants did not like that the entire procedure of the experiment was given to them and that there were too many mandatory questions.

Competence.

With competence there is not such a clear image on first sight (figure 3). There are slight differences visible in the number of participants mentioning positive or negative competence for the IBL and DI approach. Although these numbers are interesting to see, it does not provide a concrete qualitative insight in the competence issues and positives. The actual statements within these categories provide more information on this, as for a high perceived competence level the challenge should not be too hard, but also not too easy, to be an 'optimal challenge' (Ryan & Deci, 2000a). These themes of statements are described further in the following sections. The conclusion of those sections is that participants made both positive and negative comments about competence, comparing the two approaches. The IBL variant could be perceived as a fun challenge, but also as being too open, whereas DI approach could be perceived as being too easy, but also provides necessary guidance for some participants.

Negative competence with DI.

Main findings:

1. Participants stated they learned less with the DI approach, for example:
    a. "*you just do something and you hardly know what you are doing*"
2. Participants stated the DI approach was too easy, for example:
    a. "*You could just fill in everything so unthinkingly*."
3. One participant stated they had too little time with the DI approach, for example:
    a. "*And we had the least spare time there. We even had too little time*."
4. Participants stated some questions were unclear in the worksheet, for example:
    a. "*At one point there was a question that we thought of; 'what do you want [us] to do here?' It didn't say 'calculate' either, but we had the idea that you had to calculate something in order to get to that answer. But it did not say so, so actually I found that harder.*"

The negative competence coding for the DI experiment is mainly characterized by the practical being too easy (five participants) and less educational (two participants) Participants said it was too easy to fill in the answers with the DI variant and that you learn more when you need to think about it, as the IBL variant, then when you hardly know what you are doing with the DI variant. Only one participant mentioned that there was too little time for the DI practical (participant 11). And two participants (participant 11 and 12) mentioned that some questions in the worksheet were unclear, and they did not understand what was expected of them. However, both also mentioned that the DI version was too easy and not a challenge to them. Thus, all participants mentioning the DI version in terms of negative competence found it either too easy or learned less. Consequently, all of these participants stated they enjoyed the IBL approach the most and chose it for a hypothetical future experiment, instead of the DI approach.

Negative competence remarks with IBL.

Main findings:

1. Participants stated they were insecure of getting good grade, for example:
    a. "*Participant 13: What I found more difficult with open [IBL] is that you, suppose, you get a mark for it and you don't really know very well the goal you have to work towards, to get an ok mark for it.*
    Participant 11: You become very uncertain of it, or so. I am doing well?
    Participant 13: Yes.
    Participant 12: Do I do everything you need to do? Because we did not receive a form from "you have to do this" or something.
    Participant 13: No you have no criteria or something and they do have that, say, if they check it. So that's a bit tricky, just there, to think of that."

2. Participants stated it was unclear what to do during the IBL practical, for example:
    a. "*Participant12: And then it did work. So, it was also a bit like; right, how should we know that we should have done it that way? […] I: Yes, so it was a little too open and a bit too difficult?*
    Participant 12: Yes, well, it was careful thinking, but it was okay to just do it. It was fine.
    Participant 14: Maybe then say clearly that you have to make this number of graphs, and yes."
3. Participants stated they had too little time, for example:
    a. "*I would have as well, because then I would have been able understand that type of questions better because now in the time that we had I didn't really understand them. Whereas, if I had a lot of time and I would be able to look further into it, I would be maybe be able to understand it more."*
4. Participants stated didn't understand what to do during preparation at home, for example:
    a. "*Participant 13: Yes, but we didn't really have a good idea in advance what we should do with that open [IBL] version. No, we figured out how to make the tables over again, and so on. […]*
    Participant 14: We did have the work plan, but we did not think of what our table would look like. So we drew that all over again."
5. Participants stated they were used to different terminology on the worksheet, for example:
    a. "*Participant 10: Well we just didn't understand some of the terminology, so... [interviewer interrupts]*
    Participant 9: That's what put us off. And then, you know, not understanding one thing, then, you know, caused us to be like: oh my god, I don't understand anything anymore."

In contrast to DI, the negative competence scores for the IBL approach are not at all characterized by being too easy. The opposite is true. Two students did not understand the preparation of the practical beforehand (school B). An important note on this is that, the preparation of the IBL experiment was much more extensive then with the DI one.

Also, two participants had difficulty knowing what they had to do to answer their research question in the IBL variant (quotation 2a). They had strange results in their experiment and did not understand why. Eventually the teacher told them how to change the method. However, they felt the experiment was not clear enough. Although they thought the difficulty of the IBL experiment was 'fine', they felt they needed more guidance in terms of which graphs they should make. So, this is an indication that the students need more guidance in the IBL variant making it more suitable to meet their competence level.

Another negative competence remark on the IBL approach is that participants did not have enough time or felt time pressure. Five participants mentioned the time restriction in a negative way. For example, when asked which approach they want to do in the future, several participants said that if there is a time restriction, they would not choose the IBL approach. When viewing the results with answers on the specific question this becomes even more clear (see next paragraph: *Answers to discussion starting questions*).

Next, three participants did not understand the terminology on the worksheets of the IBL experiment. As with not understanding the questions in the DI approach, this negative competence for the IBL approach is more related to the worksheet than the approach itself.

At last, as the students of school B received a grade for the national exam for the practical, three of these students mention that they are insecure of getting a good grade with the IBL approach. This is because it is less straightforward and provides less support than the DI approach (see quotation 1a). As there is not a form with clear steps which they have to follow during the IBL practical, they were insecure if they did it right according to how the teacher would assess and grade it. This is also visible in the positive competence scores of the DI practical, as one participant likes "*doing things knowing I'm doing it right*".

In conclusion, in contrast to the DI approach the remarks on the IBL approach were mostly characterized by being (too) difficult, too little guidance and time pressure. However, seven of the eight participants in this category did choose the IBL approach as a hypothetical future experiment instead of DI, and from one participant it was unclear (see next paragraph: *Answers to discussion starting questions).* The last participant enjoyed the DI approach the most. The rest of the participants enjoyed the IBL approach the most despite their negative statements about its competence.

Positive competence remarks on DI.

1. Participants stated they liked knowing they did it right, for example:
   a. *"I liked the method one, with the method [DI]. Because I like doing things knowing I'm doing it right."*
2. Participants stated they liked it being more straightforward and thus easier, for example:
   a. "*I: Which approach did you enjoy most? P9: the step by step one [DI], the more straight forward one. It was easier*."
   b. "*Participant 9: Well yeah with 2A [DI] it was way easier to... P10: Understand. P9: to und... And like it said this and this and this and that's what you are supposed to do here is a table to write it down"*

In contrast to the insecurity of getting a good grade with the IBL approach, in the DI approach one participant mentioned that he liked the DI approach because he liked doing things knowing he did it right. Also, two participants said cooperation went more smoothly because the DI practical was easier to understand (quote 2a). Additionally, one of those two participants enjoyed this approach more because it was easier. In conclusion, for these participants the DI version of the practical was better for their perceived level of competence.

Although making positive comments on the perceived competence, one of these participants did choose the IBL version of the practical as a hypothetical future experiment (see next paragraph: *Answers to discussion starting questions*), instead of the DI approach. However she did enjoy the DI approach more, but her future experiment choice was based upon having enough time for the IBL experiment, which she did not have during the ISP practical. Of the other two it was unclear which approach they chose for the future experiment, but one of them stated he liked the DI experiment better and they both only made negative comments upon their perceived competence of IBL.

Positive competence with IBL.

1. Participants stated they thought it was a fun challenge instead of being too difficult, for example:
   a. "*I think the open [IBL] [Is the most difficult], but it wasn't really difficult but is was more of a fun challenge*"
   b. "*It is just a bit of a challenge, just not everything is being spelled out for you all the time*"
   c. *"Yes and why, because you have to dive into it before you start doing that assignment, because it is not spelled out. So, you have to dive into 'gosh how does this work' and 'what can I do with it?' And with the closed [DI approach], everything has already been worked out, and yes, do something. We have not even read the theory 9 out of 10 times with the closed [DI approach]*"
2. Participants stated they learned the most, for example:
   a. "*Open [IBL], because we got to do it ourselves and explore the different ways of doing the experiment which taught us more*"

b. *"[…] if you think more [about it], then I think you also learn more from it then when you just do something and barely know what you are actually doing"*

While the DI approach was preferred because it was easier, the IBL approach was more liked for its difficulty. Four participants mention that the IBL experiment was more of a positive challenge than too difficult, as the experiment was not spelled out for them. One participant also found they learned more because of IBL being more of challenge than DI (quote 1c).

Also, participants found that they learned the most from the IBL experiment, because you needed to '*think of it yourselves instead of barely knowing what you are doing*', '*explore the different ways of doing the experiment*' and '*because you look for something you want to look for'*.

In conclusion, IBL was difficult, but also experienced as a fun challenge. Consequently, all of these participants stated they enjoyed the IBL approach the most and chose it for a hypothetical future experiment, instead of the DI approach.

Answers to discussion starting questions.

Apart from the coding of the focus groups, it is also interesting to look at the answers on the questions asked during the focus groups. The answers of participants on the closed discussion starting questions '*which approach did you enjoy the most*?' and '*Which approach would you choose for a hypothetical future experiment*?' (full wording of questions in Appendix B2) are shown in figure 4. The rest of the answers on the focus group questions are visible in Appendix D as they only confirm wat was coded by the coding scheme and thus provide no further information to this investigation.

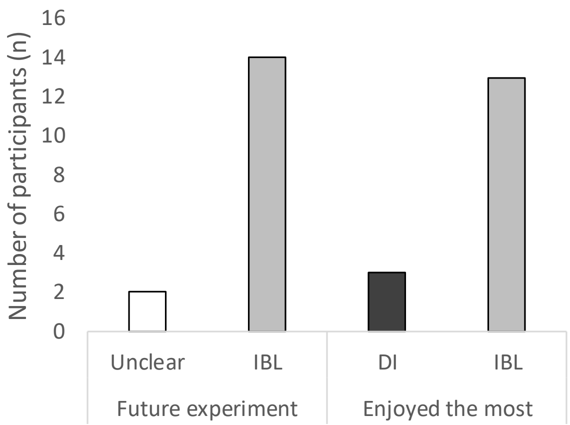


Figure 4. Answers on discussion starting questions. It is shown what number of participants gave what answer on the different discussion starting questions in this study. From two participants the statements were unclear. These participants said 'DI' indistinctly while another was talking about the time restriction after the question and before a discussion with the general consensus choosing the IBL variant.

Most enjoyment.

Most participants enjoyed the IBL approach the most. When viewing figure 6 this is true for 13 of the 16 participants. For one participant this preference was because of the topic of the IBL experiment rather than its approach. Their reasons for their choice were for example:

Participant 6: *"I feel like the more you get to do it yourself, the more you are like in control of the experiments, the more fun it is. […] Because then you are more focussing and paying attention. But when it is kind of given to you, you have to follow the formula and follow the booklet, it gets more boring and therefore less engaging."*

Participant 12: *"With the closed [DI] variant is was like, do this and if you have a few braincells less, it is also fine. You can also do it. Then you get a bit of the robot effect, let me say, so do this, do that, do this, etcetera. […] But if you think more [about it], then I think you*

> *also learn more from it then when you just do something and barely know what you are actually doing."*

So participants liked it for being in control and the experiment being more difficult. However, three participants found the DI experiment the most fun. This was because one found it easier, another liked knowing he does the experiment right and for the last participant this was because the newness of the IBL variant was lost after the preparation beforehand in school.

Future experiment.

With the choice for the approach of a hypothetical future experiment, most participants (14) chose the IBL approach (see figure 4). However two participants stated '*step-by-step'* (DI) indistinctly in the background if there is a time restriction, before the discussion in the focus group started:

> *"Participant 7: Well if there is a 30-minute time restriction, [background: P8: step by step one P10: Step by step] probably the step-by-step one, but if it wasn't limited to a certain amount of time, I probably would have picked the open [IBL] one.*"

After this, a discussion started about the time restriction. The general consensus was that they prefer the IBL approach if the experiments take the same amount of time. The initial participants saying DI in the background did not contradict this general consensus. It is thus unclear if they just agreed with the 'time restriction' statement or if they would choose the DI approach also if there was enough time.

Reasons for choosing the IBL experiment by other participants were topics as more interesting, fun, educational and challenging. These conclusions arose frequently after heated discussions on the circumstances of this hypothetical future experiment. Six participants explicitly stated that their choice was dependent upon having enough time to do the IBL experiment. This is due to participants experiencing time pressure during the conduction and them not finishing in time. For example, some participants needed to be ensured multiple times that it takes the same time and there is enough time, after also including in the question beforehand that it takes the same amount of time:

> *Participant 11: Well now you can't prepare anything anymore. And we have had quite a lot of preparation for the open [IBL] version, and the closed [DI approach] well that can be done. But I find that more boring than the open [IBL] one.*
> *Interviewer: And suppose the preparation is also included, so you are the same... The closed [DI] version is then just a little longer.*
> *Participant 11: Then the open [IBL], because I find that more interesting and more fun and challenging.*
> *Participant 12: Yes me too, I think you learn a little more from that and some more, that can also apply to other things, and so on. So I like doing that better than, yes.*
> *Participant 13: Yes, but that depends a bit on the length, because we did not finish the open [IBL] version within the time".*

A note to this is that the last participants (13 and 14) had problems with the preparation of the IBL experiment in the lesson before due to circumstantial reasons (doing preparation at home rather than in the lesson), which may influence her statement. However, during multiple discussions other students agreed on having too little time with the IBL experiment.

Another point of discussion was the preparation for the IBL experiment limiting its newness. One student explicitly mentioned that if the preparation of both experiments would be at the start of the whole practical, she would choose the IBL approach. However, other students also mentioned during the focus group that they got more excited because of the preparation of the IBL variant. So, for some students the preparation is positive and for others negative.

In summary, most participants enjoyed the IBL practical and would choose it for a future experiment, but there are some aspects of the IBL practical that need to be changed such as not being too difficult and having enough time.

Conclusion and discussion

The first sub-question of this investigation was: **To what extent does the version of the practical, IBL versus DI influence the free-choice behavior (for a specific follow up task)?** The inquiry-based learning (IBL) experiment was chosen more than twice as much during the follow-up task than the direct instructional (DI) experiment. However, this is not statistically tested as only a small sample was used. Also, the choice for the IBL experiment in the follow-up task is not necessarily positively influenced by the IBL approach itself. One of the reasons behind the choice for the follow-up task was because of interest in the topic. This could be influenced by the DI or IBL approach being more interesting, and thus raising interest for the follow-up task. This would be the sought after situational motivation (Vallerand, 1997). However, it could also be influenced by previous experience with these topics, rather than the version (IBL or DI) of the practical. This would be more contextual or global motivation. For example, if one finds math boring in general, which is very abundant in one of the topics, the student would be more likely to choose the other topic regardless of the approach used in the practical. When participants were asked if their choice was based upon the practical they conducted, this was not always the case. Conversely, when viewing the reasons behind the choices, only the IBL approach itself was mentioned as being interesting or fun as a reason for choosing the experiment of the IBL approach, and the DI approach was not. Thus, this indicates that the free-choice behavior of choosing the IBL experiment is positively influenced by the IBL approach itself.

In case of interest or enjoyment because of the approach it can be concluded that for these participants the version of the IBL practical positively influenced their intrinsic motivation, as these reasons are based on intrinsic motivation, according to the situational motivational scale of Vallerant et al. (1997). This is a partial answer on the second sub question*:* **To what extent is the observed free-choice behavior (choice for a specific task) following the practical based upon intrinsic motivation?** Another reason for the free-choice behaviour for either the IBL or DI experiment in the follow-up task of watching a video was that the other topic was too simple or they had more knowledge on that experiment. These reasons indicate that this experiment suited more with the need for competence, as it was not too simple or too hard. Thus, this decision could also be induced by more intrinsic motivation for the chosen experiment.

However, when asked which experiment the participants would tell about to their friends or family, the reason '*better understanding'* or '*more knowledge*' could also be less internal, as this choice can be externally influenced (see section *Results*). It can depend on the external pressure to be able to explain the experiment sufficiently when telling a friend or family about it. As there is *personal importance* to be able to explain the experiment sufficiently (Vallerand, 1997), this choice could be motivated by identified regulation.

Additionally, the reasons '*less understanding*' or '*less knowledge*' to watch a video (specific follow-up task) could be out of intrinsic motivation to know more about it. However it could also be based on a form of extrinsic motivation (identified regulation), as one could have made this choice '*for their own good'* (Vallerand, 1997). For example, one can find that he or she needs more knowledge or has a test upon the subject and wants to know more about it. In conclusion, some, but not all observed free-choice behaviour was necessarily based on intrinsic motivation. This indicates that it remains important to determine the reasons behind behaviour.

The third sub question was: **To what extent are characteristics of IBL supportive of basic psychological needs (competence, autonomy and relatedness)?** In terms of relatedness this was not clear. There were no differences found between IBL and DI. This can be explained by the fact that students collaborated with each other during both approaches and had teacher guidance with both DI and IBL. However, one has to consider the possibility of peer pressure to not say anything negative about their duo partners during the focus groups. Another possibility could lie in the questions being not fitting enough to elicit relatedness.

In contrast, we observed a distinct positive influence of IBL on autonomy. Autonomy was often mentioned positively for IBL and solely negatively for DI. This confirms the hypothesis that autonomy is supported by IBL, because students can determine what they are going to investigate themselves (Buchanan et al., 2016). They like doing, deciding, and thinking for themselves. In contrast, DI does not provide this room for autonomy.

Unexpectedly, IBL has shown no distinct positive influence on competence over DI. It was hypothesised that students perceived competence would be raised by IBL, opposed to DI, as it is found that inquiry raises confidence and self-efficacy through autonomy and empowerment over the learning process (Saunders-Stewart et al., 2012). It was also hypothesised that this empowerment over the learning process enabled students to adapt the difficulty of their experiment to their own competence level, making is an 'optimal challenge'. This 'optimal challenge', a challenge that is not too difficult or too easy, stimulates a positive perceived competence level (Ryan & Deci, 2000a). Most students indeed said they liked IBL because it was a fun challenge. However, other students experienced the IBL experiment not as a fun challenge, but also as too difficult. Participants often did not understand what to do during the experiment. Participants also experienced having to little time, which is not necessarily a negative side of IBL. This can be based upon the teaching practice, but shortage of time can also be a result of the experiment being too difficult and thus students not being fast enough.

Surprisingly, the empowerment over the learning-process with IBL, making it a fun challenge, came with a downside; participants were insecure of getting a good grade, as they decided most of the experiment by themselves. They felt too little guidance to know if they are '*doing it right'*. In contrast, the DI practical did provide more guidance and therefore provided the feeling of '*knowing you do it right',* and participants liked it for being more easy. However, it was also experienced as being too easy, which is also not an 'optimal challenge'. So, both approaches were not supportive of the perceived competence level for all students.

The main research question was: **What is the influence of an inquiry-based ISP practical on the intrinsic motivation of learners in secondary education?** There are indications that IBL has a positive effect on IM, for some students. Only the IBL approach is mentioned as a cause of being more interested or thinking the experiment is the most fun. Additionally, when students are specifically asked to which of the approaches they would choose for a hypothetical future experiment, almost all participants chose the IBL approach (two participants unclear), if the circumstances (enough time, same preparation) of the two experiments would be the same. This is in line with 'choice in academic activities among alternatives' of Lee and Brophy (1996), indicating intrinsic motivation. Thus, in this investigation it is concluded that possibly not for all, but for most students in this investigation the inquiry-based learning practical was experienced as being supportive of intrinsic motivation. This is an indication that the IBL version of the ISP-practical could have a positive influence on intrinsic motivation.

This positive effect is mainly influenced by autonomy. However, Ryan and Deci (2000a) state that to have IM, the psychological need for both competence and autonomy should be provided. For some students the perceived competence level for the IBL approach was high, but this was not the case for all. This was also found by Van Asseldonk (2019). However in the current investigation, it is found what the mechanism behind this is. Some students did not understand what to do, felt time-pressure and were insecure of getting a good grade. They perceived having more, sometimes too much, support during the DI practical. This was also noticed during the discussion among students regarding the circumstances (enough time, preparation) of the aforementioned 'future experiment'. Therefore, it is concluded that IBL in this ISP practical is not supportive enough of IM, as the perceived level of competence was not supported for all students. However, as it is a promising method to increase IM because of its positive effect on autonomy and potency in proving a fun challenge. With the findings of this research, it could be beneficial to alter the level of guidance, time-limit and possibly extrinsic factors such as grading, to support IM to a larger extend. In conclusion, the IBL practical needs to be changed to be fully supportive of intrinsic motivation. Future research should aim to improve the perceived competence of students in this IBL practical, instead of only offering more autonomy. This way students will be allowed to just enjoy the challenge.

Reliability

The interrater reliability of the coding in this study was substantial to almost perfect. This increases the internal reliability of this investigation. One of the limitations of this investigation is that the nature of this qualitative study was semi-experimental, but not fully controlled. Firstly, there was no random selection of participants and assignment to the experiments. This lowers the external and internal validity as students can choose to do an experiment they are already interested in and teachers choosing certain students who participate in this investigation. Secondly, one school had done more preparation for the IBL experiment than the DI experiment with the experiments and one class performed an extra DI experiment. Every school having a different approach on conducting practical's of the ISP is characteristic for this national practical. However, it limits the experimental nature and internal viability of this investigation. Also, one class received grades for the national exam, and the other was only tested on their skills in a school exam. These extrinsic factors can influence participants' intrinsic motivation (Edward L Deci, Koestner, & Ryan, 2001).

On the other hand, to increase the validity, the students performed both approaches, which enabled the comparison between the approaches to be made within the student, and not within different small groups. This prevents large motivational differences between two groups each describing a different educational approach (DI or IBL). Additionally, participants collected from different schools and classes also has the benefit of including diverse views upon the practical. In this we attempted to minimize the effect of the limitations above.

The level of competence autonomy, relatedness and intrinsic motivation is not measured quantitatively as this was an qualitative study (see for example another study of Van Asseldonk, 2019). A strength of this approach is that there is room for discussion of the participants, it can by analyzed in-depth how the participants experienced IBL, and how it influences CAR. However, it is important that one is careful with concluding from this investigation that one approach of the practical is better in supporting IM than the other, beyond the participants in this investigation. Nevertheless, the current research provides insights in how IBL supports IM and how to improve the practical.

References

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children*, *46*(2), 26.

Banfield, J., & Wilkerson, B. (2014). Increasing Student Intrinsic Motivation And Self-Efficacy Through Gamification Pedagogy. *Contemporary Issues in Education Research (CIER)*, *7*(4), 291. https://doi.org/10.19030/cier.v7i4.8843

Buchanan, S., Harlan, M. A., Bruce, C. S., & Edwards, S. L. (2016). Inquiry based learning models, information literacy, and student engagement: A literature review. *School Libraries Worldwide*, *22*(2), 23–39. https://doi.org/10.14265.22.2.03

Capps, D. K., & Crawford, B. A. (2013). Inquiry-Based Instruction and Teaching About Nature of Science: Are They Happening? *Journal of Science Teacher Education*, *24*(3), 497–526. https://doi.org/10.1007/s10972-012-9314-z

Carnine, D. (2000, April). *Why Education Experts Resist Effective Practices (And What It Would Take To Make Education More Like Medicine).* Retrieved from https://eric.ed.gov/?id=ED442804

Cerasoli, C. P., Nicklin, J. M., & Ford, M. T. (2014). Intrinsic motivation and extrinsic incentives jointly predict performance: A 40-year meta-analysis. *Psychological Bulletin*, *140*(4), 980–1008. https://doi.org/10.1037/a0035661

Deci, E L, Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin*, *125*(6), 627–668; discussion 692-700. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10589297

Deci, Edward L. (1971). Effects of externally mediated rewards on intrinsic motivation. *Journal of Personality and Social Psychology*, *18*(1), 105–115. https://doi.org/10.1037/h0030644

Deci, Edward L, Koestner, R., & Ryan, R. M. (2001). Extrinsic Rewards and Intrinsic Motivation in Education: Reconsidered Once Again. *Review of Educational Research*, *71*(1), 1–27. https://doi.org/10.3102/00346543071001001

Ebbens, S., & Ettekoven, S. (2013). Effectief leren : basisboek. In *TA - TT* - (3e [gew.]). Groningen [etc.] SE - 215 p. : ill. ; 24 cm.: Noordhoff.

Gago, J. M., Ziman, J., Caro, P., Constantinou, C., Davies, G., Parchmann, I., … Sjøberg, S. (2005). *Europe Needs More Scientists: Report by the High Level Group on Increasing Human Resources for Science and Technology*.

Gnambs, T., & Hanfstingl, B. (2016). The decline of academic motivation during adolescence: an accelerated longitudinal cohort analysis on the effect of psychological need satisfaction. *Educational Psychology*, *36*(9), 1698–1712. https://doi.org/10.1080/01443410.2015.1113236

Gottfried, A. E., Marcoulides, G. A., Gottfried, A. W., & Oliver, P. H. (2009). A Latent Curve Model of Parental Motivational Practices and Developmental Decline in Math and Science Academic Intrinsic Motivation. *Journal of Educational Psychology*, *101*(3), 729–739. https://doi.org/10.1037/a0015084

Hassandra, M., Goudas, M., & Chroni, S. (2003). Examining factors associated with intrinsic motivation in physical education: a qualitative approach. *Psychology of Sport and Exercise*, *4*(3), 211–223. https://doi.org/10.1016/S1469-0292(02)00006-7

Kuhlthau, C. C., Maniotes, L. K., Caspari, A. K., & Alsop-Cotton, J. (2009). Guided Inquiry: Learning in the 21st Century. *The Journal of Academic Librarianship TA - TT -*, *35*(1), 102. https://doi.org/10.1016/j.acalib.2008.10.012 LK - https://utrechtuniversity.on.worldcat.org/oclc/4928704853

Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics*, *33*(1), 159–174. https://doi.org/10.2307/2529310

Lavigne, G. L., Vallerand, R. J., & Miquelon, P. (2007). A motivational model of persistence in science education: A self-determination theory approach. *European Journal of Psychology of Education*, *22*(3), 351–369. https://doi.org/10.1007/BF03173432

Lee, O., & Brophy, J. (1996). Motivational patterns observed in Sixth-Grade science classrooms. *Journal of Research in Science Teaching*, *33*(3), 303–318. https://doi.org/10.1002/(SICI)1098-2736(199603)33:3<303::AID-TEA4>3.0.CO;2-X

Lepper, M. R., Corpus, J. H., & Iyengar, S. S. (2005). Intrinsic and extrinsic motivational orientations in the classroom: Age differences and academic correlates. *Journal of Educational Psychology*, *97*(2), 184–196. https://doi.org/10.1037/0022-0663.97.2.184

Lepper, M. R., Greene, D., & Nisbett, R. E. (1973). Undermining children’s intrinsic interest with extrinsic reward: A test of the "overjustification" hypothesis. *Journal of Personality and Social Psychology*, *28*(1), 129–137. https://doi.org/10.1037/h0035519

Loukomies, A., Pnevmatikos, D., Lavonen, J., Spyrtou, A., Byman, R., Kariotoglou, P., & Juuti, K. (2013). Promoting Students’ Interest and Motivation Towards Science Learning: The Role of Personal Needs and Motivation Orientations. *Research in Science Education*, *43*(6), 2517–2539. https://doi.org/10.1007/s11165-013-9370-1

MacLeod, J., Yang, H. H., & Xiang, Z. (2017). Understanding College Students' Intrinsic Motivation and Social Interdependence in Intercultural Computer-Supported Collaborative Learning Between USA and China. *The Asia-Pacific Education Researcher*, *26*(3), 205–217. https://doi.org/10.1007/s40299-017-0341-6

Mayring, P. (2014). *Qualitative content analysis: theoretical foundation, basic procedures and software solution*. Retrieved from http://nbn-resolving.de/urn:nbn:de:0168-ssoar-395173

McAuley, E. D., Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the intrinsic motivation inventoiy in a competitive sport setting: A confirmatory factor analysis. *Research Quarterly for Exercise and Sport*, *60*(1), 48–58. https://doi.org/10.1080/02701367.1989.10607413

Niemiec, C. P., & Ryan, R. M. (2009). Autonomy, competence, and relatedness in the classroom: Applying self-determination theory to educational practice. *Theory and Research in Education*, *7*(2), 133–144. https://doi.org/10.1177/1477878509104318

Nooijen, T. (2017). *Improving Students' Intrinsic Motivation by Using an Inquiry-based Learning Practical* (Universiteit Utrecht). Retrieved from https://dspace.library.uu.nl/handle/1874/353621

Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research. *Studies in Science Education*, *50*(1), 85–129. https://doi.org/10.1080/03057267.2014.881626

Ryan, R. M., & Deci, E. L. (2000a). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology*, *25*(1), 54–67. https://doi.org/10.1006/CEPS.1999.1020

Ryan, R. M., & Deci, E. L. (2000b). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American Psychologist*, *55*(1), 68–78. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11392867

Saunders-Stewart, K. S., Gyles, P. D. T., & Shore, B. M. (2012). Student Outcomes in Inquiry Instruction. *Journal of Advanced Academics*, *23*(1), 5–31. https://doi.org/10.1177/1932202X11429860

Vaino, K., Holbrook, J., & Rannikmäe, M. (2012). Stimulating students' intrinsic motivation for learning chemistry through the use of context-based learning modules. *Chem. Educ. Res. Pract.*, *13*(4), 410–419. https://doi.org/10.1039/C2RP20045G

Vallerand, R. J. (1997). Toward A Hierarchical Model of Intrinsic and Extrinsic Motivation. *Advances in Experimental Social Psychology*, *29*, 271–360. https://doi.org/10.1016/S0065-2601(08)60019-2

Van Asseldonk, K. K. W. (2019). *Enhancing students' intrinsic motivation for radiation physics by inquiry-based learning: A quasi-experimental study of student behaviour* (Universiteit Utrecht). Retrieved from https://dspace.library.uu.nl/handle/1874/383398

Vedder-Weiss, D., & Fortus, D. (2011). Adolescents' Declining motivation to learn science: Inevitable or not? *Journal of Research in Science Teaching*, *48*(2), 199–216. https://doi.org/10.1002/tea.20398

Vedder-Weiss, D., & Fortus, D. (2012). Adolescents' declining motivation to learn science: A follow-up study. *Journal of Research in Science Teaching*, *49*(9), 1057–1095. https://doi.org/10.1002/tea.21049

Verburg, M. B. (2018). *Direct Instruction versus Guided Inquiry-Based Learning in a Physics Practical* (Utrecht University). Retrieved from https://dspace.library.uu.nl/handle/1874/363938

Wentzel, K. R., & Miele, D. B. (2016). Handbook of motivation at school. In *Educational psychology* *handbook series TA* - *TT* - (Second edi). New York, NY SE - xi, 532 pages ; 27 cm.: Routledge.

Appendix

Appendix A. Examples of worksheets of the ISP practical.

Worksheets A1 and A2 are worksheets from the IBL version of the practical. Worksheet A3 is of the same topic as worksheet A1 and A2, but with a DI approach.

Universiteit Utrecht

OPEN

Faculteit Bètawetenschappen
Ioniserende Stralen Practicum

Experiment 2A

Radioactief verval van radon-220

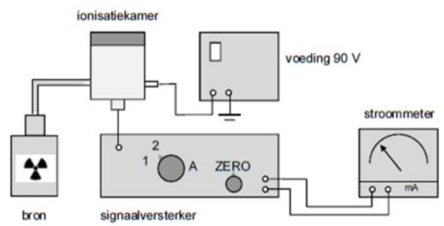
Lees eerst de inleiding op het experiment in het informatieboekje *Experimenten met radioactieve bronnen en röntgenstraling* over het verval van radioactieve stoffen.

Doel

- Bepalen van het verband tussen de ionisatiestroomsterkte (of: de activiteit van de bron) en de tijd.
- Bepalen van de halveringstijd van het gasvormige radon-220.

Meetopstelling

De opstelling bestaat uit een ionisatiekamer die via een slang verbonden is met een plastic flesje met thorium-232 (^{232}Th). In het flesje zit het gasvormige radon-220 (^{220}Rn): een vervalproduct van het ^{232}Th. Het radongas wordt in de ionisatiekamer gespoten. De door het radon uitgezonden α-straling ioniseert daar de lucht. De bij deze ionisaties gevormde lading is als een elektrische stroom via een signaalversterker te meten met een stroommeter. De gemeten stroomsterkte I op het tijdstip t is een maat voor het aantal radioactieve radonkernen N_t op dat moment. Want: hoe groter het aantal radioactieve kernen is, des te sterker is de ionisatie van de lucht en des te groter is de gemeten stroomsterkte.
Voorafgaand aan het meten moet je de signaalversterker goed instellen: zet schakelaar A van de signaalversterker op stand 1 (de instelstand), regel met de knop 'set zero' de aanwijzing van de stroommeter af op I = 0 mA en zet daarna schakelaar A op stand 2 (de meetstand). Het meetbereik van de stroommeter is 6 mA.
Je brengt het radongas op de volgende manier in de ionisatiekamer: open de slangklem op de slang tussen het plastic flesje en de ionisatiekamer, knijp een paar keer rustig in het plastic flesje tot de wijzer van de stroommeter voldoende uitslaat en sluit daarna de slangklem.
Voor het meten van de tijd gebruik je een stopwatch.



Met deze meetopstelling is de halveringstijd $t_{1/2}$ van ^{220}Rn te bepalen uit een meting van de ionisatiestroomsterkte I als functie van de tijd t.

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 tijd t.
- Geef deze hypothese ook in de vorm van een schets van het verband tussen deze grootheden in een I,t-diagram.
- Stel ook een hypothese op over de grootte-orde van de halveringstijd $t_{1/2}$ van ^{220}Rn.

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.

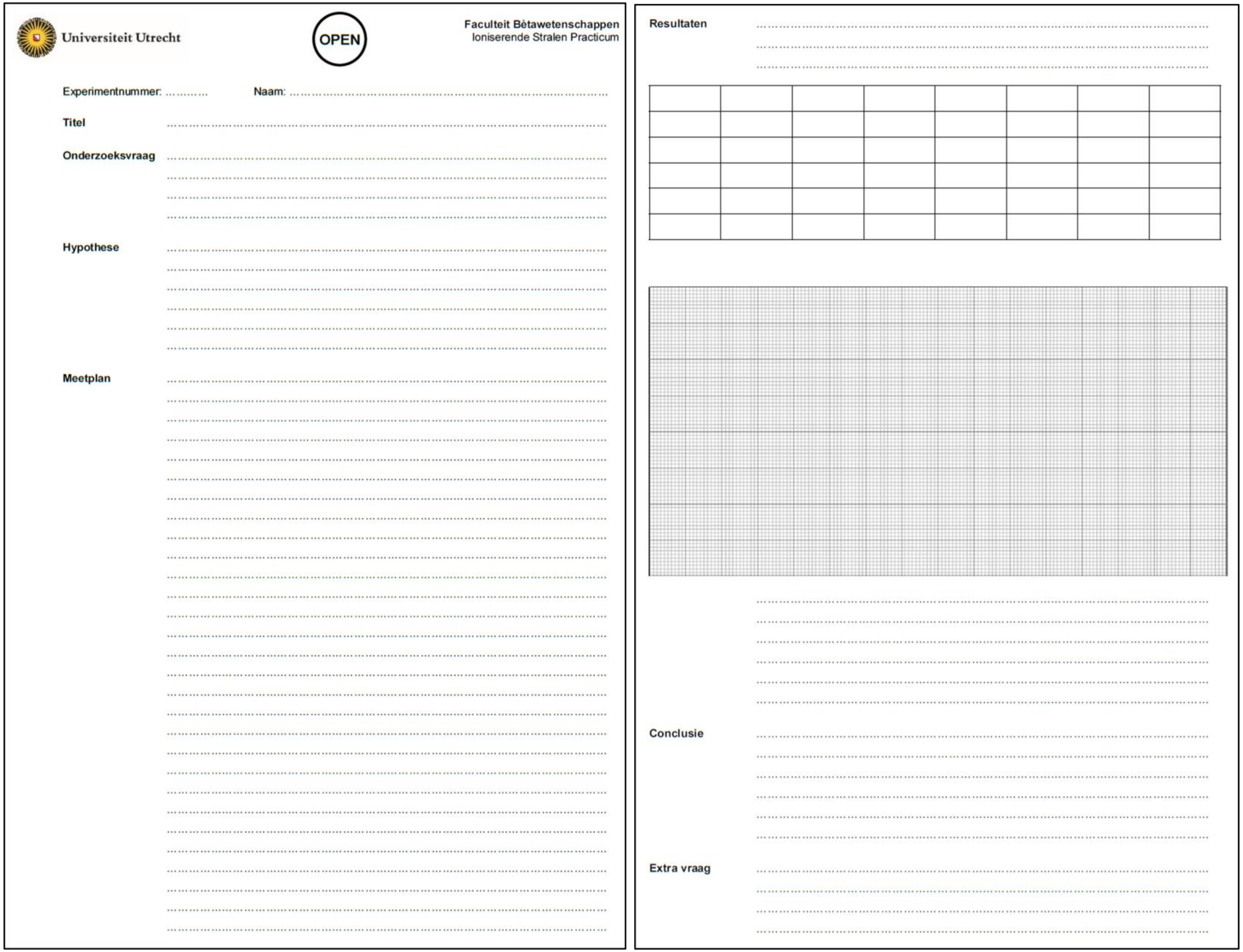
Aanwijzingen
- Geef de meetresultaten in de vorm van een diagram
> Bepaal uit het diagram van de metingen de halveringstijd $t_{1/2}$ van ^{220}Rn.
- In het boekje *informatieboekje Experimenten met radioactieve bronnen en röntgenstraling* staat informatie over het zo nauwkeurig mogelijk bepalen van grootheden uit een grafiek op enkellogaritmisch grafiekpapier.
> Vergelijk de nauwkeurigheid van het bepalen van de halveringstijd $t_{1/2}$ van ^{220}Rn uit je meetresultaten in een grafiek op normaal en op enkellogaritmisch grafiekpapier.

Extra vraag
Het RIVM heeft in 2013 aangetoond dat er in een gemiddelde woning in Nederland een activiteit heerst van 15,6 Bq per m³ lucht, afkomstig van Radon. Wanneer je aanneemt dat je longen (volume 6,0 L) voortdurend met deze lucht gevuld zijn, hoeveel alfadeeltjes krijg je dan per jaar te verwerken?

Verslag

- Schrijf een verslag van dit onderzoek in de vorm van een *meetrapport*. In dat meetrapport staan je *onderzoeksvraag*, de opgestelde *hypothesen*, de (verwerkte) *meetresultaten* en de daaruit getrokken *conclusies* over het al dan niet juist zijn van die hypothesen.

Figure A1. Worksheet IBL approach on half-life.



Universiteit Utrecht

OPEN

Faculteit Bètawetenschappen
Ioniserende Stralen Practicum

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

Titel ....

Onderzoeksvraag ....

Hypothese ....

Meetplan ....

Resultaten ....

Conclusie ....

Extra vraag ....

Figure A2. Measurement report worksheet IBL approach on half-life.

Universiteit Utrecht

Faculteit Bètawetenschappen
Ioniserende Stralen Practicum

Experiment 2A

Naam: ....

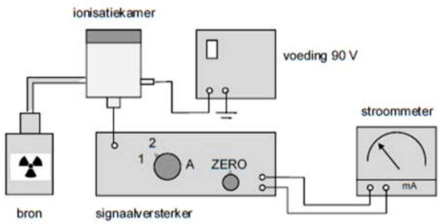
Radioactief verval van radon-220

Doel

Bepalen van de halveringstijd van het gasvormige radon-220.

Opstelling

De opstelling bestaat uit een ionisatiekamer die via een slang met slangklem verbonden is met een plastic flesje met thorium-232 (^{232}Th). In het flesje zit het gasvormige radon-220 (^{220}Rn): een vervalproduct van het ^{232}Th. Het radongas wordt in de ionisatiekamer gespoten. De door het radon uitgezonden α-straling ioniseert daar de lucht. De bij deze ionisaties gevormde lading is als een elektrische stroom via een signaalversterker te meten met een stroommeter. De gemeten stroomsterkte I op het tijdstip t is een maat voor het aantal radioactieve radonkernen N_t op dat moment. Want: hoe groter het aantal radioactieve kernen is, des te sterker is de ionisatie van de lucht en des te groter is de gemeten stroomsterkte.



Lees eerst de inleiding bij experiment 2A en 2B in het informatieboekje *Experimenten met radioactieve bronnen en röntgenstraling* over het verval van radioactieve stoffen.

Metingen

1 Zet schakelaar A van de signaalversterker op stand 1. Controleer of de wijzer van de stroommeter op nul staat. Zo niet, zet die wijzer dan op nul met de knop 'set zero'. Zet schakelaar A nu op stand 2.

2 Open de slangklem. Knijp een paar keer rustig in het plastic flesje tot de wijzer van de stroommeter uitslaat tot voorbij de 6 mA. Sluit nu de slangklem.

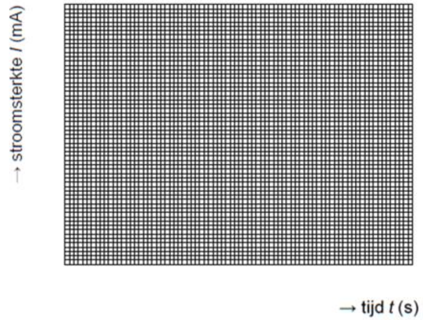
3 Wacht tot de wijzer van de stroommeter langzaam terug begint te lopen. Start de stopwatch op het moment dat de wijzer de 6 mA passeert. Dit is het tijdstip t = 0 s. Lees op de stopwatch de tijd t (in s) af als de wijzer van de stroommeter de 5, 4, 3, 2 en 1 mA passeert. Noteer de gemeten tijden in de tabel hieronder.

stroomsterkte I (mA)	6	5	4	3	2	1
meettijd t (s)	0					

Uitwerking

1 Maak een grafiek van je meetresultaten op de achterkant van dit werkblad.

2 Bepaal uit de bij opdracht 1 getekende grafiek driemaal de halveringstijd $t_{1/2}$ van ^{220}Rn. Doe dit door drie verschillende beginwaarden van de stroomsterkte I te kiezen (A, B en C), en bij elk van de gekozen beginwaarden uit de grafiek af te lezen hoe lang het duurt tot de stroomsterkte is gedaald tot de helft van die beginwaarde. Noteer de gekozen waarden van de stroomsterkte I en de gevonden halveringstijden in de regels naast de grafiek. Bereken daarna het gemiddelde van die drie halveringstijden.



De stroomsterkte I daalt

A van ...... naar ...... mA in ...... s

B van ...... naar ...... mA in ...... s

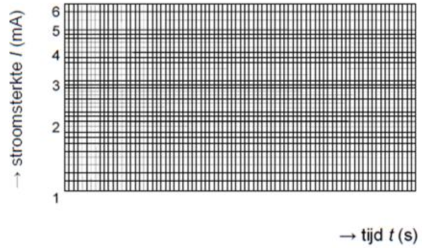
C van ...... naar ...... mA in ...... s

Gemiddelde halveringstijd $t_{1/2}$ van ^{220}Rn:

$t_{1/2}$ = ... s

3 Maak nogmaals een grafiek van je meetresultaten, maar nu op het enkellogaritmisch grafiekpapier hieronder. Wat valt je op aan de nieuw getekende grafiek?

....
....
....



4 Bepaal uit de nieuw getekende grafiek opnieuw de halveringstijd $t_{1/2}$ van ^{220}Rn:

$t_{1/2}$ = ... s

5 In opdracht 2 en 4 heb je op twee verschillende manieren de halveringstijd van ^{220}Rn bepaald. Welke van die twee manieren is het nauwkeurigst, en waarom?

....
....
....
....

Zie het informatieboekje (Enkellogaritmisch grafiekpapier) voor de redenen om bij het bepalen van de halveringstijd enkellogaritmisch grafiekpapier te gebruiken.

6 Wat is de literatuurwaarde van de halveringstijd $t_{1/2}$ van ^{220}Rn op de isotopenkaart in het informatieboekje? Hoeveel wijkt de gevonden waarde af van die literatuurwaarde?

Literatuurwaarde: ...... s. Afwijking: ...... %

7 Bereken de tijd waarin de activiteit van ^{220}Rn zal afnemen tot 6,25% van de beginactiviteit (100%).

Tijd: ...... s

8 Het gasvormige ^{220}Rn is een vervalproduct van het ^{232}Th in het plastic flesje. Het ^{232}Th vervalt naar het stabiele ^{208}Pb volgens de vervalreeks hieronder.

$^{232}_{90}Th \xrightarrow[1{,}4\cdot10^{10}\,a]{\alpha} {}^{228}_{88}Ra \xrightarrow[.......]{...} {}^{228}_{89}Ac \xrightarrow[.......]{...} {}^{228}_{90}Th \xrightarrow[.......]{...} {}^{224}_{88}Ra \xrightarrow[.......]{...} {}^{220}_{86}Rn \xrightarrow[.......]{...}$

$^{216}_{84}Po \xrightarrow[.......]{...} {}^{212}_{82}Pb \xrightarrow[.......]{...} {}^{212}_{83}Bi \xrightarrow[.......]{...} {}^{212}_{84}Po \xrightarrow[.......]{...} {}^{208}_{82}Pb$ (stabiel)

Zet boven de pijlen de bij het verval uitgezonden soort straling (α of β) en onder de pijlen de halveringstijd van dat verval. Deze halveringstijd vind je op de isotopenkaart in het informatieboekje.

9 Wat kun je zeggen over het gevaar, bij inademing, van het gasvormige ^{220}Rn voor het menselijk lichaam?

....

Extra vraag Het RIVM heeft in 2013 aangetoond, dat er in een gemiddelde woning in Nederland een activiteit heerst van 15,6 Bq per m^3 lucht. Wanneer je aanneemt dat je longen (6 L) voortdurend met deze lucht gevuld zijn, hoeveel alfadeeltjes krijg je dan per jaar te verwerken?

....
....
....

Figure A3. Worksheet DI approach on half-life.

Appendix B. The pilot and final interview schemes of the individual interviews and focus groups.

Interview schemes B1 and B2 include final interview questions with substantiation from research. Interview schemes B3 an B4 include the pilot interview questions.

Scheme B1. Final interview scheme individual interviews.

Questions	Question based upon:
Firstly, you may choose between the two movies, concerning the practical. They take about the same time to watch. You can watch the video after the interview.	
1) Which video do you want to watch? a) Why did you choose this video, and not the other one? b) Is this choice based upon the practical?	*Intrinsic motivation: "Interest or curiosity in learning beyond the lesson content, engagement in tasks beyond the requirements or expectations of the classroom and choice in academic activities among alternatives" (Lee & Brophy, 1996, p. 309)*
2) If you would tell about one of the two experiments to your friends or family, which one would that be? a) Why?	*Based upon interview question of Macleod (2017)*
3) Which experiment did you find most interesting? a) Why?	*Based upon interview question of Banfield and Wilkerson (2014). Interest in the experiment can indicate intrinsic motivation* (Hassandra et al. 2003).

Scheme B2. Final interview scheme focus groups.

Questions	Question based upon…
1) What did you think of the ionizing radiation practical?	*Based upon interview question Banfield and Wilkerson (2014)*
You did two variants of the practical: open [IBL] and closed [DI].	
2) Could you tell something about how it went? a) How did the preparation, the actual experiment and working out of the practical go?	*General impression*
In one experiment you followed a set of clearly described steps, and with the other experiment you needed to do more by yourself.	
3) Which approach did you enjoy most, and why?	*Engaging in the activity out of enjoyment is one of the features of intrinsic motivation (Lepper et al., 2005)*
4) With which approach did you investigate what you wanted to investigate the most, and why?	*Perceived autonomy* (Hassandra et al. 2003).
5) Which approach did you find most difficult, and why? 6) With which approach did you learn the most, and why?	*Perceived competence* (Hassandra et al. 2003).
7) With which way of working did the cooperation go most smoothly and why?	*Perceived relatedness* (Deci & Ryan, 2000)
8) How was the teacher support during the practical? a) How was the support of the teacher from your school? b) How was the support of the teacher from the university?	
9) Imagine that you need to do another experiment after this, and you can choose which approach you work with. Both approaches take the same amount of time (half an hour) and you don't get a grade for it. You can choose the topic	*Intrinsic motivation: "Choice in academic activities among alternatives" (Lee & Brophy, 1996, p. 309)*

yourself, within the radiation practical. Which approach (step-by step plan [DI], or open [IBL]) would you choose, and why?

Scheme B3. Pilot interview scheme individual interviews.

First you may choose between watching two video's about the practical. They take about the same time.

1) Which video do you want to watch?
   a) Why did you choose this video, and not the other one?
   b) Is this choice based upon the practical?
2) If you would tell about one of the two experiments to your friends or family, which one would that be?
   a) What would you tell?

Scheme B4. Pilot interview scheme focus groups.

- What did you think of the ionizing radiation practical?

You did two variants of the practical: open [IBL] and closed [DI].

- Could you tell something about how it went?
  a) How did the preparation, the actual experiment and working out of the practical go?
- Did you have enough freedom with conducting the experiments, could you investigate what you wanted to investigate?
  a) Was there enough freedom with both, or only open [IBL] or closed [DI]?
- Did you find it difficult?
  a) Were the experiments equally difficult? Wat was difficult?
  b) Do you have the feeling that you understood everything during the experiment?
- Did the worksheets help you?
- How was it to do the experiments in a group?
  a) Did the corporation went smoothly during this practical?
- How was the teacher support during the practical?
  a) How was the support of the teacher from your school?
  b) How was the support of the teacher from the university?
- Which of the experiments was most interesting to conduct?
  a) Why?

Appendix C. Intercoder reliability results

The different codes with the calculated Cohen's kappa results are shown for the interviews (table C1) and the focus groups (table C2).

Table C1. Cohen's Kappa results of interview codes.

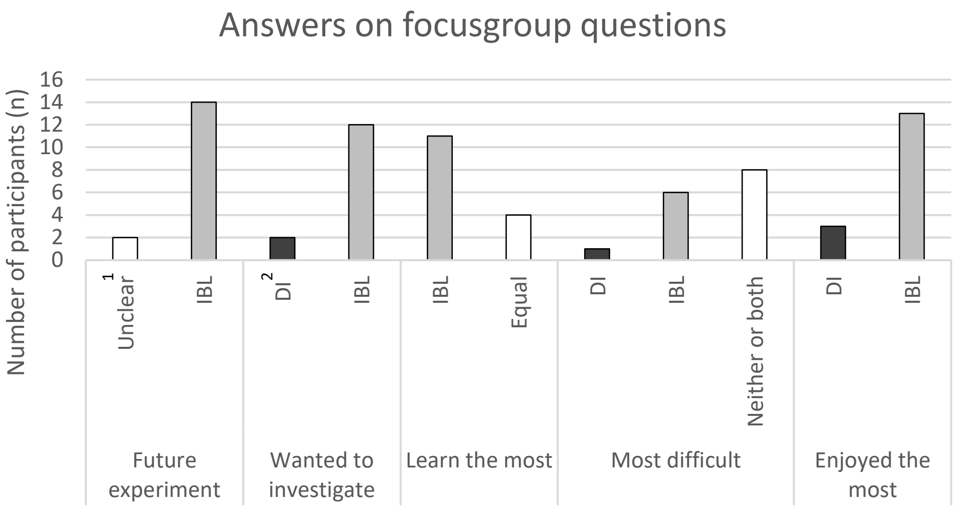
Code	Cohen's Kappa
Other topic too simple	1
(Other not) interesting (topic)	0,79
(Other not) interesting (approach)	1
Fun (topic/general)	0,80
Fun (approach)	0,65
More knowledge	0,79
Less knowledge	1
Easier to understand for another	0,79
Better understanding (topic/general)	0,77
Better understanding (approach)	1
Spend most time	0,66
Less previous knowledge	0,65

Table C2. Cohen's Kappa results of focus group codes.

	Code	Cohen's Kappa
IBL	Competence negative	0,93
	Competence positive	0,88
	Autonomy negative	Not coded by both coders
	Autonomy positive	0,84
	Relatedness negative	Not coded by both coders
	Relatedness positive	Not coded by both coders
DI	Competence negative	0,92
	Competence positive	1
	Autonomy negative	0,88
	Autonomy positive	Not coded by both coders
	Relatedness negative	Not coded by both coders
	Relatedness positive	1

Appendix D. Answers on discussion starting questions.

The answers of participants on the closed discussion starting questions 3-6 and 9 are reported here (see focus group questions in appendix B2).



Note. [1] *Indistict statements: participants said 'DI' indistinctly while another was talking. It is not clear if this was in agreement to 'time restriction with IBL' or as an answer to the question asked.* [2] *Responses not based on autonomy.*

Figure D1. Answers on discussion starting questions. *It is shown what number of participants gave what answer on the different discussion starting questions in this study.*

In figure D1 it is visible that in every category most participants chose the IBL approach rather than DI. In the coding of the focus groups it was already seen that participants had more autonomy with the IBL experiment, this is also visible when viewing the answers on the question '*With which approach did you investigate what you wanted to investigate the most?*'. This is also the case with the question '*With which approach did you learn the most*'. Only IBL was mentioned in this regard, as already seen in the focus groups. Some participants mentioned it was equal, because they had just had an exam on the subject matter. At last, IBL was also experienced as the most difficult by most participants, apart from an unclear question in the DI worksheet. Participants finding both approaches as difficult was due to having a lot of previous knowledge and because the IBL approach was experienced as a 'fun challenge' rather than difficult. These were results that were already seen in the coding of the focus groups. The 'future experiment' and 'enjoyed the most' categories are discussed in the main text.