The effects of an Inquiry-based Learning physics practical on the students' intrinsic motivation, a mixed methods research.

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Author Note

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Abstact

This mixed-methods study investigates the effects of an Inquiry-based Learning secondary education physics experiment on the intrinsic motivation of students, compared to a Direct Instruction equivalent. In a quasi-experiment, 376 students from 9 high schools in The Netherlands were assigned to a control group (Direct Instruction experiment – 208 students) and an experimental group (Inquiry-based Learning experiment – 168 students) and their intrinsic motivation was measured by a questionnaire, pre- and posttest. The ANCOVA analysis, with the pre-test as the covariate showed a significant difference between the variants from pre- to posttest on one of the three sub-scales of the questionnaire (Interest/enjoyment). The effect size, measured by the Partial Eta Squared was small, $\eta^2 = .011$, favoring the Inquiry-based Learning variant experiment. From the 376 students, 22 students from 2 schools were randomly sampled for 6 focus group sessions. Students reported that they enjoyed the autonomy offered by the Inquiry-based Learning experiment but they also noted that they found the Inquiry-based Learning variant harder to perform, compared to the Direct Instruction. The results of this study show that Inquiry-based Learning had a small positive effect on students' intrinsic motivation in comparison to the Direct Instruction experiment. We conclude that the Inquiry-based Learning experiment supports the students' basic psychological need for autonomy, however it fails to adequately support their need for competence. Suggestions for improvement are given.

Keywords: Intrinsic motivation, Self-determination Theory, Inquiry-based Learning, mixed-methods, Ionizing Radiation Practical

The effects of an Inquiry-based Learning physics practical on the students' intrinsic motivation: a mixed methods research.

From infancy humans have a natural tendency toward growth and learning (Cordova & Lepper, 1996). The need for exploration, discovery and understanding is intrinsic in humans and it is central in their motivation toward learning (Deci & Ryan, 1985). However, several studies have shown that the intrinsic motivation of children toward learning declines after they enter school (Cordova & Lepper, 1996). The decrease of students' intrinsic motivation during school years presents an educational problem because being intrinsically motivated to learn has been shown to improve the quality of learning (Deci & Ryan, 1985, p. 256).

Furthermore, research has demonstrated a decline in the attitude of students toward science (Osborne, Simon, & Collins, 2003). In 2001 Gottfried et al. reported a decline in academic intrinsic motivation from age nine to age seventeen for mathematics, science and reading but not for social studies (Gottfried, Fleming, & Gottfried, 2001). Gottfried et al. (2001) attribute this mean decline to the school curriculum. Furthermore, in a more recent study Taylor et al. (2014) also found evidence of a decreasing intrinsic motivation in students between the ages of twelve and seventeen over the period one year.

Furthermore the 2016 Gallup Student Pole (2016) report a significant decrease in student engagement from Grade 5 to Grade 12. The Gallup Student Pole defines engagement as the involvement and enthusiasm for school and was conducted in the US and Canada with 3000 schools participating.

Reasons proposed by researchers for the decreasing intrinsic motivation in school are related to the increase in extrinsic stimuli in school (e.g. grades) as well as the increasingly controlling classroom environments (Eccles et al., 1993; Gottfried et al., 2001; R. Ryan & Deci, 2000a). Positive attitude toward science has been connected to classrooms which high student-to-student interaction, high use of innovative strategies and low levels of teacher control; on the contrary classrooms with high levels of teacher control have been linked with negative attitudes toward science (Myers & Fouts, 1992)

In science education direct instruction is traditionally prevalent in schools. Direct instruction (DI) which is based on the behaviorist approach, describes a group of instructional models based on specific teacher-student interaction; DI models facilitate task-related student behavior under the monitor and control of the teacher (Magliaro, Lockee, & Burton, 2005). The control and direction of the teacher starts with the choice of learning tasks and continues in the classroom where the teacher maintains a central role during the instruction (Joyce, Weil, & Calhoun, 2000). In summary, the teacher presents theory to the students who in turn internalize it and then apply it in problem solving situations. The teacher will also present different examples of problems and the strategies the students should use in order to solve them.

Inquiry-Based Learning (IBL) on the contrary is based on the constructivist approach (Minner, Levy, & Century, 2010). IBL is a teaching approach that facilitates student initiated investigations in which students have to answer their own research questions using data they collect as evidence (Capps & Crawford, 2011). The students are guided by the teachers in order to formulate their own research questions and hypotheses. They then develop the experimental process in order to investigate their hypotheses and draw conclusions.

Furthermore, laboratory instruction and experiments have been proposed as tools to arouse the interest, attitude, curiosity and satisfaction of students in science education (Shulman &Tamir, 1973). The DI approach to laboratory exercises translates to experiments carried out by following a set of predetermined steps. In contrast, the IBL approach to laboratory exercises invites students to generate their own research question and perform the experiments in order to obtain answers. The teacher is guiding the process, rather than directing it. IBL can potentially support the students' basic psychological needs for autonomy, competence and relatedness (R. Ryan & Deci, 2000b). The IBL approach to experiments provides enhanced autonomy to students; consequently, it could be a possible direction for physics education to stimulate students' intrinsic motivation. However, one important provision is that an IBL experiment should offer sufficient support to the students in order to foster their inherent need for competence.

IBL has been shown to have a positive effect on the attitude and interest of students toward science education (Savelsbergh et al., 2016). Nevertheless, there is a lack of research concerning the effect of IBL experiments on the intrinsic motivation of students. There is some evidence of the positive effect of IBL programs on the attitude (and performance) of middle school students (Gibson & Chase, 2002; Wolf & Fraser, 2008). Furthermore, Teun Nooijen's (2017) pilot study found a significant positive effect on the intrinsic motivation of students following an IBL practical, albeit with a small sample. Thus, the need for more research concerning the relation between IBL and the students' intrinsic motivation towards science remains.

The purpose of this research is to investigate whether an IBL approach to a physics experiment has a positive effect on the intrinsic motivation of students in comparison to the DI approach. Furthermore, this research will aim to gain insight into the experiences of students with the IBL experiments. Finally, we will also investigate the mechanism that potentially connects IBL experiments and intrinsic motivation.

Theoretical Background

Self-Determination Theory and Intrinsic Motivation

The definition of intrinsic motivation used in this research stems from the work of Richard Ryan and Edward Deci (1985, 2000a, 2000b). According to Ryan and Deci (2000b) intrinsic motivation is the "inherent tendency to seek out novelty and challenges, to extend and exercise one's own capabilities, to explore and to learn" (p. 70). Intrinsic motivation is the desire to engage in activities for no reason other than enjoyment, pleasure, challenge or interest (Lepper, Corpus, & Iyengar, 2005). On the contrary extrinsically motivated behaviors are those that people engage in because there is an external incentive, such as a reward or a punishment (Santrock, 2010).

The Self-Determination Theory (SDT), and specifically one of its mini-theories, Cognitive Evaluation Theory (CET) identifies three inherent needs that form the basis for self-motivation These are the needs for:

1. Autonomy, or “the need to self-regulate one’s behavior”
2. Competence which is “the need to feel effectance and mastery” and
3. Relatedness which translates to the need “to feel socially connected” (R. M. Ryan & Deci, 2017, p. 10).

The need for competence can also be associated with Lev Vygotsky’s zone of proximal development (ZPD), which is defined as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (Vygotsky, 1978, p. 86). In one definition, the ZPD describes a range of tasks that an individual can complete, with assistance or support (Wass & Golding, 2014).

Intrinsic motivation is an important aspect of education since it is connected to the enjoyment of learning in school which in turn is connected to curiosity, persistence and the learning of novel, challenging tasks (Gottfried, 1985; Gottfried et al., 2001). Furthermore, research has shown that intrinsic motivation has a positive effect on achievement. Gottfried (1985) reported significant correlations between intrinsic motivation and achievement tests. In the same study, students that reported higher intrinsic motivation also reported a better perception of their academic competence and less anxiety (Gottfried, 1985). In addition, Taylor et al. (2014) in their meta-analysis also report a positive relation between intrinsic motivation and school achievement. In another meta-analysis

Cesaroli, Ford and Nicklin (2014) found intrinsic motivation to be an accurate predictor of achievement.

Inquiry Based Learning

The Inquiry Based Learning (IBL) approach is a more student-centered approach to teaching and learning. Inquiry-based learning facilitates an environment of active participation and learner's responsibility for discovering new knowledge (De Jong & Van Joolingen, 1998)

The teacher functions as a facilitator of the inquiry, giving the setting and the theme, after which the students take charge of the process. The students formulate their own research question and then investigate by conducting experiments, discovering relationships in the process (Pedaste, Mäeots, Leijen, & Sarapuu, 2012). With IBL the learning process is self-directed; the students decide about the way in which a problem will be addressed (Hutchings, 2007). We define inquiry learning as a process of discovering new relations, with the learner formulating hypotheses and then testing them by conducting experiments and/or making observations. IBL has been hypothesized to facilitate the discovery of information by the students; information that has been discovered by the students has the potential to be immediately ready to be used in problem solving (Bruner, 1961).

IBL is not a singular teaching approach. On the contrary IBL has been described as a four-level continuum (Banchi & Bell, 2008). According to Banchi and Bell (2008) the four levels of IBL are:

- **Confirmation Inquiry**: Students are provided with the question as well as the procedure. The results are also known from the beginning.
- **Structured Inquiry**: Students are provided with the question and the procedure; however, the students need to explain the phenomena based on evidence.
- **Guided Inquiry**: Students are provided only with the research question and they have to decide on the procedure they will follow to answer it.

- **Open Inquiry**: Students are responsible for the research question, the procedure as well as arriving at an answer based on their analysis.

In experimental settings, contrary to DI the students are presented with the relevant theory and the experimental equipment, but they have to formulate their own research questions, design and carry out the experiments to answer them. In this research, the approach of IBL taken can be characterized as Guided Inquiry Based Learning (GIBL). This will be further discussed in the methods section in the next chapter.

Inquiry-based Learning and Intrinsic Motivation

The SDT defines the three psychological needs that must be fulfilled for a person to be intrinsically motivated, the needs for Competence (C), Autonomy (A) and Relatedness (R). The IBL approach offers a possible path to support the three psychological needs defined by Ryan and Deci, as was also proposed by van Asseldonk (2019).

Students performing an GIBL experiment, such as the IBL variant of the ISP, work in groups to perform the experiments. The students pose their own research question, develop their own experimental process, collect and analyze data in order to obtain the answer to their research question. In the GIBL approach, students work autonomously during the sessions (A) based on their own planning. Moreover, the students always work in groups with their peers in the presence of their teachers which enhances their feeling of relatedness (R). Finally, the students are supported by the ISP worksheets that support the students in their GIBL experiments. Support is important because it fosters the students need for competence (C) during the experiments.

Supporting all three psychological needs during the experimental process is important in order to foster intrinsic motivation and furthermore ensure that students are learning within their zone of proximal development (Vygotsky, 1978) by being properly supported in their effort. This means that providing autonomy must be coupled with support in order to enhance intrinsic motivation.

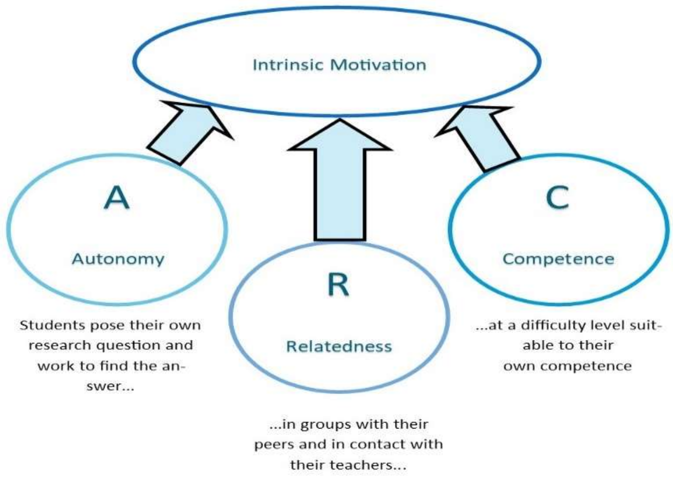

Figure 1: Visualization of the hypothetical mechanism between the three psychological needs defined in the SDT and IBL

The mechanism proposed by van Asseldonk (2019) could provide a blueprint for a method to support the intrinsic motivation of students through IBL experiments. However, there is no research on the subject. This mechanism is the hypothesis on which this research is based on. The hypothesis is that providing students with more autonomy while adequately supporting them at the same time will increase their intrinsic motivation.

Research Question

Research has shown that IBL can have a positive effect on the attitude as well as the achievement of students (Furtak, Seidel, Iverson, & Briggs, 2012; Gottfried et al., 2001; Savelsbergh et al., 2016; Taylor et al., 2014).

The hypothesis of this research is that IBL experiments have the potential to positively affect the intrinsic motivation of students compared to DI experiments, by supporting their needs for autonomy and competence. The effect of the two variants on the need for relatedness is not investigated in this research, because the experiments of both variants are performed in groups. Nonetheless, there is a relative dearth of research concerning the effect of IBL-themed laboratory work on the intrinsic motivation of students.

The main research question is: “To what extent does an Inquiry Based Learning Practical about ionizing radiation result in higher intrinsic motivation when compared with a traditional Direct Instruction experimental approach?”. The first sub-question is: “To what extent do DI and IBL settings change the self-reported intrinsic motivation of students?”

The second sub research question is: “To what extent are the needs for Competence and Autonomy supported in IBL experiments as compared to DI experiments?”. The need for relatedness is not included in this research because students in both conditions (DI or IBL) work in groups with their peers.

Methods

Setting: Ionizing Radiation Laboratory

This research was conducted within the setting of the Ionizing Radiation Laboratory, or Ioniserende Stralen Practicum (ISP) in Dutch. The ISP is an initiative of the Freudenthal Institute of the University of Utrecht (Ioniserende Stralen Practicum, 2018).

The ISP offers the opportunity to all Dutch secondary education physics students to practice experiments with radioactive substances and X-Rays (Ioniserende Stralen Practicum, 2018). Schools can either perform the ISP experiments at the University of Utrecht in the ISP laboratory or at the school with one of the available ISP mobile units. The laboratory session lasts approximately two hours and the students perform three to five experiments under the supervision of the ISP staff and their own teachers (Ioniserende Stralen Practicum, 2018).

The ISP has offered step-by-step experiments or DI variant experiments since 1972 but in recent years open variant experiments (IBL) have been developed (Ioniserende Stralen Practicum, 2018). The schools have the choice to perform the IBL or the DI variant experiments.

The DI variant of the experiments provides students with a worksheet that lists the steps that they need to follow. Methods of data collection and processing are specifically mentioned in the DI variant worksheet (Ioniserende Stralen Practicum, 2018).

On the other hand, the IBL variant of the experiments offers an opportunity to the students to conduct a more authentic scientific inquiry. The IBL variant worksheets provide the relevant theory, guiding students toward a research question, describe the experimental set up and support them in developing their experiments. Consequently, the students' inquiry is guided, although they still must pose their own research question and develop the experiment that will answer it. Capps and Crawford developed a spectrum to categorize the level of inquiry in science lessons (Capps & Crawford, 2013). Their matrix can be found in Appendix A.

Researchers at the Freudenthal Institute have examined the ISP IBL variant worksheets; they cross-referenced the research of Capps & Crawford (2013) as well as Pedaste et al (2015). According to Verburg (2018) the ISP experiments can be classified as Guided Inquiry Based Learning (GIBL) .

Research Design

For this research a mixed methods approach was chosen. In order to answer the main research question a quantitative approach was selected. Furthermore an experimental strategy was adopted because the aim is to study the effect of the IBL approach on students' intrinsic motivation (Denscombe, 2014). However, the decision on which variant the students practice is made by the school teachers, therefore it is not possible to randomly assign students to an experimental and a control group. Consequently a quasi-experimental approach was chosen (Creswell, 2014). A questionnaire was used pre- and posttest.

A qualitative approach is selected to answer the sub-questions. The qualitative phase is designed to follow the quantitative and build on the results that phase yields; the trends observed in the quantitative results are explored in the qualitative part of the study. The goal of collecting qualitative data is to develop a deeper understanding of the underlying mechanism that connects the open variant of the ISP with the students' intrinsic motivation.

Participants (Population and Sample)

The population for this research can be specified as Dutch high school students in the final or pre-final grade of secondary education, meaning between grades 10 and 12, HAVO or VWO (ages 16-17). Convenience sampling was used because the students in the sample came from schools that performed the ISP experiments. The selection of variant (IBL or DI) is made by the teacher of each class; the ISP cannon dictate which variant the students will perform.

During the first period of this research, the strategy followed was to only ask for permission from the teachers to be present during the sessions and survey the students. All schools sampled during the first four months of the research performed the DI variant of ISP. Our strategy was subsequently adapted, and the open variant was proposed to all teachers that were contacted for permission. The final choice as always rested with the teacher of the attending school.

The data collected during the first period was not used in the analysis; during this period a first data collection protocol was piloted, adapted and finalized. The final protocol was used for the collection of the actual data used in the analysis.

The quantitative data included in the analysis was collected from a total of nine different schools either at the University of Utrecht or at the school locations. The schools included in the sample come from different parts of the Netherlands. Furthermore, some of the schools have different educational approaches to others, for example the Montessori approach. The Montessori school was included after careful consideration and discussion with the teachers; this discussion revealed that the physics classroom is not different than that of any other school in the sample. In table 2 one can find more information on the sample used for this research.

Table 1

Sample information in chronological order of data collection

School	School Type	School Province	Location	Number of students	Class	Variant(s) Performed
1	College	Gelderland	School	53	HAVO 5, VWO 6	IBL
2	College	Utrecht	University	22	HAVO 5, VWO 6	IBL and DI
3	College	Noord-Holland	School	60	HAVO 5, VWO 6	DI
4	College	Zuid-Holland	School	66	HAVO 5, VWO 6	IBL
5	Lyceum	Utrecht	University	31	VWO 6	IBL and DI
6	College	Noord-Brabant	School	53	HAVO 5, VWO 6	DI
7	College	Utrecht	University	20	VWO 6	DI
8	School	Drente	School	26	HAVO 5	IBL and DI
9	College	Zuid-Holland	School	43	VWO 6	IBL and DI

In both locations (UU and school) the material and worksheets were identical and the only people present were the teacher, the ISP employee and the researcher, making the conditions practically equal.

Regardless, the location difference was carefully considered, because the trip to the university location could potentially excite the students and increase their motivation. However, after interviews with students it became evident that the location was less important (or exciting) than the experiments themselves. Students mentioned experimenting with radioactive materials as a source of excitement rather than the location. Furthermore, both the trip to the Utrecht University and the presence of the mobile unit at the school were reported by the students as exciting during interviews.

Another difference among the schools that performed the IBL variant experiments is that students from some schools prepared in advance of the ISP session while others did not. For example, students from some schools had prepared their research question and plan of action from before. This could potentially affect the starting condition. However, this is controlled by investigating the differences between pre- and posttest.

Students from two of the nine schools were sampled for the qualitative part of the research. The two schools were selected based solely on the teachers' willingness to assist with the research by allocating time for the focus groups. Both schools performed the IBL and the DI variant.

Data Collection

Quantitative

The quantitative data analyzed in this study was collected on different dates between September 2018 and February 2019. Data collection took place either at the ISP laboratory at the University of Utrecht (UU)[1] or at school locations.

The protocol followed for the data collection was developed after several months of piloting different processes. In the UU location the pretest was administered before the safety instruction by the laboratory assistant. As soon as the students entered, they received a small introduction about the research and the questionnaires and then they were asked to fill out the pre-test. In addition, they were asked to raise their hands as soon as they were finished with the first experiment of the session in order for the second (post-test) questionnaire to be administered.

The presentation given by the laboratory assistant at the UU was done with the use of a PowerPoint presentation. The visual aid was considered as a possible influence on the motivation of students and so the pre-test was applied before the presentation.

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[1] Minnaert Building

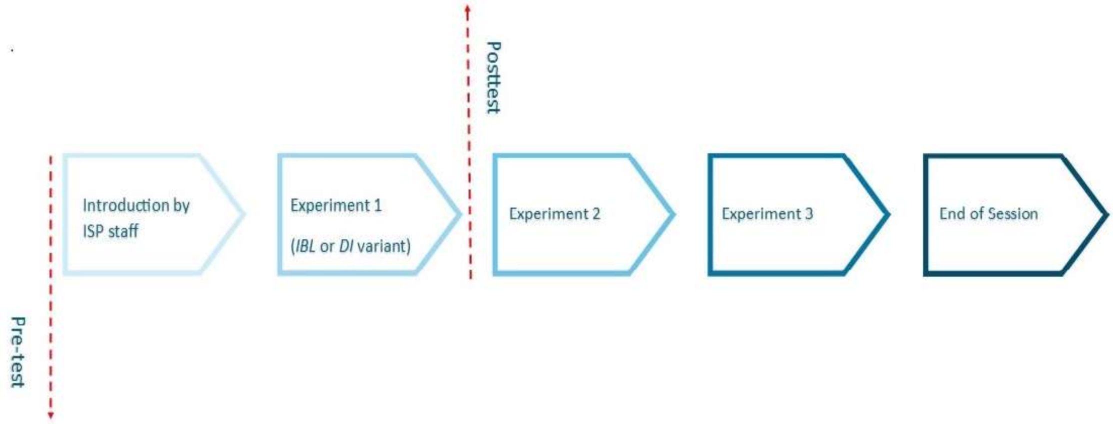

Figure 2: Process of quantitative data collection at the ISP UU location

Adaptations were made to this process for the data collections at the school locations. The presence of the laboratory at the school, the fact that multiple classes were usually scheduled to perform the experiments in consecutive sessions added pressure to the teachers and the ISP staff. Moreover, the safety presentation was given without the use of a PowerPoint presentation. Consequently, the pre-test was administered *after* the introduction by the ISP staff, right before the first experiment.

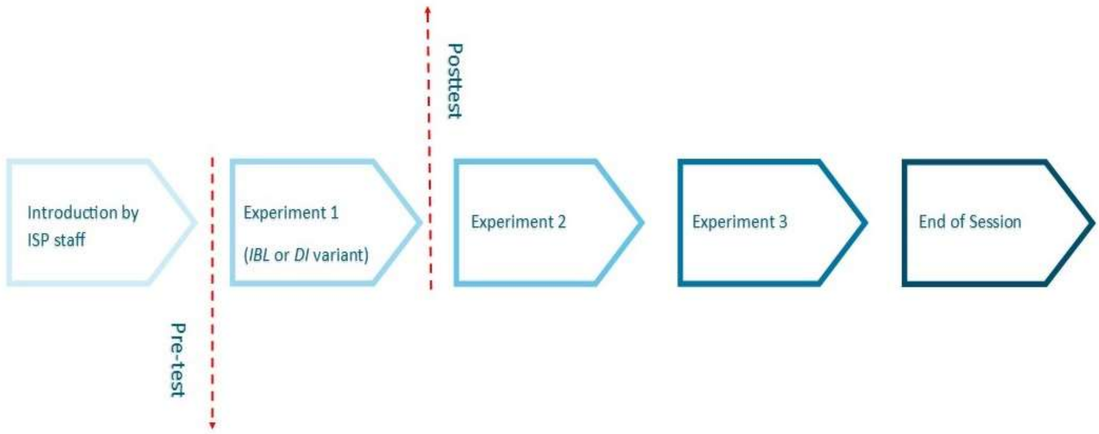

Figure 3: Process of quantitative data collection at school locations

Statistical comparisons between specific questions of the pre-test questionnaire were performed to compare the two processes. The results revealed no significant effect on the students' intrinsic motivation, so the processes were kept as such.

In both cases the posttest was administered before the first experiment of each session. This was designed in order to obtain an unbiased understanding of the effect of that one experiment (IBL or DI) on the intrinsic motivation of the students. The inclusion of more experiments between pre- and posttest application of the questionnaire would have compromised the data.

The Intrinsic Motivation Inventory

The instrument employed to collect the quantitative data was the Intrinsic Motivation Inventory (IMI) developed by Ryan (1982). The IMI is a multidimensional measurement tool designed to assess the subjective experience of participants regarding specific activities (Self-Determination Theory, 2018). The IMI consists of seven subscales, which assess the participant's:

- Interest / Enjoyment
- Perceived competence
- Effort / Importance
- Value / Usefulness
- Felt tension and pressure
- Perceived choice
- Relatedness

The most important of these scales is the Interest/Enjoyment which is considered as a self-reported measure of intrinsic motivation. The IMI is a valid measurement instrument for intrinsic motivation (McAuley, Duncan, & Tammen, 1989). For this research a modified version of the IMI that fit the ISP setting and the purpose of the research was used. The modified questionnaire was developed and tested during previous research at the Freudenthal Institute (Nooijen, 2017) and contains sixteen questions on four subscales:

- Interest / Enjoyment

- Perceived competence
- Effort / Importance
- Value / Usefulness

The *Felt Tension and Pressure* scale was eliminated because all students work on a limited time and moreover some schools grade the students' reports while other schools do not. As a result, this scale would have been compromised. The *Perceived Choice* scale was eliminated because the students are obliged by their schools to perform the experiments which renders this scale unreliable as well. Finally, the relatedness scale which examines interpersonal interactions was eliminated because in both variants students work in groups of two making the conditions equal (Nooijen, 2017).

The same basic questions are asked in the pre and posttest, although in the posttest the tense is changed to the past, for example, from "The ISP-practical seems to be fun to do" to "The ISP practical was fun to do". In addition, the order of the questions was altered in the posttest to prevent the students feeling they are filling the same questionnaire twice. All questions are based on a 1 – 5 Likert scale where 1 is "completely disagree" and 5 "completely agree". The pre and posttest questionnaires can be found in Appendix B.

Reliability

The reliability of the IMI questionnaire was investigated by calculating Cronbach's α for all the subscales pre and post-test. The results of this analysis can be seen in Table 2. Scales with α >.7 are considered reliable when dealing with psychological constructs (Kleine, 1999 as cited in Field, 2017). One of the four questions of the Interest / Enjoyment subscale has been omitted from all data analysis. This was the "I *could not keep an eye on the attention during the ISP practical*" in the pre-test and "*I think I will not always keep my attention during the ISP practical*" in the posttest.

This question was found to compromise the reliability of several sets of data collected during the pilot period. In addition, when included in the reliability analysis of the actual data, Cronbach's Alpha drops to $\alpha = .766$ for the pre-test and $\alpha = .770$ for the posttest. Although both values are acceptable, they are still lower than when this particular question is removed, as can be seen in Table 2. The decision was additionally supported by the fact that this particular question was also found to compromise reliability in the past when used in the same setting (Nooijen, 2017).

Table 2

Reliability Analysis of IMI subscales

	Cronbach's Alpha	
	Pre-test	Posttest
Subscales		
Interest / Enjoyment	.845	.840
Perceived Competence	.732	.766
Effort / Importance	.793	.645
Value / Usefulness	.757	.867

Furthermore, the posttest for the Effort / Importance scale yielded a measure of $\alpha = .645$ which is below the $\alpha = .7$ threshold for reliability. After further investigation of the results no specific question could be identified as responsible for compromising the reliability of the scale. Therefore, the Effort / Importance scale is excluded from any further analysis.

Quantitative Data Analysis

The analysis of the quantitative data was conducted on SPSS. Inferential statistics were used to compare the two groups. More specifically, analysis of covariance (ANCOVA) was conducted with the pre-test scores as the covariate for the two groups. ANCOVA was selected to account for any differences between schools, by using the pre-test as a covariate. Before using ANCOVA we checked if the assumptions for ANCOVA were met: the posttest must be normally distributed, the covariate must be independent from the treatment variable and finally homogeneity of the regression slopes must be met.

Normality was investigate using the Shapiro-Wilks test for the IBL and DI variant on all constructs. The Shapiro-Wilks test yielded very significant results (<.001) for all constructs. As ANCOVA is robust against non-normality, Q-Q plots were designed for all constructs to investigate if there are important differences from normality. In figures 1,2 and 3 the typical Q-Q plots can be seen:

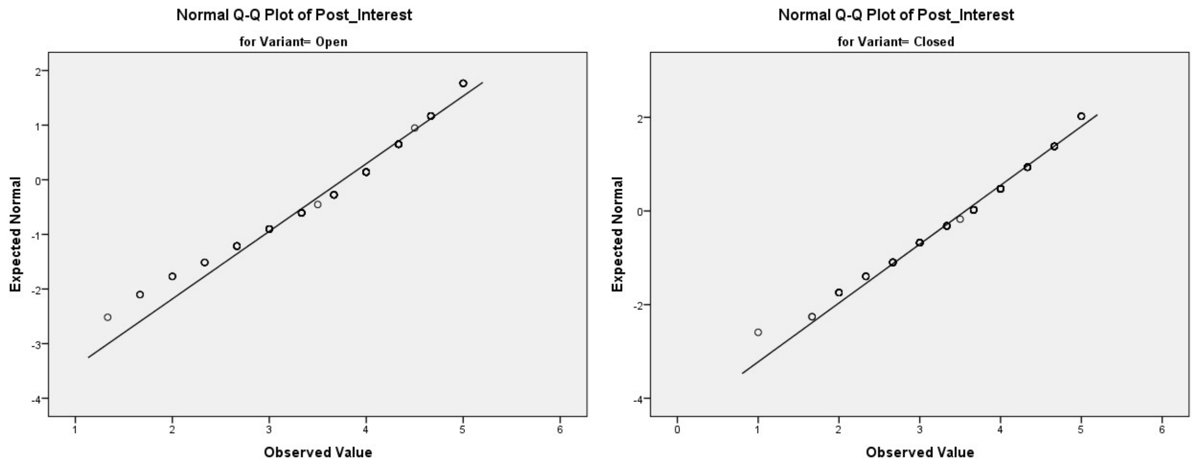

Figure 4: Q-Q plots for Open and Closed variants for the Interest / Enjoyment Scale

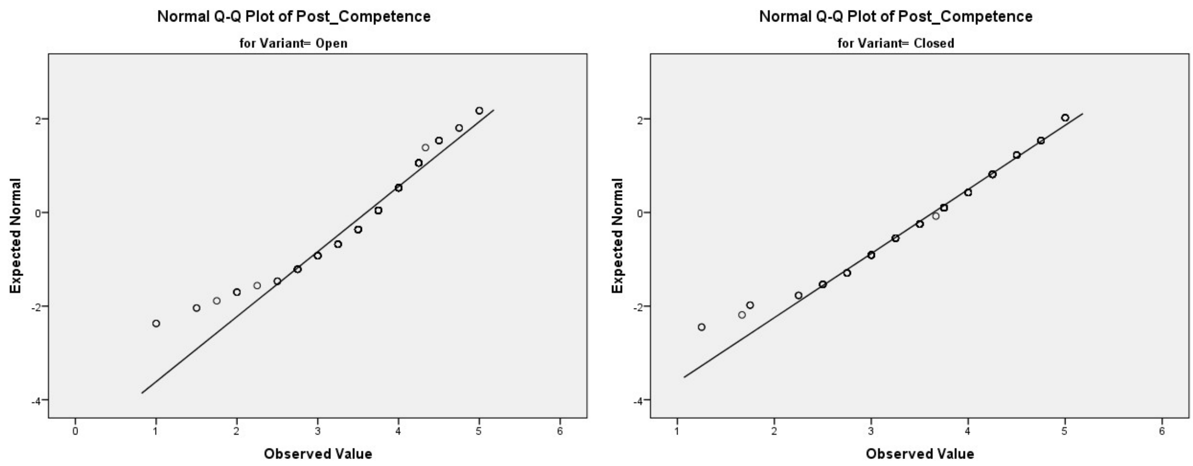

Figure 5: Q-Q plots for Open and Closed variants for the Perceived Competence Scale

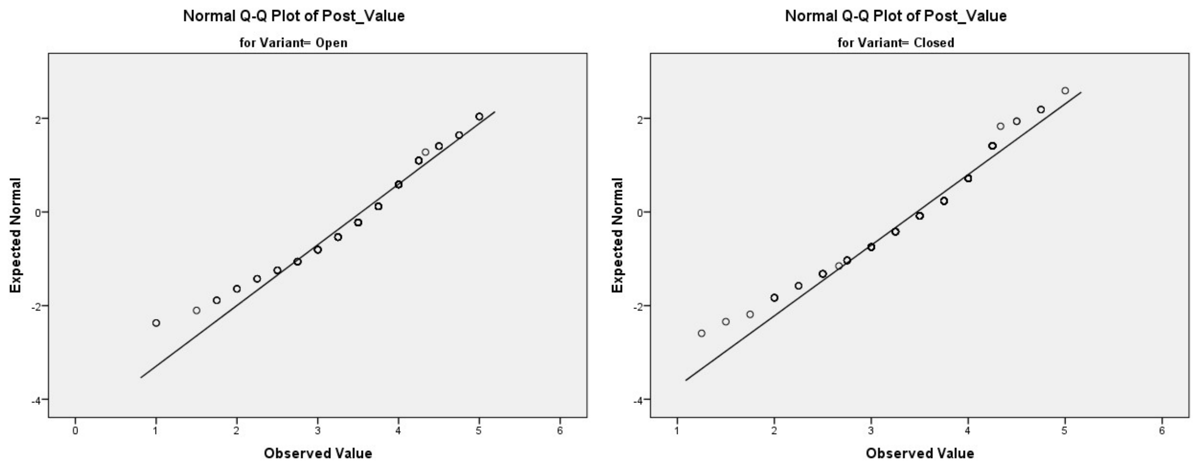

Figure 6: Q-Q plots for Open and Closed variants for the Value / Usefulness Scale

From the Q-Q plots it is visible that there are no large deviations from a normal distribution. Moreover, the pattern of deviations observed is consistent with the results of Nooijen (2017).

The second assumption that must be met in order to use ANCOVA is the independence of the covariate and the treatment variable. This assumption was met for all scales apart from the Effort / Importance scale which was already excluded because of low reliability. Finally, the assumption of homogeneity of the regression slopes was met by all three constructs. ANCOVA was thus considered a viable test to examine the significance of the results of the data.

Qualitative

Qualitative data was collected in order to form a more complete understanding of the effects of the IBL variant on the students' intrinsic motivation, compared to the DI variant. A semi-open focus group was selected as the method to collect qualitative data. The method was selected because focus groups stimulate interaction between the students about their shared experience and thus yield useful additional information (compared to one-on-one interviews). Additionally, it gave us the chance to sample more students in less time which was important.

The focus groups took place approximately a week after the students performed the ISP in order for the students to better appraise and discuss their experience. All focus groups took place at the schools during physics class or recess. We requested permission to interview students from many schools but only two responded positively and were willing to accommodate our needs.

A search in literature for an interview scheme on the topic of intrinsic motivation yielded no results, so an interview scheme was developed for this research. The scheme was designed based on the analysis of the quantitative data in order to better explore the patterns revealed by the analysis of the quantitative data. The interview scheme can be found in Appendix C1.

The students were randomly selected. Students were informed about what would take place and asked for their permission to be recorded. They were also informed that their names would never be mentioned and nothing they said could ever be traced back to them. It was important to gain the trust of the students to allow them to speak honestly and openly about their experience. Furthermore, students were given the choice to opt out of participating; no student opted out. The focus groups took place in a separate classroom that was prepared in advance. It was recorded using two devices and lasted around 10 to 15 minutes depending on the number of students.

The first school (School 1) was a college from the province of Utrecht, the students came from one group (class) and they performed the experiments at the Utrecht University. Furthermore, the students interviewed from this school performed both IBL and DI experiments. Two focus groups were held in School 1, six students participated in each of the two groups.

The second school (School 2) sampled was a college from the Noord Holland province, the students came from two groups (classes) and they performed the experiments at the school location. An important difference is that the students from the second school performed experiments of only one variant; i.e. the students that performed an IBL experiment did not perform a DI experiment and vice versa. Three focus groups were held at School 2, with ten students participating. One group that practiced the closed variant and two groups that practiced the open variant. In total twenty-two students were sampled from both schools.

Table 3

Focus Group Information

Group	School	Variant	Number of studens
1	1	Open and Closed	6
2	1	Open and Closed	6
3	2	Open	3
4	2	Closed	3
5	2	Open	4

Qualitative Data Analysis

The data from the interviews was first transcribed into a Word file and all following analysis was conducted there. After the transcription of the first two focus groups a preliminary exploratory analysis was conducted (Creswell, 2014). The two files were read several times and a first coding key was developed. The focus group interview scheme and the coding key here developed around the concepts of *competence* and *autonomy.* The full coding key can be found in Appendix C2. A summary of the coding key can be found in Table 4.

Table 4

Coding Scheme Summary

Variant	Construct	Relationship	Code
IBL	Autonomy	Positive	Int. Op. A +
		Negative	Int. Op. A -
	Competence	Positive	Int. Op. C +
		Negative	Int. Op. C -
DI	Autonomy	Positive	Int. Cl. A +
		Negative	Int. Cl. A -
	Competence	Positive	Int. Cl. C +
		Negative	Int. Cl. C -

The first coding key also contained codes on other constructs which were eliminated in the process. The codes correspond to the students reporting a positive or negative feeling of autonomy or competence with respect to one of the two variants. For example:

> *Student F: Well, I think the closed ones I liked more better because it was easier*

The above comment from Student F was coded as *Int.Cl.C+* meaning that that students is reporting a positive feeling of competence or feeling that the closed version is "easier" than the open. On the contrary:

> *Student E: [unintelligible] he was my partner [point to Student D] so we had the hard experiment so, I agree with him that it would have been too hard to make the open version of that experiment.*

The above comment by Student E was coded as Int. Op. C– significant of a negative feeling of competence with respect to the open variant. A final example comes from students F again:

> *Student F: <u>Well, the closed one you can just do what they say, fill it in, next question</u> while with the open one you have to think about what you are doing because you have, you have to do it right and you have to come up with a way to measure what you want to measure on your own. You have to think more about what you are doing.*

The underlined part of the text is an example of a student reporting a negative feeling of autonomy related to the closed variant which means a code Int. Cl. A– while the rest of the student's comment reports a positive feeling of autonomy for the open variant and was coded as Int. Op. A+.

Five focus group sessions were conducted, transcribed and coded, yielding 86 coded segments of dialogue. A second rater also coded the data and Cohen's Kappa was calculated to assess the inter-rater reliability. The 86 segments were coded by both coders, resulting in 72 agreements (84% agreement) and Cohen's Kappa .8. According to Cohen (1960) this means substantial agreement (.61 to .81 are the margins proposed by Cohen for substantial agreement).

Results

Quantitative

The data included in the analysis came from nine different schools and the data collections took place between September and December of 2018. There were 168 students that performed the IBL variant and 208 the DI variant giving us a sample of N = 376. In Table 5 you can see the averages and standard deviations of all three scales, pre- and posttest for both variants; in the same table we report the gains for each scale from pre- to posttest. . Gains were calculated by:

$$G = M_{Posttest}^{Scale} - M_{Pre-test}^{Scale}$$

$M_{Posttest}^{Scale}$ and $M_{Pre-test}^{Scale}$ are the average value for the pre- and posttest of each of the three scales analyzed here: Interest/Enjoyment, Perceived Competence and Value/Usefulness. Significant gains on all the three scales for a variant would mean an increased intrinsic motivation for that variant. The gains (G) are presented to determine which variant increased intrinsic motivation more after the experiment.

Table 5

Averages of all scales pre- and posttest for both variants

	DI			IBL		
Averages (SD)	Interest / enjoyment	Perceived competence	Value / usefulness	Interest / enjoyment	Perceived competence	Value / usefulness
Pretest	3.5144	3.0208	3.7133	3.6171	2.9851	3.7857
	(.77384)	(.63393)	(.53892)	(.81375)	(.59104)	(.58915)
Posttest	3.5633	3.6398	3.4700	3.7619	3.6017	3.5407
	(.79527)	(.72983)	(.66263)	(.80781)	(.72030)	(.77156)
Gains (G)	0.0489	0.619	-0.2433	0.1448	0.6166	-0.245

In Table 6 we report the gains on all scales for both variants for more clarity. Moreover, we report the difference in the gains on all scales between the two variants. The difference between the gains was calculated by:

$$\Delta G|_{Scale} = G_{IBL}^{Scale} - G_{DI}^{Scale}$$

A positive ΔG for any of the three scales means there was a greater increase from pre- to posttest for the IBL variant. On the other hand, a negative ΔG means that the average for a scale increased more for the DI variant.

Table 6

Gains and differences between IBL and DI Variant

Gains	Interest / Enjoyment	Perceived Competence	Value / Usefulness
IBL	0.145	0.617	-0.245
DI	0.049	0.619	-0.243
Differences (ΔG)	0.096	-0.002	-0.002

From tables 5 and 6 we observe that there is a marginally greater increase for the IBL variant on the Interest / Enjoyment scale in comparison to the DI. The opposite is reported for the Perceived Competence scale where the closed variant presents an even more marginally larger gain. Finally, both variants show a decrease in the Value / Usefulness scale. Although marginal, it is interesting to note that there is a marginally greater increase in the Perceived Competence scale for the DI scale.

A One-way ANCOVA test was conducted to determine the significance of the differences between pre- and posttest on the three scales for IBL and DI variants, controlling for the pre-test. The results of the ANCOVA tests can be seen in Tables 4,5 and 6; p values are reported and the Partial Eta Squared η^2 as a measure of the effect size for each scale has been calculated using the formula:

$\eta^2 = \frac{SS_{treatment}}{SS_{treatment}+SS_{error}}$ (Richardson, 2011). To assess the effect sizes Cohen's rule is used according to which: $\eta^2 = .01$ signifies a small effect, $\eta^2 = .06$ a medium effect and $\eta^2 = .14$ a large effect (Cohen, 1988).

Table 7

Analysis of Covariance Summary for the Interest / Enjoyment Scale

Source	Sum of Squares	*df*	Mean square	*F*	*p*	Partial Eta Squared
Pre-test	58.829	1	58.829	121.191	<.001	0.245
Variant	2.005	1	2.005	4.131	.043	0.011
Error	181.064	373	0.485			

In the case of the Interest / Enjoyment scale the p value for Variant is .043 which makes it a significant result. Moreover the Partial Eta Square of 0.011 indicates a small effect according to Cohen. In other words, the variant had a small effect on the interest of the students, favoring the IBL variant.

For the two other scales, Perceived Competence and Value / Usefulness we report non-significant differences with p values .790 and .745 respectively. Furthermore, in both scales the variant had no effect on the observed differences between pre- and posttest. The results can be seen in tables 8 and 9 on the next page. It is worth noting, that there is a decrease from pre- to posttest on the Value/Usefulness scale for both variant. Although statistically not significant, it could have some implication for the ISP.

Table 8

Analysis of Covariance Summary for the Perceived Competence Scale

Source	Sum of Squares	*df*	Mean square	*F*	*p*	Partial Eta Squared
Pre-test	47.128	1	47.128	117.367	<.001	0.239
Variant	0.029	1	0.029	0.071	.790	0.000
Error	149.776	373	0.402			

Table 9

Analysis of Covariance Summary for the Value / Usefulness Scale

Source	Sum of Squares	*df*	Mean square	*F*	*p*	Partial Eta Squared
Pre-test	57,882	1	57,882	163,036	0,000	0,304
Variant	0,038	1	0,038	0,106	.745	0,000
Error	132,424	373	0,355			

Qualitative

The distribution of the codes for the constructs of autonomy and competence on the two levels (positive – negative) for the open and the closed variant can be seen on figure 7:

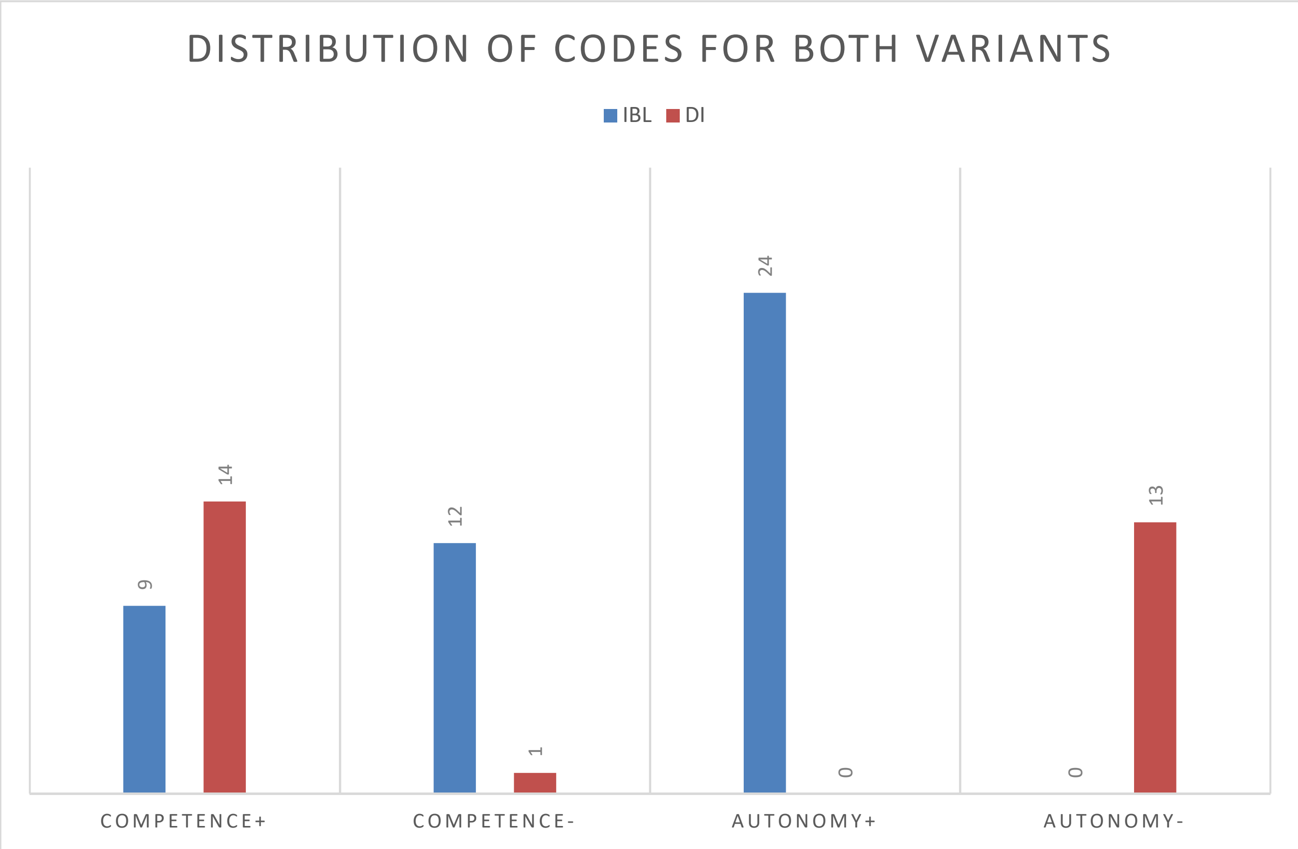

Figure 7: Distribution of codes

The results presented on figure 7 provide a better image of the students' perception on the two variants. Starting with the construct of competence, positive comments for the DI variant outnumber those for the IBL version. On the contrary, negative comments for the IBL version outnumber even more so those for the DI version. In other words, the DI variant made the students feel more competent while the IBL variant made them feel less competent.

Students reported the IBL variant as being harder than the DI on several occasions:

> *Student F1: Well, I think the closed ones I liked more better because it was easier [Students Laugh]…With the other one you had to think a lot more*

and you had to prepare a lot more and for me it was a lot of chaos. So, I liked the other one better, but I think you learn more from the open one.

In this quote student F1 touches on two aspects: the difficulty level of the DI variant. Moreover, Student F1 refers to the diminished competence they felt while practicing the IBL variant.

Two other students discussing their shared experience of the IBL variant reported:

Student F2: Doesn't..? It depends on how hard the assignment is, yeah, because we had open assignment was hard [Dutch]

Student B2: Yeah I, me and [unintelligible] we had an open assignment but it was one of the hardest so we stayed for like overtime because it all went wrong but there was a lot of extra questions with the investigations. So, that really took a lot of time but, it was mainly because the work we did before was unusable so it was so different, so much more that we had to do, all that plus the experiment and that was why it was so much time, why it took so much time.

Another example of two students discussing their difficulties with the IBL variant experiment:

Student A2: Well, I thought the open assignment was a little boring..

Student D2: Yes, because it was so difficult

Student A2: Well, it was difficult and we had already been working for two hours and we had to do another one and now we had to really think even more and the one I was working with also lost concentration and we didn't get it so we had to ask everything. We didn't knew how it worked, *so it wasn't boring, I don't know if I would describe it as boring but it was, it wasn't, yeah..*

On the contrary, regarding the construct of autonomy, the IBL variant has a complete monopoly on the positive comments while negative comments were exclusive for the DI variant.

Student B3: I liked the fact that there were little guidelines so you really had to do it yourself, and it felt like it was your research, so I liked that.

Student E3: Ehm, I think we chose it, I chose it because I thought it would be more fun to, see if I could like come up with an experiment myself instead of just following guidelines, because have done that more often, also with chemistry, just get guidelines and you just do what the papers says, so I thought it would be fun to see if I could come up with an experiment myself, to try and get to the point.

Student F1 also comments limited autonomy they experienced while practicing the DI variant:

Student F1:…you just filled in the answers and you just measured what you, you did what they said and you knew the answer and then you were done.

Even students that chose to perform the DI variant experiment could perceive the difference in the levels of autonomy offered by the two variants

Student D4: Well, I think, you know, every step was on the paper, so you didn't really have to think for yourself what to do, but that's what we chose for I think, because if you wanted to have the freedom you had to choose the open one, I think.

Students also spoke about the rote nature of the DI variant:

> *Student F1: It depends on the experiment because with my closed experiment it was like, here are the formulas, just fill in the formulas, next question. Here are more formulas, fill them in, so you didn't have to think at all, you just have to read carefully and you knew the answer.*

Moreover, the focus groups revealed a third pattern, relevant to the research. Students that had an intrinsic interest on physics preferred the IBL variant experiment.

> *Student F1: Yeah I think it's the same for me cause if you like physics then you choose the open one because you learn more about, but if you don't like physics I think you choose the closed one because that's ea*

Furthermore, student D2 expresses a similar view:

> *Student D2: It really depends on what subject it's about. I think if it's about physics, I would only choose the open one, because I like physics and it's also more difficult sometimes, it is really..*

In addition, student E2 generalizes into other subjects other than just physics:

> *Student E2: Well if I had to do a chemistry experiment, I would choose the closed version, but if it's biology experiment I would choose the open.*

The results from the analysis of the transcripts can be narrowed down to three points; students felt more autonomous but less competent while performing the IBL variant. On the other hand, students felt more competent and less autonomous when performing the DI variant. The IBL variant appears to support the need for autonomy nevertheless, it does not support the need for competence. On other hand, the DI variant while supporting the need for competence, it does not support the need for autonomy. Finally, students that had an intrinsic interest toward physics reported that they would prefer IBL variant experiments in the future. These three points will be further analyzed in the discussion section.

Conclusions

The aim of this study was to investigate the effects of an IBL experiment on ionizing radiation, on the intrinsic motivation of students, in comparison to the DI approach. The main research question was: "To what degree does an Inquiry Based Learning experiment about ionizing radiation result in higher intrinsic motivation when compared with a traditional Direct Instruction experiment?". Our hypothesis was that the IBL variant has a positive effect on the intrinsic motivation of students compared to the DI variant.

A One-way ANCOVA test was conducted to investigate if there is a statistically significant difference between the IBL and DI variant on the three scales, controlling for the pre-test. There is a significant effect of the experimental variant (IBL) on the Interest/Enjoyment scale after controlling for the pre-test $F(1, 373) = 4.131$, $p = .043$. The effect size however, calculated by the Partial Eta Squared $\eta^2 = .011$ indicates a small effect. There was no significant result observed for the Perceived Competence scale $F(1, 373) = 0.071$, $p = .740$, nor for the Value Usefulness scale $F(1, 373) = 0.10$, $p = .745$. To summarize, only one of the three scales with which we measured intrinsic motivation yielded a significant result, with a small effect size. Consequently, we can conclude that there was a small significant increase of the students' intrinsic motivation due to the IBL variant, compared to the DI variant, as it was measured by the IMI.

The results of the ANCOVA test lead us to reject our hypothesis; there is only but a small effect of the IBL variant on the intrinsic motivation of the students when compared to the DI variant. The answer to the main research question is that an IBL experiment about ionizing radiation resulted in higher intrinsic motivation only to a small degree, compared to the DI variant.

The first sub-question is: “To what extent do DI and IBL settings affect the self-reported intrinsic motivation of students?” To answer this question, we look to both the quantitative and qualitative data collected. The answer to this question is that their self-reported intrinsic motivation was only altered to a small extent.

The students reported enjoying the autonomy provided by the IBL experiments, finding it refreshing not following step-by-step instructions. However, several students referred to the IBL experiments as difficult, expressing the need for more support than provided.

On the other hand, regarding the DI variant experiments, students mentioned them as more straightforward to perform compared to the IBL variant. However, the students also reported that the repetitive and procedural (step-by-step) nature of the DI experiments left them disenchanted.

In order to adequately answer this sub question we turn to the answer the students gave to the following question during the interviews: “If you had to do another experiment, on any science topic, physics, biology, chemistry would you perform an IBL or a DI experiment?”. The students were presented with the hypothetical case in which they would have to spend one hour in the laboratory regardless of variant and there would be no grade whatsoever for their effort. All but a few students responded that in this case they would prefer an IBL experimental set-up. More importantly, most of those students also mentioned that they were already intrinsically motivation toward physics. Fewer students replied that they would perform the DI variant; many of these students also reported that they would be open to an IBL experiment for a subject they were interested in.

Therefore, we can conclude that the IBL variant had a positive effect on the students’ self-reported feeling of autonomy, but that this was countered by the lack of proper scaffolding in the practical (insufficient support of the psychological need of competence). This insufficient support limited the effect of the IBL experiment on the intrinsic motivation of students.

The second sub research question is “To what extent are the basic psychological needs for competence and autonomy, supported in IBL experiments as compared to DI experiments?”. The answer to this question is also based on the analysis of the transcripts from the focus group sessions. The discussions with the students revealed two patterns concerning the IBL experiments and the two basic psychological needs. The IBL variant completely supports the students’ need for autonomy. However, the IBL variant does not adequately support the need for competence. Although the students reported they felt more autonomous when practicing the IBL variant experiments compared to the closed variant, they also reported feeling less competent.

On the other hand, the DI variant supports the psychological need for competence. Nevertheless, it does not support the students’ need of autonomy. The students reported feeling more competent performing the DI variant compared to the IBL. However, the students also reported feeling significantly less autonomous performing the DI variant. Consequently, the answer to the second sub-question is that the IBL variant supports the need for autonomy but does not support the need for competence and the DI supports the need for competence but not the need for autonomy. Neither of the two variants properly support both the basic psychological needs. As we will discuss in the next section this has implication for the ISP and IBL experiments in general.

The students’ intrinsic motivation was measured by three scales, Interest/Enjoyment, Perceived Competence and Value. Although the open variant has a significant but small effect on the Interest/Enjoyment scale there is no statistically significant effect on the other two scales. Consequently, the open variant did not increase the students’ intrinsic motivation as measured by the IMI in an appreciable manner.

These results are further supported by the analysis of the focus groups held with the students. Students reported that although they did experience more freedom and autonomy while practicing the open variant, they also perceived themselves as less competent compared to the closed variant. Moreover, they appreciated the change from performing step-by-step experiments during which they must only "*fill in answers*" to the IBL experiments during which you "*have to think for yourself*". The students additionally reported that they welcomed the challenge of the IBL variant experiments. However, the students also referred to the IBL experiments as reducing their feeling of competence, which is crucial because it decreased their intrinsic motivation. The insufficient support offered by the IBL experiment is crucial because it hindered the feeling of competence, which in turn countered the feeling of the autonomy the students felt. The result was a diminished increase of student's intrinsic motivation after performing the IBL variant.

The assumption under which this research was conducted was that the autonomy offered by the IBL variant experiments would lead to an increased intrinsic motivation, provided that the need for competence was adequately supported as well. This was proposed as a possible mechanism to enhance intrinsic motivation. For this mechanism to work as intended both the psychological needs for autonomy and competence had to be supported.

Consequently, the IBL variant experiments of the ISP have the potential to foster the students' intrinsic motivation by supporting their need for autonomy. However, the IBL experiments do not provide adequate guidance to support their need for competence. Autonomy by itself is not enough to foster intrinsic motivation; it is important to sufficiently support the students to further foster their perception of their own competence.

Discussion

Limitations

The results and scope of this research are subject to methodological limiting factors. Initially it must be mentioned that the very subject of the ISP, which is ionizing radiation does not lend itself to generalization. Students reported that the subject is exciting, adding a "danger" element which contributed to an exciting initial condition. Consequently, it would be hard to generalize the results of this research to other, more “mundane” subjects such as classical mechanics.

A second limitation of this research stems from the quasi-experimental approach that was followed. Due to the operation of the ISP, randomly assigning students to the control and the experimental group was not possible. Additionally, there was a limit to the control we had over the way the students performed the experiments. Schools choose to perform the ISP experiments and pay a fee, consequently the schools choose the location, the variant the students perform and whether the students prepare in advance for the experiments or not. The quasi-experimental approach limits the generalizability of this research. However, it must be underlined that we did control for the differences between the schools and the methods by using the pre-test as the covariate.

A third limiting factor comes from the time duration of the intervention. The time that elapsed between pre- and posttest application of the IMI questionnaire was around one hour, the time needed to perform one experiment. The time of one hour could be potentially considered insufficient for the intervention to take full effect on the students. Moreover, the intervention included only a single (DI or IBL) experiment, which could additionally limit the effect.

Finally, we must mention limiting factors regarding the qualitative part of this research. As mentioned in a previous section, focus groups were conducted at two schools. Students from School 1 performed both IBL and DI experiments. On the other hand, students from School 2 performed either an IBL or a DI experiment. This difference between the participants in the focus groups somewhat limits the scope of the results, because not all participants shared the exact shame experience at the ISP. Moreover, only students from one of the two schools could speak from experience about the experiments of both variants.

Implications

Several implications concerning the ISP stem from this research, more importantly the IBL variant of the experiments. Previous research had indicated that students learn equally well performing the IBL or DI variant experiments of the ISP (Verburg, 2018). However, this research highlights that if students are not adequately supported in their inquiry there could be an adverse effect on their motivation.

For the ISP, it is advisable to take specific steps towards supporting students performing IBL experiments better. That means improving the worksheets of the IBL experiments, so that they support the students more. The IBL worksheets already guide the students through the process, however there is room for additional scaffolding. Additionally, the ISP could advise schools that wish to perform the IBL variant to prepare students in advance of the actual experimental session. Student preparation could include students compiling their plan of action and discussing it with their teachers. Moreover, additional material could be provided to the schools, such as practical information on the instruments that the students will use during the session, including photos of the instruments. Students noted that their lack of knowledge on the instruments influenced their perception of the experiments themselves.

In addition, schools that prefer to practice both variants should be advised to perform first the IBL variant followed by the DI variant. Students that performed the variants the other way around reported that while going through the DI experiment worksheet they inevitably made comparisons with their own plan of actions for the open variant experiment. When their plan was found to be lacking, students lost confidence on their own plan, which in turn diminished their own perception of their competence thus decreasing their intrinsic motivation.

An important implication regarding the ISP stems from the decrease on the Value/Usefulness scale from pre- to posttest on both variant. Although statistically not significant, this decrease indicates that students did not appreciate the importance of experiments on ionizing radiation. Changes could be made to the ISP booklet and worksheets (IBL and DI) to highlight the connection between the experiments and real life. It is important for the students that practice either the IBL or the DI variant to understand the importance of knowledge on ionizing radiation. That could contribute to the students leaving the laboratory room aware of the value of the experiments they performed.

Finally, a connection appears to exist between the IBL variant experiment and intrinsic motivation, which was noted by students during the focus groups. Students that were already intrinsically motivated toward physics, favored the challenge offered by the IBL experiments. However, we have not established causality. Students appreciate challenges on subjects they are interested in. This could inform teachers on deciding which experiments to propose to their students depending on the subject.

Future Research

The results of this study with the limitations that accompany them offer possible paths for future research at the Freudenthal institute and beyond. In this study, a mechanism to increase intrinsic motivation was proposed and tested on an ionizing radiation experiment. The topic, which is somewhat exotic limits the generalizability of the results presented here. Consequently, it would be intriguing to test the same mechanism on a more “mundane” topic of physics, like mechanics for example. Furthermore, expanding beyond physics could serve as a long-term objective.

In addition, future research could replicate this study with a smaller sample size taking a pure experimental approach. That would mean having almost total control over the experiment, assigning students to a control and experimental group and prescribing exactly how experiments are performed. That however, would require changes to the operation of the ISP and in addition schools willing to participate under these conditions. A longitudinal approach could also be an interesting path to explore; studying a group of students over a longer period and after a more than just one experiment.

The ISP is fertile ground for research, because it has access to large numbers of students annually from across the Netherlands. Future research should focus on improving the IBL variant worksheets of the ISP based on the results reported here. The focus should be put on support and scaffolding through the material provided to them. Design Research cycles could offer a possible path to revise the IBL experimental material, test it with students, improve them and repeat.

Finally, it would be interesting to investigate the perception, opinion and motivation of teachers toward IBL experiments. Teachers make the choice between the two variants in the ISP and more importantly their motivation toward IBL experiments could potentially influence their students' motivation. Therefore, it would be interesting to speak to teachers at length about Inquiry-based Learning experiments in the contemporary physics classroom.

This study built on the findings of previous studies by Nooijen and Verburg. We tested the hypothesis that, the increased autonomy provided by an IBL experiment would increase the intrinsic motivation of students, compared to the DI equivalent. The results however indicated otherwise, which lead us to the important conclusion that supporting the need for autonomy in not enough in and of itself. The students' inherent need for competence plays a pivotal part in supporting their intrinsic motivation. Students must be enabled to explore, investigate and learn on their own volition, but it is crucial that they are supported and assisted in this process.

Appendix A

Table presenting the spectrum of practicing inquiry from student- to teacher-initiated.

Reprinted from Capps & Crawford (2013)

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

Appendix B

Pre- and posttest questionnaire in Dutch as they were administered to the participant students

Pre-test:

Klas: 4 havo / 5 havo / 4 vwo / 5 vwo / 6 vwo	Name:
Ik heb de volgende experimenten gedaan:	

Geef voor de volgende stellingen zo goed mogelijk aan in hoeverre deze waar zijn. Geef slechts één antwoord door het te omcirkelen, foute antwoorden kunnen worden doorgestreept.

Stelling	Helemaal niet mee eens	Een beetje oneens	Neutraal	Een beetje eens	Helemaal mee eens
Ik denk veel moeite te gaan hebben met het ISP-practicum.	1	2	3	4	5
Het ISP-practicum lijkt me leuk om te doen.	1	2	3	4	5
Ik zal mij tijdens het ISP-practicum niet veel inspannen.	1	2	3	4	5
Ik zou het ISP-practicum als interessant willen omschrijven.	1	2	3	4	5
Ik denk dat ik tijdens het ISP-practicum mijn aandacht er niet altijd bij kan houden.	1	2	3	4	5
Ik denk dat het ISP-practicum een belangrijke bijdrage zal leveren aan mijn begrip van radioactiviteit.	1	2	3	4	5
Het ISP-practicum lijkt mij saai.	1	2	3	4	5
Het ISP-practicum lijkt mij nuttig.	1	2	3	4	5
Ik denk dat ik in vergelijking met andere leerlingen het ISP-practicum goed zal doen.	1	2	3	4	5
Ik vind het belangrijk om het ISP-practicum goed te doen.	1	2	3	4	5
Ik denk dat ik erg goed zal zijn in het doen van het ISP-practicum.	1	2	3	4	5
Ik voel mij vaardig genoeg om het ISP-practicum te doen.	1	2	3	4	5
Ik zal niet veel energie in het ISP-practicum stoppen.	1	2	3	4	5
Ik denk dat het ISP-practicum nuttig is voor het onderwerp radioactiviteit.	1	2	3	4	5
Tijdens het ISP-practicum zal ik proberen erg mijn best te doen.	1	2	3	4	5

Post-test:

Klas: 4 havo / 5 havo / 4 vwo / 5 vwo / 6 vwo	Name:
Ik heb de volgende experimenten gedaan:	

Geef voor de volgende stellingen zo goed mogelijk aan in hoeverre deze waar zijn. Geef slechts één antwoord door het te omcirkelen, foute antwoorden kunnen worden doorgestreept.

Stelling	Helemaal niet mee eens	Een beetje oneens	Neutraal	Een beetje eens	Helemaal mee eens
Tijdens het ISP-practicum heb ik geprobeerd mijn best te doen.	1	2	3	4	5
Het ISP-practicum was leuk om te doen.	1	2	3	4	5
Ik heb mij tijdens het ISP-practicum niet veel ingespannen.	1	2	3	4	5
Tijdens het ISP-practicum kon ik de aandacht er niet bijhouden.	1	2	3	4	5
Ik vind dat het ISP-practicum nuttig is voor het onderwerp radioactiviteit.	1	2	3	4	5
Ik voel mij vaardig genoeg om het ISP-practicum te doen.	1	2	3	4	5
Ik denk dat ik erg goed ben in het doen van het ISP-practicum.	1	2	3	4	5
Ik heb niet veel energie in het ISP-practicum gestopt.	1	2	3	4	5
Ik vind dat het ISP-practicum mij helpt om radioactiviteit te begrijpen.	1	2	3	4	5
Kijkend naar andere leerlingen vind ik dat ik het ISP-practicum erg goed gedaan heb.	1	2	3	4	5
Ik vind het ISP-practicum nuttig.	1	2	3	4	5
Ik vind dat het ISP-practicum een belangrijke bijdrage heeft geleverd aan mijn begrip van radioactiviteit.	1	2	3	4	5
Ik had veel moeite om het ISP-practicum te doen.	1	2	3	4	5
Ik vond het belangrijk om het ISP-practicum goed te doen.	1	2	3	4	5
Ik vond het ISP-practicum saai.	1	2	3	4	5
Ik zou het ISP-practicum als interessant willen omschrijven.	1	2	3	4	5

Appendix C1

Interview protocol designed for this research and used during the focus group sessions with the students

Focus Group Protocol

Date:

School:

Group Number:

Number of Students:

Student Class:

ISP Variant:

Interviewer:

Questions:

1. What did you like the most about the experiments you performed?

2. Why did you choose the closed / open experiment and why?

Or[2]

3. During the session you performed experiments in two different approaches (or ways). What do you remember about the two approaches?

4. Which one did you enjoy more and why?

5. How would you describe the level of difficulty of the experiment(s) you performed?
   i. **Follow up:** How do you think the level of difficulty of the experiments affected your experience? I would like to make clear that the "difficulty scale" starts from "too easy" and goes up to "too difficult". **Or:** Ok, so you found the experiments *so and so* difficult. How would you say did that affect your enjoyment of the experiments?

[2]Questions 3 and 4 were used at the school that practiced both IBL and DI variant experiments. Question 2 was used at the school were students performed experiments of only one variant.

ii. **Follow up:** Did you feel supported by the worksheets/ How much did the worksheets help you during the experiments?

6. Imagine you had to do another experiment in one hour, not necessarily a physics experiments, it could be chemistry or biology for example, that would last one hour, and you would not be graded for your effort. Would choose to do another closed – open (depending on the group) experiment or would you try the other "kind" of experiment? Why is that?

7. What would you improve about the experiments? Specifically, about the organization, worksheets, planning, equipment grading, etc.

Appendix C2

Coding key developed for this research project to analyze the focus groups

Coding Key: Competence & Autonomy Scales

Category	Construct	Relationship	Code	Description
Open	Competence	Positive	Int. Op. C +	Comments pointing to a positive feeling of competence by the students regarding part of the open variant experiments. Involves students finding one or the other variant easy. e.g. *it was easy*. Or *it was pretty straightforward*.
		Negative	Int. Op. C -	Comments pointing to a negative feeling of competence i.e. students not feeling competent enough to perform part of an open variant experiments. Involves students reporting the open variant as difficult. e.g. *It would be too had to do the open version*.
	Autonomy	Positive	Int. Op. A +	Students reporting a positive feeling of autonomy during the experiments. Moreover, any comment describing the student performing self-directed actions, ex. *you have to think by yourself*.
		Negative	Int. Op. A -	Students referring to action that were prescribed to them by the experiment worksheet or other material. Moreover, students referring to them

				following instruction from the worksheets.
Closed	Competence	Positive	Int. Cl. C +	Comments pointing to a positive feeling of competence by the students regarding part of the closed variant experiments, e.g. *it was easy*.
		Negative	Int. Cl. C -	Comments pointing to a negative feeling of competence i.e. students not feeling competent enough to perform part of an open variant experiments, e.g. *It would be too had to do the open versio*n. **Furthermore**, this code includes comments about the closed variant being *too easy* and thus becoming less interesting. Statements of that nature also take the same code.
	Autonomy	Positive	Int. Cl. A +	Students reporting a positive feeling of autonomy during the experiments. Moreover, any comment describing the student performing self-directed actions, ex. *you have to think by yourself*.
		Negative	Int. Cl. A -	Students referring to action that were prescribed to them by the experiment worksheet or other material. Moreover, students referring to them following instruction from the worksheets

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