Supporting Intrinsic Motivation through IBL: Scaffolding a Physics Experiment

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Abstract

This study investigates the dynamics between scaffolding of inquiry based learning (IBL) and intrinsic motivation for the task at hand. Within the context of an IBL version of a 11th/12th grade physics practical (Ionising Radiation Practical), a literature survey and analysis of earlier research results was followed by two cycles of design-based research. Based on scaffolding categories from literature, earlier qualitative research was revisited, demonstrating that during the IBL work students were reporting difficulties in terms of two main areas: process knowledge, i.e., how to approach the practical and nonsalient tasks, e.g., how to use the equipment involved.. Based on these results, two design cycle iterations were performed, with a total of 17 students participating in focus group interviews after each iteration. After trying out the final redesign, students reported an increase in perceived competence support, while still retaining a sense of autonomy. Moreover, student remarks suggest that the scope of support for intrinsic motivation went beyond the scaffolding itself. The results suggest that appropriate scaffolding can increase students' competency, while retaining their autonomy, thus supporting more autonomous types of motivation in the Self-Determination Theory. Implications for education and suggestions for further quantitative research are proposed.

Keywords: Intrinsic motivation, Self-determination Theory, Inquiry-based Learning, scaffolding, radiation physics education, Ionizing Radiation Practical

Introduction

In the science subjects, studies have shown that motivation and attitude have been in decline in recent years. In their systematic review, Potvin and Hasni (2014) found a decline in interest, motivation and attitude towards science with every school-year and age. This decline is especially pronounced when students transition from elementary to secondary education. Large-scale international studies support these findings, reporting low levels of interest for science among secondary school students, especially in Western European countries (Organisation for Economic Co-operation and Development [OECD], 2007; Sjøberg & Schreiner 2005; Van Griethuijsen *et al.*, 2015). The literature review by Osborne *et al*. (2003) already highlighted the decline in attitude towards science in earlier decades, which seems to have continued in more recent years: the OECD (2016) found that, specifically in The Netherlands, 15-year-old's students motivation for science has declined significantly over the last twelve years, which has led to it becoming one of the lowest in Europe. This decline in motivation for the sciences is a sign of a nascent crisis in scientific education, especially in The Netherlands.

Of particular interest in the context of the aforementioned crisis is *intrinsic* motivation, the driving force that shapes what students (and humans in general) want and will pursue to learn (Deci & Ryan, 2010). It comes from within the learner themselves, translating into interest, enjoyment, active participation and self-regulation both within as without the classroom setting (Ryan & Deci, 2000a). Indeed, one might expect an intrinsically motivated student to pursue a career that is in line with their intrinsic interests, such as an interest for sciences (Jacobs, Finken, Griffin, & Wright, 1998; Lavigne, Vallerand, & Miquelon, 2007). Additionally, educational research has theorized and found empirical evidence of the beneficial effects the facilitation of intrinsic motivation can have on both learner well-being and academic results (Deci & Ryan, 2010; Niemiec & Ryan, 2009; Ryan & Deci, 2000a; Ryan & Deci, 2017; Taylor *et al.*, 2014).

The development of intrinsic motivation in learners does not always occur in common teaching practice, unfortunately. Teachers often implement *extrinsic* motivators, in the form of grades, threats of punishment or extra points on tests. Research on high school drop-outs (Hardre & Reeve, 2003; Vallerand, Fortier, & Guay, 1997) shows that when students are more extrinsically motivated (by e.g. their teachers) they are more likely to stop, rather than persist in education. Furthermore, Ryan and Deci (2017) have explained how this extrinsic motivation leads to a decrease in intrinsic motivation, and consequentially hampers students to academically perform as well as they could and diminishes their well-being. This further highlights the need for new methods of supporting intrinsic motivation in teaching.

One pedagogical approach that in theory could support intrinsic motivation during science experiments is inquiry-based learning (IBL). The core aspect of IBL is the requirement of students to let their own inquisitiveness answer their own questions. Rather than being explained curriculum content, as is common in traditional direct instruction, students collect their own evidence and draw conclusions from their findings to understand the content (Capps & Crawford, 2013). In their review of various didactical approaches to self-regulation in science education, Schraw, Crippen and Hartley (2006) state “inquiry may increase motivation because the student takes greater ownership and shares authority" (p. 119), i.e. indicating that an IBL setting could support students’ sense of autonomy. Thus far, research on the effectiveness of IBL has primarily focussed on whether or not conceptual understanding or academic success improves (e.g. Edelson, Gordin & Pea, 1999; Gormally, Brickman, Hallar & Armstrong, 2009; Furtak, Seidel, Iverson & Briggs, 2012). The field of research that directly investigates the effects of IBL on motivation is considerably less extensive, with only few studies reporting on a possible empirical link (e.g. Crow, 2011; Gallaghar, Stepien & Rosenthal, 1992).

A clear theoretical link between IBL and intrinsic motivation can, however, be constructed by relating IBL to the self-determination theory (SDT) (Ryan and Deci, 2000a) and the three basis psychological needs of competency, autonomy and relatedness. These three needs of learners should be catered for, in order to foster intrinsic motivation within them. IBL could support the needs of competence and autonomy by giving learners (a degree of) control on how they want to understand the content they are tackling, which facilitates learners choosing approaches that lie within their field of proximal development (Chaiklin, 2003; Vygotsky, 1980). Autonomy in IBL is facilitated by learners finding answers to their own line of inquiry themselves, granting them ownership of these answers. Relatedness in IBL is facilitated by learning within a social context, e.g. learning science together with other learners. Thus, in theory, IBL provides a didactical approach that allows for intrinsic motivation, following the SDT principles (Van Asseldonk, 2019).

Science experiments, especially those employing IBL, can thus be considered interesting contexts for researching the empirical link between IBL and SDT. Hofstein and Lunetta (2004) have highlighted how science experiments could naturally lend themselves for student’s inquiry through their engagement with authentic scientific materials and phenomena. And regarding the effect experiments could have on student motivation; already two decades ago, Bergin (1999) postulated the potential experiments could have in heightening students' intrinsic motivation for the subject. The field of studying science experiments and their impact on motivation has not been investigated extensively, however, with only several studies showing a conflicting results. One study, for example, reports that the implementation of authentic scientific experiences could arrest the aforementioned decline in motivation for sciences by having science experiments contribute to scientific studies (Hellgren & Lindberg, 2017). In a small-scale, quasi-experimental study on differences in students' intrinsic motivation between an IBL and a traditional version of a physics experiment (Nooijen (2017), signs of a small but significant effect on students' intrinsic motivation for the task were found, students favouring the IBL version as compared to a control group using a direct-instruction approach. Follow-up research on the very same experiments, also the context of the present study, failed to reproduce these results however (Nikandros, 2020; Van Asseldonk, 2019). These findings are further supported by qualitative research reporting that although students experienced autonomy support in the IBL version, students felt thwarted in their competency when performing the IBL experiment[1] (Blekman, 2020).

The precise reasons and mechanisms underlying this lack of perceived competence in the design of the IBL version remain obscure. This knowledge gap gives rise to the question as to which aspects of the IBL version cause students' perceived loss of competency? And following this line of inquiry, one wonders how an IBL experiment can be designed in such a way that students actually perceive to be competent? At the same time students' sense of autonomy and relatedness should be retained in this design, in order to facilitate all three basic psychological needs. Previous research suggests that the core of designing any IBL activity lies within the *scaffolding* students are provided with, that guide their inquiry (Hmelo-Silver, Duncan, & Chinn, 2007; Quintana *et al.*, 2004). Although literature on the link between scaffolding scientific experiments and motivation is scarce, the positive influence correct scaffolding can have on students' autonomy and competence support has been found in several studies (e.g. Guthrie, Wigfield, & Perencevich, 2004; Meyer & Turner, 2002).

The current study extends the work of Blekman (2020), Nikandros (2020), Nooijen (2017) and Van Asseldonk (2019). The effects of implementing scaffolding design changes in IBL-based tasks on the perceived competence of students are investigated, while aiming to keep

[1] Relatedness remained unchanged between IBL and DI version of radiation experiment across the studies of Nooijen (2017), Van Asseldonk (2019), Blekman (2020) and Nikandros (2020): students worked in pairs for both versions.

the students' sense of ownership of learning. Hence, the following research question was asked:

> How can an IBL-based secondary school radiation physics experiment be constructed in such a way that students' psychological need for competence is catered for, while also retaining their perception of autonomy?

This research-question was divided and narrowed down to two sub-questions:

1. What are the causes of perceived lack of competence support in the radiation physics experiment?

2. How can scaffolding be implemented in the radiation physics experiment to increase students' perceived competence?

If scaffolding aspects were to be found in which both autonomy and competency can be achieved in an IBL experiment, these techniques could also be implemented in similar and other contexts, to facilitate students' intrinsic motivation for science. This in turn will hopefully help halt, diminish or even alleviate the decline in attitude and motivation for the sciences. Additionally, this study assists in bridging the gaps between scaffolding, IBL and SDT literature and extending on those fields.

Theoretical Background

Intrinsic motivation and Self-Determination Theory

Several decades ago, researchers already struggled in finding consensus for a clear definition of motivation and the theoretical frameworks surrounding it (Kleinginna & Kleinginna, 1981). Since then, a general trend on certain aspects of motivation has emerged, as highlighted by Huitt (2001), with motivation being "an internal state or condition that serves to activate or energize behaviour and give it direction" ("Definition", para. 1). Within learning and education, motivation research follows an academically popular theoretical framework wherein motivation is split into and defined by two main types: *intrinsic* and *extrinsic* motivation. Following Ryan and Deci's (2000b) definitions: intrinsic motivation refers to the learner undertaking something because of its inherent enjoyment or interest therein. This contrasts with extrinsic motivation, which stimulates the learner's undertaking through external factors or consequences. For example, a learner might start learning the anatomy of a plant because they enjoy knowing more about plants (intrinsic motivation, coming from within the learner themselves). If, however, the learner learns about the anatomy of the plant for a grade, is pressurized by their parents or for a higher social status -factors and/or consequences from without-, then it entails extrinsic motivation.

In their Self-Determination Theory, Ryan and Deci (2000a) further differentiate the two types of motivation to a range with various levels of motivation. Figure 1 illustrates this range, and further elaborates it by highlighting the regulatory styles, perceived loci of causality and relevant regulatory processes associated with each type of motivation. Of particular note is the contrast between the perceived locus of causality and extrinsic motivation for the regulatory styles *identified regulation* (i) and *integrated regulation* (ii). In both these cases, the individual experiences extrinsic motivation *as if* it is intrinsic motivation. Here, (i) the individual identifies the goal or behaviour as being valuable in itself or, even more internalized, (ii) they "are fully assimilated to the self, which means they have been evaluated and brought into congruence with one's other values and needs." (Ryan & Deci, 2000a, p. 73). An example of identified regulation within the context of this study would be a student completing a physics experiment in order to pass the exam and reach their goal of graduating and moving on to university, but not doing it out of inherent enjoyment or interest. The student does, however, identify the usefulness of and attributes importance to completing the physics experiment. Further internalizing this same regulation, i.e. moving towards integrated regulation, would mean the completion of physics experiments is fully integrated in

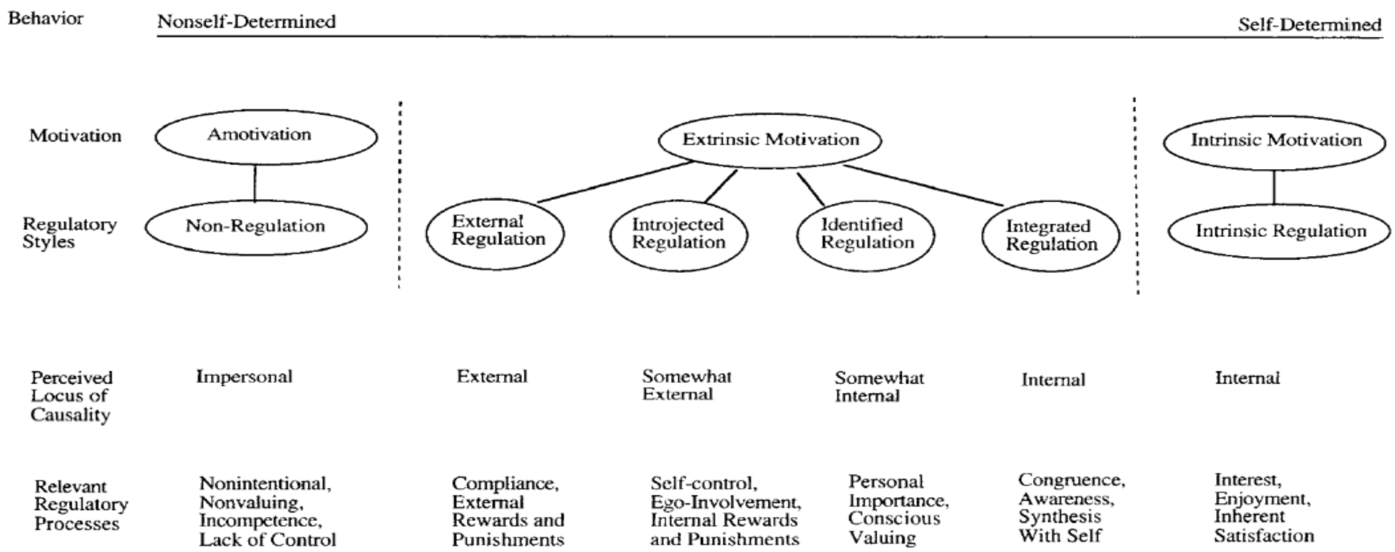

Figure 1. The Self-Determination continuum showing types of motivation with their regulatory styles, loci of causality, and corresponding processes. Reprinted from Ryan and Deci (2000a).

the life of the student and their belief system (e.g. completing physics experiments is in accordance with their belief that studying daily leads to mastery).

An intrinsic aspect of the theoretical framework is that self-determination theory proposes three basic psychological needs that, if catered for, will "yield enhanced self-motivation and mental health and when thwarted lead to diminished motivation and well-being" (Ryan & Deci, 2000a). These needs are:

1. Competence, i.e. "the experience of behaviour as effectively enacted." (Niemiec & Ryan, 2009, p. 135).

2. Autonomy, i.e. "the experience of behavior as volitional and reflectively self-endorsed." (Niemiec & Ryan, 2009, p.135)

3. Relatedness, i.e. "People tend to internalize and accept as their own the values and practices of those to whom the feel, or want to feel, connected, and from contexts in which they experience a sense of belonging." (Niemiec & Ryan, 2009, p. 139).

The theory that properly addressing competence, autonomy and relatedness (CAR) will help develop and support intrinsic motivation is backed up by a large body of empirical studies (see e.g. Niemiec & Ryan, 2009; Ryan & Deci, 2017; Vansteenkiste, Niemiec & Soenens, 2010), with the link between autonomy and competence, and intrinsic motivation being firmly supported .

In one study, Koestner *et al.* (1984) found that if a teacher set more controlling limits during learning, students became less intrinsically motivated, whereas setting more autonomy-supportive limits heightened their intrinsic motivation. As for influencing students' perceived competence, effectance-promoted feedback (i.e. positive feedback focused on students' performances) and the absence of demeaning evaluation heightens students' intrinsic motivation (Ryan & Deci, 2000a). It is important to note that competence and autonomy also interact with each other. Studies have shown (Fisher, 1978; Ryan, 1982) that intrinsic motivation will not be enhanced by perceived competence unless it is supported by a sense of autonomy.

As aforementioned, in designing the IBL scaffolding of the experiments, the aim was to heighten the competence of students, whilst retaining their sense of autonomy. Thus, the design was constructed from an SDT perspective. Furthermore, during this design phase, the balancing of competence and autonomy functioned as an overarching design principle.

Inquiry-based learning

Although extensively researched and implemented in teaching, the definition and scope of IBL vastly varies in literature. In their overview of various inductive didactical approaches, Prince and Felder (2007) define IBL as “Any instruction that begins with a challenge for which the required knowledge has not been previously provided” (Prince & Felder, 2007, p. 15). By doing so, Prince and Felder allow IBL to serve as an umbrella category for various other forms of inductive learning. Chinn and Malhotra (2002), however, differentiate between different types of inquiry, namely authentic scientific inquiry and simple scientific inquiry. Authentic scientific inquiry refers to all aspects of the studies working scientists have to undertake in their research. Examples of such aspects are: using advanced techniques for data analysis, forming theories and operating advanced machinery. In theory, simple scientific inquiry would incorporate core aspects of authentic scientific inquiry, through teaching or books, within the limitations of the school-context. Chinn and Malhotra (2002) conclude that, unfortunately, simple scientific inquiry generally in practice does not relate to or has little resemblance with authentic scientific inquiry.

The National Research Council (2000) has identified eight key aspects of inquiry, which Capps and Crawford (2013) assembled into a matrix (see Appendix A) that can be employed to gauge the extent to which a certain design can be considered “open” or “student-initiated” . This matrix guides the assessment as to what degree inquiry is student- or teacher-initiated. For this assessment, a four-point scale is implemented per aspect, with the scores 4 being the most student-initiated IBL and 1 corresponding with the most teacher-initiated inquiry. The score 0 can be given as well, which entails that the presence of any form of inquiry (be it teacher- or student-initiated) is absent (i.e. knowledge is shared purely through direct instruction). The key aspects of inquiry, according to Capps and Crawford (2013), are the following: a student 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 amount of evidence linking intrinsic motivation and IBL is, as aforementioned, scarce. Gormally *et al.* (2009) found that, although self-confidence in students' scientific abilities did increase through IBL, suggesting a positive effect on students' motivation, students could still be experiencing low competency levels. Van Asseldonk (2019) hypothesized a mechanism of interaction between the key aspects of IBL as explained by Capps and Crawford (2013) and Ryan and Deci's (2000a) SDT (see Figure 2). According to Van Asseldonk (2019), the three basic psychological needs of SDT (*autonomy*, *competence* and *relatedness*) should be catered for by these aspects of IBL and thus, as a consequence, lead to intrinsic motivation. As students are in control as to which questions they pose (aspect 1), how they set up their investigation (aspect 2) and their method of evidence collection (aspect 3), the students are *autonomous*. Furthermore, this autonomy gives the students the ability to regulate the difficulty of their IBL process and level it to their own zone of proximal development (Vygotsky, 1980; Chaiklin, 2003). In other words, students' ownership ensures their feelings of *competence* are retained. Finally, *relatedness* to their peers or teachers is facilitated by students communicating and justifying their explanations (aspect 6) and discussing them.

Van Asseldonk's (2019) study on this hypothesized mechanism, within the same context as the present study, found that, although the autonomy of students' was higher in the inquiry-based learning (IBL) version than the direct-instruction (DI) version of the experiments, there was not "sufficient support of students' competence in order to increase their intrinsic motivation." (p. 11). Van Asseldonk suggests providing students with feedback during intermediate steps of their inquiry might improve their feelings of being competence supported, as there were several reports of students putting forth the need to know if they are 'on the right track'. Additional research on this IBL version by Nikandros (2020) and Blekman (2020) also reports students being autonomy supported, but also thwarted in their competence. Blekman (2020) also reports students remarking that they wanted to know if they were 'doing it right' (Blekman, 2020, p. 23).

Scaffolding in Scientific Inquiry

Although literature that directly links scaffolding techniques with IBL is rare to find, there are studies that provide definitions, overviews of strategies and emphasize the importance of scaffolding for scientific inquiry. The most prominent study linking IBL and scaffolding was done by Quintana *et al.* (2004). In this study, Quintana *et al.* not only attempt to explore which tasks scaffolding can serve for inquiry (sense making, process management, and articulation and reflection), but also which challenges each of these tasks may face.

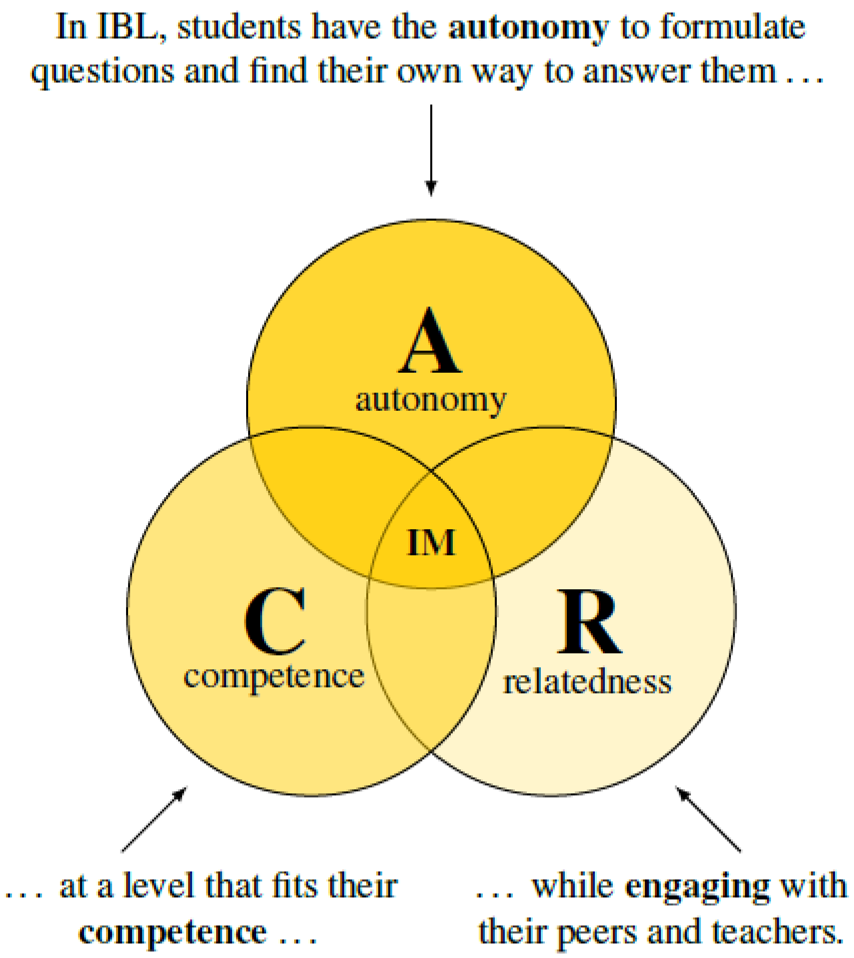

Figure 2. Hypothetical mechanism of interaction between aspects of inquiry-based learning (IBL) and intrinsic motivation (IM) in terms of the three basic psychological needs from self-determination theory (Ryan & Deci, 2000a). Reprinted from Van Asseldonk (2019).

Furthermore, Quintana *et al.* (2004) suggest a vast selection of guidelines and strategies one may implement to tackle these challenges. Altogether, this has led to the construction of a whole theoretical scaffolding design framework which has been summarized in Table 1. To briefly surmise the scaffolding tasks proposed by Quintana *et al.* (2004):

1. *Sense making* refers to operations that "must connect reasoning about a phenomenon to a process for testing a conjecture and from the empirical data generated in that testing back to the implications for the phenomenon" (Quintana *et al.*, 2004, p. 344)
2. *Process management* refers to "mechanisms that direct the knowledge and strategies needed to control and steer the investigation itself such as implementing an investigation control plan and keeping track of hypotheses and results". (Quintana *et al.*, 2004, p. 358)

Table 1

Summary of the inquiry scaffolding design framework. Reprinted from Quintana et al. (2004).

Scaffolding Guidelines	*Scaffolding Strategies*
Science inquiry component: Sense making	
Guideline 1: Use representations and language that bridge learners' understanding	1a: Provide visual conceptual organizers to give access to functionality
	1b: Use descriptions of complex concepts that build on learners' intuitive ideas
	1c: Embed expert guidance to help learners use and apply science content
Guideline 2: Organize tools and artifacts around the semantics of the discipline	2a: Make disciplinary strategies explicit in learners' interactions with the tool
	2b: Make disciplinary strategies explicit in the artifacts learners create
Guideline 3: Use representations that learners can inspect in different ways to reveal important properties of underlying data	3a: Provide representations that can be inspected to reveal underlying properties of data
	3b: Enable learners to inspect multiple views of the same object or data
	3c: Give learners "malleable representations" that allow them to directly manipulate representations
Science inquiry component: Process management	
Guideline 4: Provide structure for complex tasks and functionality	4a: Restrict a complex task by setting useful boundaries for learners
	4b: Describe complex tasks by using ordered and unordered task decompositions
	4c: Constrain the space of activities by using functional modes
Guideline 5: Embed expert guidance about scientific practices	5a: Embed expert guidance to clarify characteristics of scientific practices
	5b: Embed expert guidance to indicate the rationales for scientific practices
Guideline 6: Automatically handle nonsalient, routine tasks	6a: Automate nonsalient portions of tasks to reduce cognitive demands
	6b: Facilitate the organization of work products
	6c: Facilitate navigation among tools and activities
Science inquiry component: Articulation and reflection	
Guideline 7: Facilitate ongoing articulation and reflection during the investigation	7a: Provide reminders and guidance to facilitate productive planning
	7b: Provide reminders and guidance to facilitate productive monitoring
	7c: Provide reminders and guidance to facilitate articulation during sense-making
	7d: Highlight epistemic features of scientific practices and products

3. *Articulation and reflection* "involves constructing and articulating an argument; this in turn involves reviewing, reflecting on, and evaluating results; synthesizing explanations; and deciding where the weaknesses and strengths are in one's thinking" (Quintana *et al.*, 2004, p. 369)

After determining which or what kind of factors created the loss of perceived competence support in earlier research on the Ionising Radiation Practical (ISP; Van Asseldonk, 2019; Blekman, 2020; Nikandros, 2020), these factors were put in perspective to Quintana *et al.*'s

(2004) theoretical framework to find strategies that could help prevent the perceived competence support loss. Additionally, during the overall design of the scaffolding of the ISP, the interaction between competence and autonomy caused by the scaffolding was considered. To elaborate, if the scaffolding would increase competency too much, it could have caused a sense of loss in students' autonomy as they feel too restricted or too much cognitive challenge is taken away (Schunk & Zimmerman, 2012, p.118-119). Similarly, if students were given too much autonomy via more open or less scaffolding, they might have perceived a lack of competence (Schunk & Zimmerman, 2012, p.118-119). Thus, the aim was to strike an appropriate balance between autonomy and competence support within the scaffolding design.

Hypothesis

On the basis of the above considerations, it is hypothesized that an IBL-based secondary school radiation physics experiment can be constructed to cater to students' psychological need for competence (while also retaining their perception of autonomy) by implementing and improving scaffolding related to sense making, process management, and reflection and articulation.

Methodology

New coding of existing qualtitative data and a quasi-experimental design approach were employed to modify an existing IBL version of the ISP and investigate its effects on students' perceived competence and autonomy.

Context and Participants

The design and investigation of its effects on competence and autonomy was executed within the context of the Dutch Ionising Radiation Laboratory (ISP; "Ioniserende Stralen Practicum", 2019). From a large amount and variety of schools across the Netherlands, upper secondary school students (grade 10 to 12 of general secondary[1] and pre-university education[2]) perform these hands-on experiments related to ionising radiation. This context was chosen due to its national significance, as up to 20,000 students per year participate in the ISP. Furthermore, the ISP's emphasis on experimental research lends a suitable setting for inquiry-based learning. The ISP has been in existence for over 40 years. Schools that apply for the ISP can choose whether the experiments will be performed in class (UU-employees visiting the school with a mobile laboratory unit) or at the university itself within a laboratory setting.

[1] Dutch: havo 4 en 5
[2] Dutch: vwo 4, 5 en 6

Table 2
Characteristics of the participating schools and students.

Label	Student research experience	Size (# students)	Participants
School A	Had experience	2900	8 (11th&12th grade)
School B	Little to no experience	1100	9 (12th grade)

Furthermore, schools can decide whether their students conduct the IBL or the DI ISP experiments. Students usually work together in duos on the ISP experiments.

Which type of inquiry-based learning the IBL ISP experiments incorporate has been gauged by three members of the ISP staff and an independent researcher familiar with the practical, using Capps and Crawford's (2013) framework (see Appendix A). Their overall average score was 3 (Nooijen, 2017), i.e. the inquiry-based approach in the ISP can be categorized as 'guided inquiry-based learning'.

Two schools were selected for this study on the grounds of availability. A total of seventeen students (eight and nine per school resp.) were either selected randomly (first school) or on a teacher perception basis (second school). Half of the students of the first school (A) were in a general secondary education class (11^{th} grade), whereas the other half were from a pre-university education class (12^{th} grade). All students from the second school (B) came from two pre-university education classes (12^{th} grade). Most students worked in pairs, with the exception of one group of three students at school B.

The teacher's selection of the second school was based on his perception of students' diligence, with half of their selected student-pairs being 'hard-working' and the other pairs needing more guidance to get to work. Additionally, students from school A prepared part of their research before the ISP started (research question, hypothesis, methods and fillable tables/charts), whereas students from school B did not specifically prepare themselves. Students of school B were actually supposed to do several DI version experiments, but our participants were selected to conduct the IBL version of this study instead.

Students' experiences with setting up research on their own varied between different schools as well. The teacher and students of school A reported that they were used to setting up a research themselves, while the teacher and students of school B indicated that they had little or no experience. Furthermore, the teacher of school A had taught the open variant of the

ISP in earlier years, whereas the teacher of school B only had experience with the DI variant. Characteristics of the schools and students are summarised in Table 2.

Study Design

This study will consist of two major phases: *Recoding Earlier Research* and the *Design Cycles* (see Figure 3). As aforementioned, earlier research highlighted students' lack of perceived competence support during their completion of the IBL ISP experiments (Blekman, 2020; Nikandros, 2020, Van Asseldonk, 2019). Students' remarks gathered in these three studies shed light on students' scaffolding needs. All 174 statements of these previous studies were recoded top-down, along 20 categories: the five main scaffolding categories (based on Quintana *et al.*, 2004) with each category split into four possible sub-categories according to it being perceived as competence or autonomy, supporting or thwarting (see Appendix B for coding document).

Then, starting the first design cycle, scaffolding was designed for two IBL ISP experiments, following the most prominent scaffolding needs. These designs were then tested by two pairs of students per experiment, followed by a focus-group interview. Open questions on students' competence and autonomy, and on the scaffolding were asked to the students (Appendix C). Transcripts of these focus groups were coded for competency, autonomy and scaffolding, following a similar coding-scheme (Appendix D). Based on the results of these

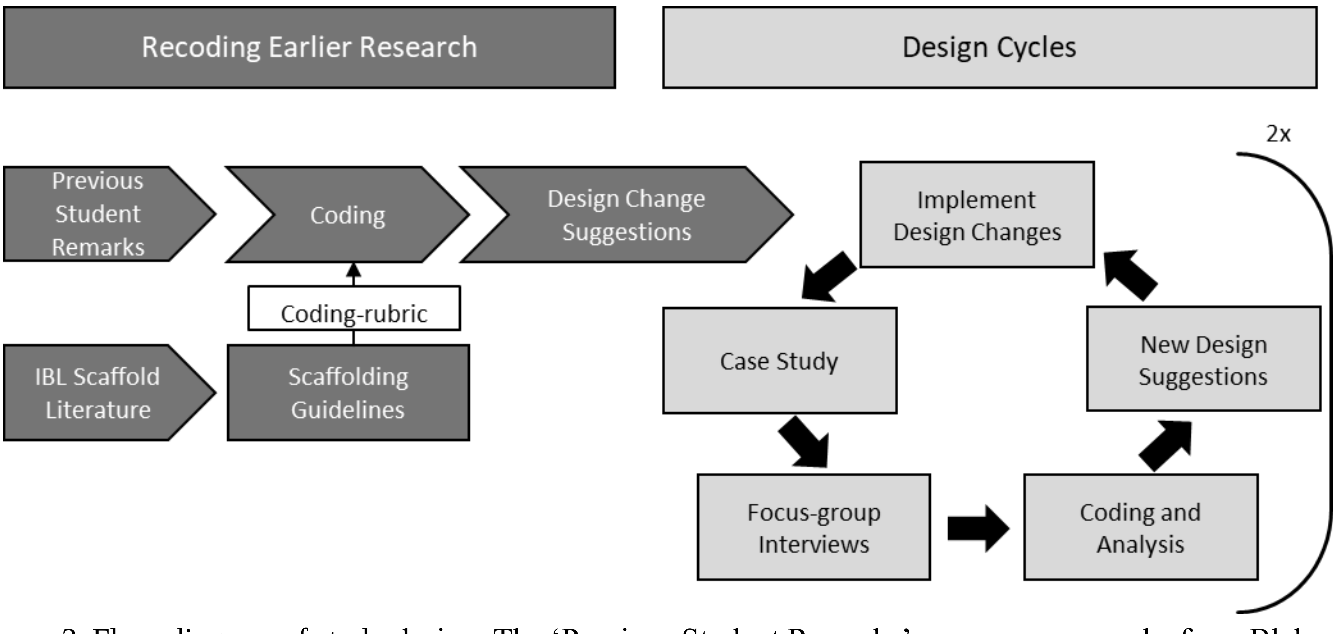

Figure 3. Flow-diagram of study design. The 'Previous Student Remarks' encompass remarks from Blekman (2020), Nikandros (2020) and Van Asseldonk's (2020) studies. One 'Case Study' entails students of one school conducting the changed design of two ISP experiments.

interviews, the scaffolding was redesigned and tested again, following the same format as the first cycle. This completes the second design cycle. And finally, conclusions were drawn from the final results.

Previous Students' Remarks

First, transcripts of Blekman's (2019) and Nikandros' (2019) focus group discussions with students on the ISP were selected. More specifically, the statements relating to the support or thwarting of competency were of interest, as they could shed light on which factors cause the students' perceived competence support loss. The statements relating to autonomy were also selected to find out which aspects of the IBL ISP support students' perception of autonomy. This additional investigation was performed because it was important, when facilitating intrinsic motivation, that these autonomy aspects were retained as much as possible in the design of the ISP scaffolding. Both competence and autonomy related statements were coded by Blekman (2019) and Nikandros (2019) in their studies. Van Asseldonk (2019) also gathered students' statements on how they experienced the DI and IBL ISP experiments via a questionnaire. As the answers to these questions could also relate to students' perceived competency, autonomy and scaffolding, we also selected answers related to any of these aspects from this dataset. The answers on the DI version of the ISP were also analysed, as students made remarks in relation to the IBL version for their argumentation.

Coding

The selection was done by coding the competence and autonomy (both supporting and thwarting) remarks of the earlier research with Quintana *et al.*'s (2004) scaffolding guidelines (Table 1), assisted by their Quintana *et al.*'s (2004) descriptions. For example, if a student remarks that they found the scientific tools too confusing to use, the remark could be categorized into scaffolding strategy 6c: "Facilitate navigation among tools and activities" (Quintana *et al.,* 2004, p. 345; see Table 1). This would suggest the creation of scaffolding that makes the scientific tools easier to navigate is necessary. Additionally, useful remarks related to the scaffolding guidelines, but not coded for competence or autonomy, were coded as 'Other Feedback'. See Appendix B for full coding document.

Design Cycles

A design research cycle approach was employed to (re)design scaffolding aspects of the ISP and qualitatively study its effects on students perceived competency support and autonomy. This design cycle model was loosely based on the micro cycle model (Van den Akker *et al.,*

2006) and the lesson study cycle (De Vries, Verhoef, & Goei, 2016). For this design, the scaffolding of two IBL ISP experiments were modified based on the findings of the two aforementioned phases (Previous Students' Remarks and Coding). The two experiments were "Absorption of γ-radiation through lead" (#12) and "Radioactive decay of protactinium-234m" (#20).

The designs were tested in a quasi-experimental setting, wherein four students (two pairs) per experiment used the (re)designed scaffolding instead of the usual format to finish their experiment. After these students had finished, a focus group interview was conducted with questions related to competence, autonomy and scaffolding. Students' answers were recorded and transcribed verbatim, followed by independent coding by two researchers on competence, autonomy and scaffolding (Cohen's kappa = 0.88). The statements were linked to the aforementioned scaffolding guidelines (Quintana *et al.*, 2004), as was done in the coding phase, but coding was limited to the specific scaffolding categories that focussed on in the scaffolding design (see Appendix D for coding scheme). After determining which scaffolding aspects could be changed, the second design cycle started. The scaffolding of the two ISP experiments were modified again to further increase competence/autonomy support in scaffolding wherever necessary (see Figure 3). The rest of the second design cycle almost completely followed the same format as the first cycle. Transcripts of the second focus group interviews were not only coded for the guidelines that were changed, but for other remarks that could be categorized for competence and autonomy as well ('Other Remarks').

Interrater Reliability

To check internal reliability of this study, a second coder, knowledgeable with intrinsic motivation literature, also coded a portion of the focus group interviews of the second design cycle (school B). 21 items were coded by both coders, using 12 different codes, with agreement on 19 of the items (90% agreement). Interrater reliability was calculated using Cohen's Kappa, resulting in a κ of 0.88. Following Landis and Koch's (1977) division, this Kappa value stands within the range of an almost perfect strength of agreement (0.81-1.00).

Results

Recoding Earlier Research

Derived from Quintana *et al.*'s (2004) seven guidelines for scaffolding, six categories were formed for coding of the previous students' remarks. These six categories were Understanding (guideline 1), Semantics (guideline 2), Representations (guideline 3), Process Knowledge

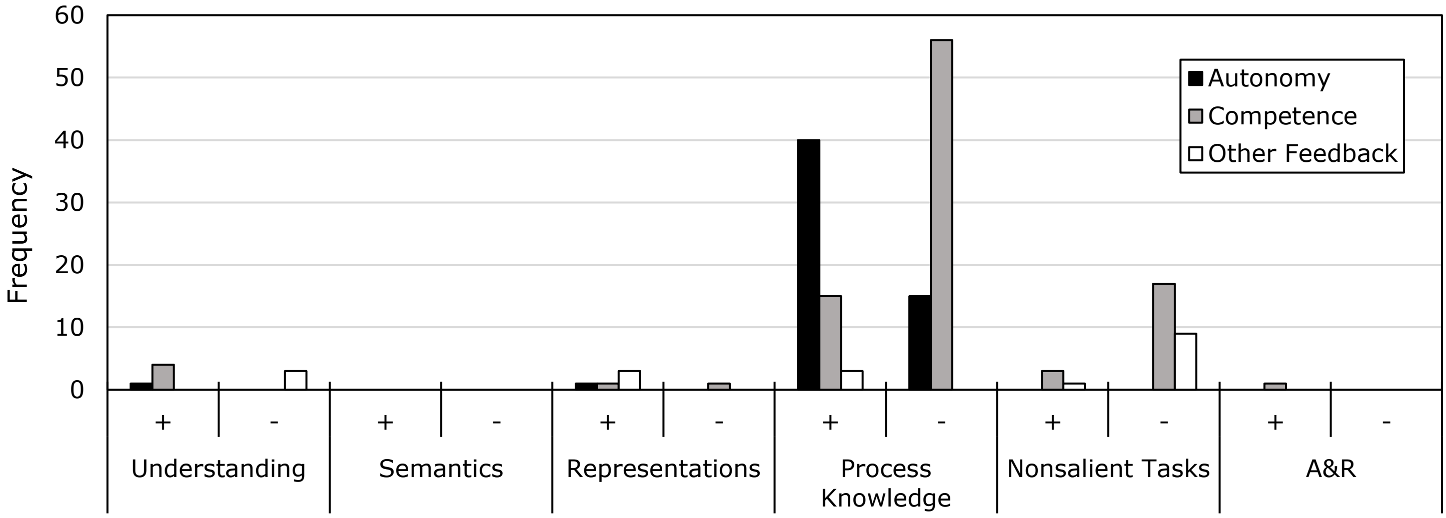

Figure 4. Frequency of student remarks from earlier research (Blekman, 2020; Nikandros, 2020; Van Asseldonk, 2019). Remarks coded for Autonomy or Competence (supporting, '+'; thwarting, '-'), and for the different guideline categories of Quintana *et al.* (2004). 'A&R' stands for the guideline 'Articulation and Reflection'.

(guidelines 4 and 5), Nonsalient tasks (guideline 6) and Articulation and Reflection (guideline 7), see Appendix B for a full explanation. Figure 4 illustrates the frequencies of every code. Interestingly, most remarks fell into the 'Process Knowledge' category (129), followed by the 'Nonsalient tasks' (30). The other four codes were rarely found in students' remarks, with 'Semantics' not even being mentioned at all. Within Process Knowledge a dichotomy can be discerned. As for choosing which steps of the research process they undertook, students made autonomy supportive remarks. For example, one student said:

> *"An open [IBL] experiment, you can also put your own ideas into an experiment and come up with your own experiment so it's more creative, so i'd like that more."*

The students' feelings of competence support for the research process, however, were in contrast with this positivity for autonomy. As shown by the exemplary remarks in Table 3, students felt unsure about their own abilities, whether the steps they chose in their research were the correct ones. Similarly, students commented on not feeling supported in their competence for Nonsalient tasks (Table 3). Especially prevalent were the remarks related to difficulties with the handling of the equipment of their given experiments, highlighting confusion on how to use it. Within the 'Other Feedback' category, one student even provided suggestions on how to improve the instructions for their set-up:

> *"Yeah, maybe in the short overview you can have a picture of every experiment, of the set up, so you know what to expect."*

Additionally, there were also several remarks related to students experiencing time constraints, for example:

a. *"Setting up methods takes a lot times."*
b. *"The time it took, it's just [a] big negative point."*

This need for time could relate to Nonsalient tasks, as time management should be a routine task that should not give pressure unnecessarily. Based on the frequency and nature of the remarks, design of the scaffolding was focused on alleviating the thwarting experiences students had with their competence in Process Knowledge and Nonsalient tasks.

Design Changes

The designed scaffolding implemented the strategies "Restrict a complex task by setting useful boundaries for learners" (4a) and "Describe complex tasks by using ordered and unordered task decompositions" (4b) from Quintana *et al*. (2004, p. 359).

To give the students more boundaries and further decompose the sections of their research, guiding questions were added to the existing worksheets. These guiding questions were inspired by the task decomposition in Pols' (2019) Scientific Graphic Organizer. Examples of these questions are: 'What would you like to know during this experiment?' (for the Research question) and 'How long/often will you measure?' (for the Methods). These questions were not commands, as that could impede students' feeling of autonomy, but they could still help limit the scope of possibilities that would otherwise demotivate students. Furthermore, by

Table 3
Examples of negative competence remarks given by students on Process Knowledge and Nonsalient tasks. Remarks were found in Blekman's (2020), Nikandros' (2020) and Van Asseldonk's (2019) data.

Process Knowledge	Nonsalient Tasks
"I just kind-of thought, well maybe this is correct but maybe not. And then, yeah, I just didn't know if it was the right thing I was doing."	"Because I think that was our biggest struggle, to actually find out what the, what the devices actually measure, when we were doing the experiment."
"I found it very confusing and difficult, and also annoying that I didn't know if I was doing it correctly."	"It was sometimes difficult to [understand] how the equipment worked."
"Am I doing everything I should do? Because we didn't receive a form with 'you should do this'."	"The experiment was doable, but it was unclear how the devices worked."
"We had difficulties with formulating a hypothesis and research question."	"I found it difficult… Also, there was no explanation how you could use the device."

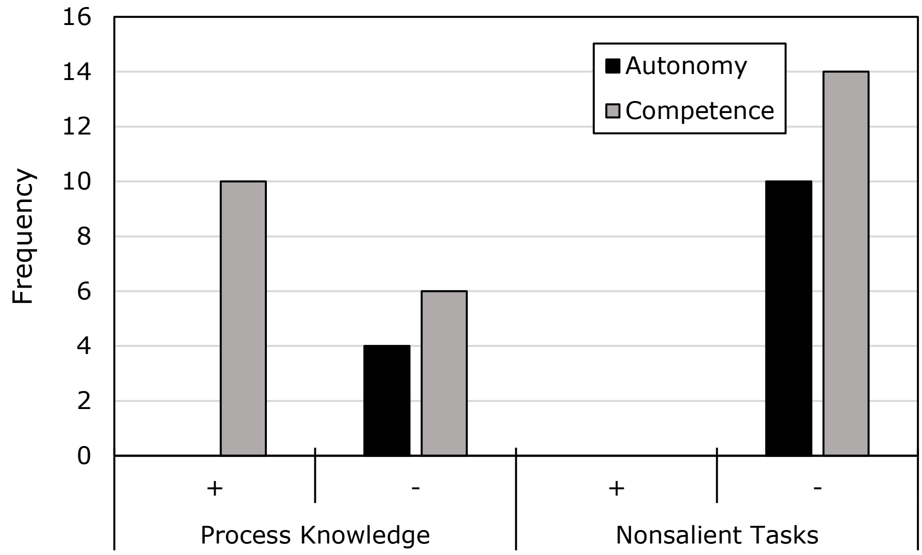

Figure 5. Frequency of student remarks after first design cycle iteration (school A). Remarks coded for Autonomy or Competence (supporting, '+'; thwarting, '-'), and for the Process Knowledge and Nonsalient Tasks guidelines, based on Quintana *et al.* (2004).

answering these guiding questions, they would have a better grasp on whether they were doing it right.

As for the design of the scaffolding for the Nonsalient tasks, a Quick-start guide (QSG) was designed as a separate new sheet. Its design was based on the guideline "Facilitate navigation among tools and activities" (6c; Quintana *et al.*, 2004, p. 366). The QSG provided a visual and step-by-step approach to handling the equipment of the experiment. Following up on one student's suggestion, pictures of the experiments were used for the explanations.

Furthermore, a checklist of important research steps with expected time required was added to the 'suggestion sheet' (a sheet students received with expectations for every phase). By reducing the cognitive load managing and estimating time gave students, the guideline "Automate nonsalient portions of tasks to reduce cognitive demands" (6a; Quintana *et al.*, 2004, p. 366) was followed. This would cater to the need of time-management for the students, allowing them to know where they were expected to be at what time during their experiment.

First Design Cycle

Figure 5 displays the frequencies of remarks students made on Process Knowledge and Nonsalient tasks in the focus group interviews of school A. These interviews took place after students had conducted our designs. Interestingly, although the competence support of Process Knowledge may seem to have improved, a considerable amount of competence and autonomy thwarting remarks were made on both Process Knowledge and Nonsalient tasks.

Two students reported to be thwarted in their Process Knowledge autonomy by the predetermined goals given by the suggestion sheet, as can be read from this example:

> *"We didn't really need to come up with anything, because you just had goals."*

This would indicate students wanted more freedom in setting up a research question. However, when asked if students would want to change the 'goal' format, they responded that they would not:

> *Student F: "Well, if you don't know what your goals are…"*
> *Student G: "Yeah, exactly, I think you have to have something to work towards. I think."*

On the competence of Process Knowledge, there were a number of remarks highlighting competence support, for example:

> *"I think the processing [of the results] will take a considerable amount of time, but I don't think it will be very difficult."*

Appropriately coding was difficult on some occasions, however. Although the students did show competence for most of the research process, they also seemed <u>over</u> competent in some of their remarks. In other words, students experienced knowing which steps to undertake as being easy, i.e. not being adequately cognitively challenging (see Appendix E):

> "*Yeah, I thought it was mostly easy, because it's very clear what you have to do: you just have to measure."*

This over competence could also be found in the Nonsalient tasks, for example:

> *"… the device measures for you. You only have to write it down."*

Even if the aim was to alleviate cognitive load of the measuring devices, it should not have led to over competence on the experiment overall. Thus, these over competent remarks were coded as competence thwarting.

Concerning the Nonsalient tasks, students also still reported some difficulties with the equipment, reducing their competence, for example:

a. "You had to figure out how the device worked. The rest was doable."
b. "It kind of explained itself, only keeping the time… And that was difficult to do for every five seconds."

Furthermore, several comments were made on needing to look up information beforehand. Even though these students seemed capable of finding the information themselves, these remarks were coded as competence thwarting, for example:

> *"So we have to look up and know information. Otherwise, it naturally will be difficult to argue your conclusion."*

Although not coded, it is interesting to note that students also mentioned that the ISP was doable or even easy because of their preparation (four remarks from three different students), for example:

> *"I would say that if you do the preparation, what's next will be easy."*

Based on these remarks, several design changes were considered and implemented (also see Appendix F):

1. The decision was made not to change the 'goals' of the suggestion sheet. Even if it seemed to have hampered their autonomy, the students remarked that they thought the goals to be necessary to complete the experiments.
2. It was decided to also not tackle the over competence issues for Process Knowledge and Nonsalient tasks. These students were clearly used to IBL approaches and may not have been representative of the average student (see Limitations).
3. The QSGs were reviewed and updated to be more intuitive. Clearer language for every step, coloured labels and further decomposition of the separate elements of the equipment were implemented (Appendix F2).
4. To address the need for information sources, explicit references to the 'information booklet' coming with the experiment, as well as to other sources, were written on the 'suggestion sheet'.
5. The old explanation of how the equipment worked was removed from the 'suggestion sheet'. This was done to prevent redundancy and confusion by having two different sources for the device's instructions.
6. To further facilitate navigation through the different sheets (following guideline 6a), explicit labels were given to every sheet ('suggestion sheet', 'worksheet' and 'Quick-start guide'). An orientation for the three sheets was also provided on the 'suggestion sheet'.
7. After carefully reviewing time management literature, it was decided to remove the checklist with timetable in its entirety. Claessen, Van Eerde, Rutte and Roe (2007)

noted in their review that externally controlled time management could have negative effects on somatic tension. Aiming to prevent such scenarios taking place, the time-management checklist was instead replaced with two general timing prompts on the work sheet.

Second Design Cycle

Figure 6 shows the frequencies of student remarks on Process Knowledge and Nonsalient tasks in the focus group interviews at school B, after students had conducted the second design of the experiments. In contrast to the previous focus group interviews, students remarked that they experienced autonomy support for their Process Knowledge, with no single remark reporting autonomy being thwarted. Furthermore, the number of supportive and thwarting remarks concerning competence for both Process Knowledge and Nonsalient tasks have similar frequencies. Thus, the implemented scaffolding seemed to have had a supportive effect on students' competence, whilst retaining their sense of autonomy. There were, however, still some remarks which highlighted students were thwarted in their intrinsic motivation that require examination.

Autonomy

As aforementioned, all remarks related to autonomy in Process Knowledge were supporting, for example:

a. *"I noticed that, when I work step-by-step, I quickly lose focus. I will do something else instead. Here, however, I was focused on 'how will I address this, how will I continue.'"*
b. *"But yeah, for the rest very fun, what they said, that you got some freedom. That you could decide yourself how you approached it."*

These remarks show students experienced autonomy support in deciding how to approach the research process. This contrasts completely with the remarks given by students in the first focus groups (school A), where students felt thwarted in their autonomy. It is important to note, that some of the students remarked that this IBL approach was different from what they normally received for a practical.

Competence for Process Knowledge

As for competence for Process Knowledge, some aspects of the research still seemed to have a competence thwarting impact, but there were many supporting remarks. Some students still remarked they had difficulty with formulating a research question or the methods, e.g. :

Student 6: "So, really formulating a research question, but also really creating a plan is always a bit difficult."

Interviewer: "And why is that difficult?"

Student 6: "Because you never really know here you need to start, I don't know."

Regarding the competence support for Process Knowledge, students did appear to be confident in setting up a research overall, for example:

"I noticed that, when I work step-by-step, I quickly lose focus. I will do something else instead. Here, however, I was focused on 'how will I address this, how will I continue.'"

These remarks showed the students' confidence in and knowledge of what is important in a research process. This indicates that the scaffolding implemented might have had a supporting effect on their overall competence in setting up and understanding a research.

Competence for Nonsalient tasks

Similar to Process Knowledge, there was a mix of both competence thwarting and supporting remarks for Nonsalient tasks. Interestingly, the competence thwarting remarks were struggles related to creating charts, for example:

"So if you had to draw relatively precisely what the value was, that was difficult."

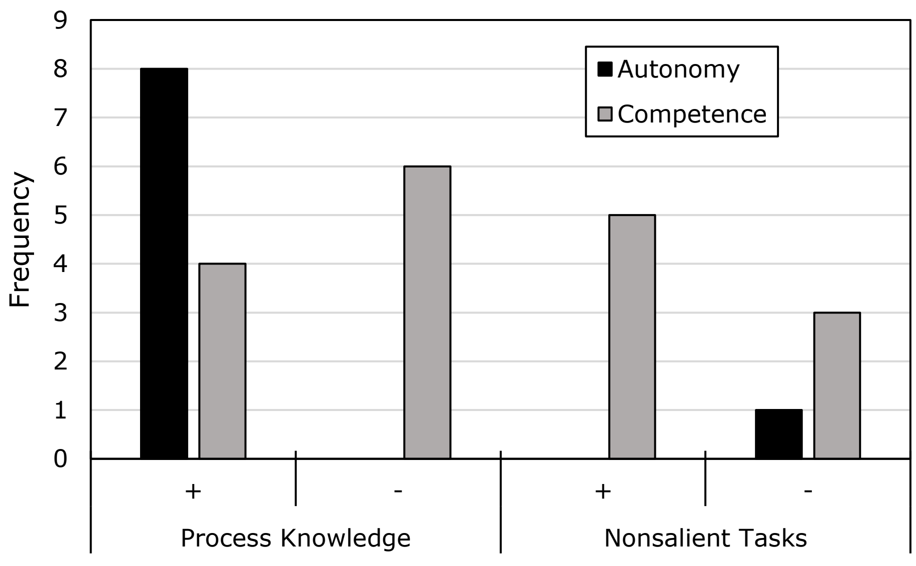

Figure 6. Frequency of student remarks after second design cycle iteration (school B). Remarks coded for Autonomy or Competence (supporting, '+'; thwarting, '-'), and for the Process Knowledge and Nonsalient Tasks, based on guidelines of Quintana *et al.* (2004).

As for competence support on Nosalient tasks, there was a variety of different remarks. There were remarks related to competence in optimizing their measurements:

> *"Yeah, you know, you learn why a research is set up as it is set up. Because we first had two set ups that didn't go completely well. And then you're just optimizing with the equipment and then you find out: 'okay, this is the way that goes the smoothest.' And then you write that down."*

Interestingly, there was one remark related specifically to the scaffolding, namely competence support through the QSG:

> *"Yeah, but also the instructions of how the equipment worked were clear. Was well done."*

Overall competence and autonomy

Figure 7 summarises the frequencies of student remarks after the second design cycle iteration, with the remarks coded as Process Knowledge and Nonsalient tasks combined into the group 'Guideline Remarks'. The 'Other Remarks' consist of remarks that could not be categorised as either Process Knowledge or Nonsalient tasks, but still can be coded for autonomy or competence. There were no autonomy thwarting remarks that could be categorized in the 'Other Remarks 'category. There were autonomy supporting 'Other Remarks', however. An example of a remark highlighting this autonomy support was:

> *"Yeah that we got more freedom. I thought that was fun."*

As for an example of competence support of 'Other Remarks':

> *"Very fun…And because you were focused on one thing during the whole experiment, instead of a couple separate assignments that you constantly have to do after each other. So, with this, you can go more in depth, that's a lot of fun."*

One of the competence thwarting remarks in 'Other Remarks' is related to how there was a disconnect between the knowledge the student had before the experiment and the knowledge required to complete the experiment:

> *"We had half-value thickness and that is of course logarithmic. It's just, yeah, I don't have a lot of previous experience with drawing logarithmic graphs."*

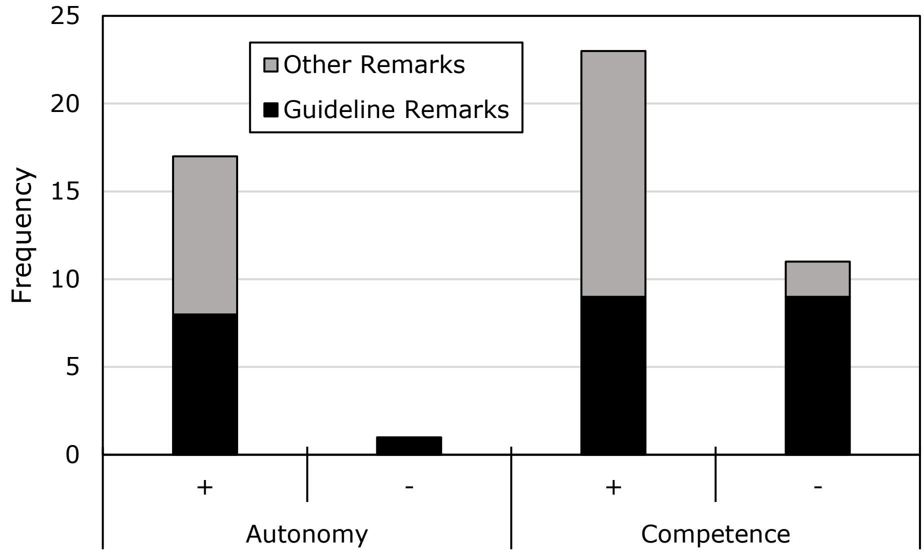

Figure 7. Frequency of student remarks after second design cycle iteration. Remarks coded for Autonomy or Competence (supporting, '+'; thwarting, '-'). The Process Knowledge and Nonsalient Tasks, based on guidelines of Quintana *et al.* (2004), are grouped as 'Guideline Remarks', whereas other remarks that did not fall within these guidelines were coded as 'Other Remarks'.

In summary, the results show that scaffolding on Process Knowledge and Nonsalient tasks does improve competence support of students, whilst retaining their sense of autonomy. What is also interesting is that the positive effect the scaffolding has on both competence and autonomy support goes beyond the boundaries of the scaffolding themselves (Figure 7). There are, however, still signs scaffolding could be improved further, as there are remarks related to competence being thwarted.

Conclusions

The aim of this study was to investigate how the scaffolding of an IBL-based physics experiment could be designed in such a way that students' need for competence support was catered for, while retaining their sense of autonomy. The first sub-question for this investigation was: <u>What are the causes of perceived lack of competence support in the radiation physics experiment?</u> The results show that students lacked most competence support for the scaffolding categories Process Knowledge and Nonsalients tasks. Concerning Process Knowledge, the most prevalent struggle students reported was not knowing whether they were taking the correct steps in their research and/or if they were doing those steps correctly. As for Nonsalient tasks, students mostly experienced difficulties with navigating through the equipment of their experiments. Additionally, there were some issues with not knowing where to look up information as well.

The second sub-question of this study was: How can scaffolding be implemented in the radiation physics experiment to increase students' perceived competence? Quintana *et al.*'s (2004) scaffolding guidelines formed the basis for the new scaffolding design of the ISP. After going through two iterations of designing, the scaffolds for Process Knowledge and Nonsalient tasks took shape in three main ways. First, guiding questions were added to the worksheet to provide stronger boundaries and task decomposition for the students' research process. Secondly, tips and prompts were given on the worksheet as well. A couple of them were also related to decomposing and limiting the openness of the research process, but most of the prompts were there to alleviate cognitive demands of Nonsalient tasks. Navigation through the different sheets was also made clearer with an overview on the suggestion sheet. Thirdly, a Quick-start guide was developed for operating the equipment of experiments, further reducing the demands of Nonsalient tasks.

Although results of the focus groups differed between iterations, the last iteration yielded promising results. Not only had the frequency of competence supported remarks within the scaffolding categories increased to similar levels of the competence thwarting remarks, but students' perception of autonomy support remained high as well. Investigation of remarks that were not related to scaffolding showed there were even more competence supporting than thwarting remarks. Figure 7 stands in stark contrast to the figures of Blekman (2020), Nikandros (2020) and Van Asseldonk (2019), where those studies had found (significantly) more competence thwarting data for the IBL version of the ISP than competence supporting. A reason behind this more positive competency support image could be that the effects of the new scaffolding went beyond what was scaffolded and contributed to the overall competency support of the students. This could be inferred from the more general nature of the competency supporting statements that could not be categorized into the different guidelines. In other words, the implementation of prompts, tips, guiding questions and the QSG appears to be supportive of students' competence.

The main research question of this study was: How can an IBL-based secondary school radiation physics experiment be constructed in such a way that students' psychological need for competence is catered for, while also retaining their perception of autonomy? The hypothesis was that the implementation and improvement of scaffolding related to sense making, process management, and reflection and articulation would cater to the need of competence, while not hampering students' autonomy. Based on our findings for answering the sub-questions, the hypothesis is rejected. The scaffolding strategies for sense making and articulation and reflection are important in their own right, but students' remarks suggest the crux for supporting intrinsic motivation lies in process management. Specifically, by implementing proper scaffolding for Process Knowledge and Nonsalient tasks will students be supported in both their competence and autonomy. The aim of having an appropriate balance between competency and competence stimulation, following Schunk and Zimmerman (2012), was achieved.

Discussion

Limitations

There were several limitations on the methodology and results of this study. As was made clear in the Methodology section, the participants of the two schools differed considerably. Whereas the students of school A seemed to be well-versed in setting up their own research, students of school B were not accustomed to such a task. This could be the reason why students of school A seemed to be over competent on certain areas of the ISP. Furthermore, school A's students were prepared for the IBL version of the ISP, having already written a significant portion of the ISP beforehand. The selected students of school B were actually supposed to conduct DI experiments, but were selected for this study by the teacher. The teacher's selection bias might have made our sample of students not representative for the whole class (as one student estimated of other people in their class). Furthermore, this being a qualitative study, the sample size was small (N = 17) and the number of experiments that were redesigned was relatively small as well (two out of ten). These limiting factors make it harder to generalise our findings, as the individual (school) experiences probably strongly influenced the remarks students made. The novelty effect of doing an own research could have raised the intrinsic motivation of school B's students to a higher level, whereas the students of school A may have reported to being over competent due to their preparation and experience. It could have also been the case that the experiments chosen for redesign are difficult to compare to other experiments, not only outside the ISP, but between the different ISP experiments as well.

Furthermore, the scaffolding approach of this study was based on data from three different sources (Blekman, 2020; Nikandros, 2020; Van Asseldonk, 2019), each with their own research aim that was not directly related to scaffolding. Thus, although the scaffolding aspects that were tackled in this study were the most prevalent from their datasets of remarks, more specific inquiry on scaffolding might have yielded a different frequency distribution. For example, none of the earlier researches specifically inquired on students' experiences with

Articulation and Reflection. In other words, the earlier research might not have been completely suitable for finding students' scaffolding needs.

Specifically for previous students' remarks on being competence thwarted in Process knowledge, there could be another reason students reported difficulties. As was the case with this study, schools from the earlier research could have also vastly differed in to what degree they teach students to conduct research on their own. It could have been the case that many of the competence thwarting remarks on Process Knowledge were made by students that had little experience with IBL research. This could have set the IBL version of the ISP outside of the zone of proximal development for these students (Vygotsky, 1980). It might require a universal curriculum adjustment across the Netherlands towards more IBL for students to make the ISP appropriately challenging, and not too demanding.

Additionally, a specific reason as to why Nonsalient tasks were mentioned as thwarting could be the nature of the ISP itself. As the devices that were given to students during this experiment are fairly unique for the school-context, operating the equipment could be especially difficult for students. Measuring devices for radiation require a different approach than, for example, a simple voltmeter. On the other hand, because students worked with both material and equipment they would normally not be in contact within a school-context, the ISP's characteristics could have made students more excited and motivated for experiments than they usually were for regular classroom experiments. Nevertheless, the students' remarks still gave insight in how they primarily experienced the ISP and which aspects they were positively challenged by and where they struggled.

Lastly, there were still aspects of the scaffolding that could be improved for competence support, after the second design iteration. For Process Knowledge, suggestions or guiding questions could still be made for how long and how often students could measure, as they remarked having difficulty with estimating what was possible. This would help set boundaries for the learners and not be too distracted by figuring out this timing (following guideline 4a; Quintana *et al.*, p. 359). Concerning Nonsalient tasks, the issues students had with setting up a graph could be alleviated, for example, through organizing the chart paper in a different way, as well as providing tips on how to chart logarithmically (following guideline 6b. Quintana *et al.*, p. 366). Thus, the employed scaffolding design approach could still further its reach.

Implications

Our findings have both theoretical and practical implications. As earlier research has shown (Blekman, 2020; Gormally *et al.*, 2009; Nikandros, 2020; Van Asseldonk, 2019), IBL is not guaranteed to support intrinsic motivation outright. Our study has highlighted possible mechanisms that interact between IBL and intrinsic motivation, and bridges their connection through scaffolding. It is scaffolding dependent whether an inquiry-based approach to learning supports students' intrinsic motivation. Scaffolding of Process Knowledge and Nonsalient tasks will serve as the condition that will determine whether learners are intrinsically motivated or not. The hypothesized mechanism by Van Asseldonk (2019) (Figure 2) would require the addition of scaffolding to more accurately link IBL and intrinsic motivation.

Because this research has shown the importance of scaffolding in experiments, designers of future science experiments could follow the guidelines and examples used in this study to support learners' intrinsic motivation for the experiment. Not only could this make students more intrinsically motivated for the experiments, but for sciences in general as well. For example, Quick-start Guides could be designed for all scientific equipment in schools. Or research processes for biology and chemistry can be scaffolded with similar prompts, hints and suggestions, as was done in our ISP design. In turn, this could contribute towards alleviating the crisis in motivation for science. Perhaps scaffolded IBL could even become an intrinsic part of science curricula, broadening the positive effect it can have on students' motivation towards science.

The challenge for future research now lies in making steps towards better understanding the relationships between scaffolding, IBL and motivation. It would be interesting to increase the scope of our design methods and investigate its effects quantitively. For example, the scaffolding techniques employed in this study could be applied to the other IBL experiments of the ISP. By using questionnaires based on the Intrinsic Motivation Inventory (McAuley, Duncan, & Tammen, 1989) and statistical analysis, more generalisable conclusions can be made on the effects of scaffolding IBL for supporting motivation. A similar quantitative approach could also be fruitful for discovering the effects of scaffolding on the learning outcome. Following Self-Determination Theory, if the intrinsic motivation of students is supported, their academic performance should improve as well (Niemiec, & Ryan, 2009). The lack of competence support in the earlier version of the ISP could have been a contributing factor as to why Verburg (2018) did not find any differences in conceptual understanding between the IBL and DI version of the ISP. Quantitative research with newly scaffolded experiments would make clear if scaffolding increases the conceptual understanding via intrinsic motivation support.

Another possible extension on this study would be a qualitative continuation. On a more fundamental level, it would be interesting to investigate effects of other scaffolding guidelines in the ISP. An example research question would be: how will scaffolding in how they articulate and reflect on their research affect students' intrinsic motivation? Additionally, a revision of the interview-scheme could lead to other, deeper struggles students experience in experiments to rise to the surface. The findings of these studies might deepen our understanding of the effects of scaffolding as well.

This study has shown that a inquiry-based learning approach on its own does not adequately support students' competence for intrinsic motivation. Appropriate scaffolding of Process Knowledge and Nonsalient tasks, however, will lead an autonomy- and competence-supportive environment that should support intrinsic motivation for students.

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Appendix A
Inquiry-based learning tasks evaluation matrix

Table A1 shows the evaluation matrix devised by Capps and Crawford (2013) on key aspects of IBL, from student- to teacher-initiated

Table A1

Shows the aspects of doing inquiry and their variations, from student- to teacher-initiated. Reprinted from Capps and 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

Coding document used for categorizing students' remarks found in Blekman (2020), Nikandros (2020) and Van Asseldonk (2020), i.e. for the Recoding Earlier Research phase of this study.

Coding document for Scaffolding guidelines.

Summary and definitions for main concepts (*sense making, process management* and *articulation and reflection*), guidelines and scaffolding strategies (Quintana *et al.*, 2004). Hmelo-Silver *et al.* (2007) only provides examples. Each guideline explanation has a '*Note'* section explaining generally the criterium/criteria for a remark. IMPORTANT: Each of these '*Note'* sections is written for remarks that highlight struggles. But remarks that actually demonstrate the reverse (a supportive experience with a certain guideline) will be categorised in that guideline as well, to highlight what should be retained in the ISP design. This slightly differs from the author's comments attached to every student remark that also start with *'Note'*, which briefly explains the coding choice.

Remarks relating to Guidelines 4 and 5 have been merged into a single category due to difficulty in distinguishing between both guidelines, when categorizing student remarks. Furthermore, guideline 7 will be split into four different types of comments due to its multifaceted nature.

Highlights:

-First, remarks will be categorized into the different guidelines, by using headers.

-Using sub-headers, remarks are categorized as either Positive (supportive) or Negative (thwarting) experiences.

-After Positive and Negative differentiation, comments are separated into another layer of categories: **Autonomy**, **Competence** or **Other Feedback**. Autonomy and competence was coded by Blekman (2020), Nikandros (2020) and Van Asseldonk (2019). **Other Feedback** relates to remarks that could still be used to modify scaffolding to improve competence, even if it was not coded as such.

-If a remark is related to *autonomy*, it has a red highlight

-If a remark is related to *competence*, it has a yellow highlight

-If a remark has no highlights, it was not coded for *autonomy* or *competence*. In the author's opinion, however, the remark could still be used to modify scaffolding to improve competence (even if it was not coded as such). Thus, these remarks are categorized as "Other".

-For overview, each remark will be given a letter in brackets to show the source: Van Asseldonk (A), Blekman (B) and Nikandros (N).

-Student remarks have comments attached to them in *italics* to explain the author's coding choice (also start with *'Note'*).

Example of coding:
Guideline 1
Positive
Autonomy

omdat je dan de materialen erbij hebt dus dan kan je gelijk je kennis die je krijgt toepassen op wat je... Kennis die je dus gaat bedenken, toepassen op de materialen. En dat vind ik wel leuk. (B)

Note: Remark shows connection between new knowledge and translation of this knowledge into practice

Sense making

"Sense making refers to the basic operations of science inquiry such as generating hypotheses, designing comparisons, collecting observations, analyzing data, and constructing interpretations. Sense-making operations must connect reasoning about a phenomenon to a process for testing a conjecture and from the empirical data generated in that testing back to the implications for the phenomenon." (Quintana *et al*., 2004, p.344)

Guideline 1
"Use representations and language that bridge learners' understanding." (Quintana *et al*., 2004, p.346)

Note: This guideline is based on connecting students' prior knowledge with the new (scientific) concepts. If a student remark is related to a disconnect between students' intuitive ideas and the disciplinary formalisms, it will fall under this guideline (1).

"Learning requires continually accessing and building on prior knowledge, so it is critical that new expert practices are connected with learners' prior conceptions and with their ways of thinking about ideas in the discipline (e.g., Clement, 1993). Tools can support learners by using representations that connect with learners' intuitions and also map onto expert practice. The representations employed in a tool can shape how people conceive a task (Norman, 1991). In this way, the tool's structure provides this type of bridging scaffold, helping learners make the connection between their own ways of thinking about problems and the concepts and formalisms used in more expert practice." (Quintana *et al*., 2004, p. 346 – 347)

Strategies:
1a: Provide visual conceptual organizers to give access to functionality.

1b: Use descriptions of complex concepts that build on learners' intuitive ideas.

1c: Embed expert guidance to help learners use and apply science content.

Guideline 2
"Organize tools and artifacts around the semantics of the discipline."

Note: This guideline is similar to guideline 1 in connecting new knowledge with students' preconceptions. However, the perspective is different as this guideline focusses on explicating the language and type of thinking within the set learning context to help the students, rather than what the students know/think beforehand. Thus, if a student remarks that they struggle with how to approach, work or create within the practical due to disciplinary (i.e. scientific method and related semantics), then the remark will be categorized into guideline 2.

"Here we discuss a complementary guideline addressing the obstacles arising from the need for learners to acquire discipline-specific ways of approaching problems. Because expert practice relies on specific background knowledge that learners lack, learners need support to implement general notions of science inquiry in specific disciplinary contexts (Reiser et al., 2001; Schauble, Glaser, et al., 1991). Guidelines 1 and 2 both exploit the role of tools in helping shape learners' conceptions of tasks. However, where Guideline 1 refers to using representations that can be productively understood from the learners' perspective, Guideline 2 focuses on the other side of the gap, helping bring disciplinary ways of thinking closer to learners by making such thinking more visible in tool interactions. Such support helps learners overcome limitations in their disciplinary knowledge by making disciplinary semantics and strategies more explicit in the tools they use and the artifacts they construct." (Quintana *et al.*, 2004, p. 351).

Strategies:
2a: Make disciplinary strategies explicit in learners' interactions with the tool.

2b: Make disciplinary strategies explicit in the artifacts learners create.

Guideline 3
"Use representations that learners can inspect in different ways to reveal important properties of underlying data."

Note: In order to be categorized into this guideline, the student's remark has to mention struggles with making sense of representations of a scientific phenomenon. An example would be a student not understanding the meaning of the graph and table they plotted for their ISP experiment.

"Guideline 3 continues our focus on limitations in learners' conceptual knowledge about the discipline. Here we discuss ways to address obstacles learners face in dealing with the representations of a phenomenon they need to understand and manipulate when making sense of that phenomenon. Access to scientific phenomena is typically mediated through the creation and understanding of representations such as tables, graphs, equations, and diagrams. However, these representations impose additional challenges for learners. Guideline 3 addresses these challenges by recommending inspectable representations to simplify the process of mapping between representations and the aspects of phenomena they encode and help learners manipulate and explore representations in different ways." (Quintana *et al.*, 2004, p. 353 – 354)

Strategies:
3a: Provide representations that can be inspected to reveal underlying properties of data.

3b: Enable learners to inspect multiple views of the same object or data.

3c: Give learners "malleable representations" that allow them to directly manipulate representations.

Process management

"Classic models of problem solving contain both basic operations and a set of control processes (e.g., Anderson, 1983). Our characterization of scientific inquiry includes the process management mechanisms that direct the knowledge and strategies needed to control and steer the investigation itself such as implementing a investigation plan and keeping track of hypotheses and results. Process management is particularly critical given the ill-structured nature of inquiry. A science investigation is ill-structured because it lacks a definitively prescribed manner for how the problem should be tackled (M. Davis, Hawley, McMullan, & Spilka, 1997) and because one cannot always define in advance the exact process to find a solution (Newell & Simon, 1972; Simon, 1973)." (Quintana *et al.*, p. 358)

Guideline 4
"Provide structure for complex tasks and functionality."

Note: Although this guideline might seem more relevant for software specifically (as was the main intent of Quintana et al.), the guideline can, in fact, be used in a more general sense. If student's remarks report struggles with not knowing which steps to undertake in their inquiry (e.g. not knowing where the boundary lies of what they can conduct in their experiment), the remark will be categorised here.

"Guideline 4 suggests that tools should structure learners' tasks and tool functionality should be structured to support learners in seeing what steps are possible, relevant, and productive. Specifically, this guideline looks at how software tools can constrain or describe tasks in ways that make them more accessible to learners. The strategies associated with this guideline help learners by limiting the scope of the activity space within which learners work. This is similar to how apprentices are given parts of an authentic task rather than being expected to work on the entire task at once (Lave & Wenger, 1991)." (Quintana *et al.*, 2004, p. 359)

Strategies:
4a: Restrict a complex task by setting useful boundaries for learners

4b: Describe complex tasks by using ordered and unordered task decompositions

4c: Constrain the space of activities by using functional modes

Guideline 5
"Embed expert guidance about scientific practices."

Note: Rather than focusing on which steps are available and relevant, as is done in Guideline 4, Guideline 5 focuses the complexity of the steps themselves. If a student does not understand the step, how can they know if it is productive to conduct this step? Thus, student's remarks related to not understanding a or multiple available step(s) due to them being too complex will be categorised in this guideline. As mentioned before, as differentiation between guidelines 4 and 5 for the students' remarks is nearly impossible, both guidelines have been combined into one category ("Process Knowledge").

"Guideline 4, our first process management guideline, emphasized how software tools can describe or constrain activity spaces to make tasks more tractable for learners. Now, Guideline 5 provides another approach for increasing the tractability of tasks to help learners manage the processes entailed in the scientific practices. Experts engaging in inquiry may see clear paths and strategies. Learners, however, rely on less elaborated and sophisticated understandings of the practice and thus encounter obstacles in understanding the specifics of performing scientific practices. Guideline 5 recommends providing access to expert knowledge about scientific practices (e.g., explaining, observing, and inferring) so learners can understand both how and why they should embark on a particular task and how to strategically steer their investigation. Expert knowledge can be made available to learners in tools that parallel the guidance provided in a more traditional, person-to-person cognitive apprenticeship. This can help learners understand the nature and rationale for scientific practices." (Quintana *et al.*, 2004, p. 363 – 364).

Strategies:
5a: Embed expert guidance to clarify characteristics of scientific practices

5b: Embed expert guidance to indicate the rationales for scientific for scientific practices

Guideline 6
"Automatically handle nonsalient, routine tasks."

Note: Guideline 6 is used to ensure students only work on the important learning tasks in their inquiry. In other words, the student should not be cognitively challenged too much by tasks that are not very relevant for their learning process. For example, a student should not spend too much time figuring out how a stopwatch works, as it is probably more important that they spend their time coming up with a relevant research question. Thus, if a student remarks that they were challenged by a nonsalient, routine task it will be categorised into Guideline 6.

"Whereas the previous two process management guidelines focused on structuring and embedding expert guidance about scientific practices, Guideline 6 provides further process management support by reducing the cognitive load learners need to bear as they engage in scientific inquiry. Engaging in complex practices requires concentration on salient activities to reach an optimal state of deep cognitive focus (Csikszentmihalyi, 1991). Such a focused state is important for learning, but to reach such a state, it is especially important to minimize distractions and disruptions that can interfere with the sense of deep engagement in the work at hand (Miyata & Norman, 1986). Because potential disruptions for learners can arise from having to deal with management and navigational tasks, Guideline 6 recommends automatically handling such nonsalient, routine tasks. This approach builds on prior conceptualizations of technology as minimizing the overhead for complex work (e.g., arguments for calculators in mathematics learning) and as cognitive tools that offload nonproductive work, thereby reducing the load on memory and cognitive resources (Anderson, Boyle, & Reiser, 1985; Anderson et al., 1995).” (Quintana *et al.*, 2004, p. 366)

Strategies:
6a: Automate nonsalient portions of tasks to reduce cognitive demands

6b: Facilitate the organization of work products

6c: Facilitate navigation among tools and activities

Articulation and Reflection

“The articulation and reflection processes support process management and sense making as well as the collaboration needed to make inquiry effective. A critical aspect of inquiry involves constructing and articulating an argument; this in turn involves reviewing, reflecting on, and evaluating results; synthesizing explanations; and deciding where the weaknesses and strengths are in one’s thinking (Collins & Brown, 1988; E. A. Davis, 2004; E. A. Davis & Linn, 2000; Loh et al., 2001).” (Quintana *et al.*, p. 369)

Guideline 7

“Facilitate ongoing articulation and reflection articulation and reflection during investigation.”

Note: This guideline encompasses many different struggles students could face. It is important to note that, within practically all of the challenges addressed by this guideline, students are unaware of their mistake. This lowers the probability of students reporting struggles with articulation and reflection. Future observational research could shed light on these “unaware struggles”. Furthermore, students might still feel competent (thus having a higher intrinsic motivation) whilst being incorrect in their understanding. Intrinsic motivation <u>after</u> receiving feedback on their scientific report could be lowered due to being wrong, but again: this is beyond the scope of this study.

Categorisation of student remarks have therefore been adapted to the interview/focus-group context:

Students’ remarks will be categorised into this guideline if: (1) The student reports that they did not know that they should articulate their ideas or how to articulate correctly. (2) The student reports that they did not (or did not know how to) reconcile or notice mismatches in group members’ ideas. (3) The student reports they decided on a path too fast, without *considering alternatives and focussing too much on the logistics (which might have led to an illusion of competence which hampers identification of shortcomings). Or (4) the student reports that they lack the critical approach needed to support their claims (e.g. they did not know which details of objects and phenomena to include or which reasons to include when discussing causality)*

Quotation note: With the other guidelines I copied the text under that specific guideline. As the Articulation and Reflection guideline section is very brief, however, I now copied the "Obstacles Learners Face in Articulation and Reflection" section.

"First, learners often do not realize that they should articulate their ideas (Linn & Songer, 1991; Loh et al., 2001; Scardamalia & Bereiter, 1991; van Zee & Minstrell, 1997). In fact, learners sometimes interpret opportunities for articulation and reflection as merely being blanks to fill in (E. A. Davis&Linn, 2000; Schauble, Glaser, Duschl, Schulze, & John, 1995). Furthermore, learners often do not know how to reflect productively (E. A. Davis, 2003a; Palincsar & Brown, 1984); thus, they need support to identify good ways to reflect on and articulate their ideas.

A second related challenge is that learners may focus on achieving quick outcomes (Schauble, Klopfer, & Raghavan, 1991). Learners working collaboratively do not necessarily identify or reconcile mismatches in group members' ideas unless they are required to reach consensus (Cohen, 1994; Webb, 1983) or commit explicitly (Bell, 1998; Golan, Kyza, Reiser, & Edelson, 2001; Reiser, this issue).

Third, learners have difficulty in planning and monitoring their investigations. They forge ahead without considering alternatives or ramifications of their decisions, get bogged down in logistical details of their work (Schauble, Glaser, et al., 1991), and focus on superficial measures of progress (Lan, 1996; Palincsar & Brown, 1984; Tien, Rickey, & Stacy, 1999; White & Frederiksen, 1998). Learners may develop illusions of competence that preclude them from identifying weaknesses in their knowledge (E. A. Davis, 2003a). Studies have shown that students who do not appropriately plan their work and monitor their understanding tend to not perform as well as students who do (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Flower&Hayes, 1980; Recker&Pirolli, 1995). Thus, learners need support for articulating and reflecting as they plan and monitor their investigations (Bielaczyc, Pirolli, & Brown, 1995; Linn & Songer, 1991).

A fourth challenge for learners in articulating and reflecting stems from the fact that the form of the articulated epistemic products of science is critical (Collins & Ferguson, 1993). For example, claims need to be supported with evidence, and arguments need to be warranted (Toulmin, 1958/1964). Descriptions should include observations but exclude inferences. Explanations should refine or expand on ideas or infer consequences (Chi & Bassok, 1989), and explanatory arguments should explore multiple hypotheses, present coherent assertions, provide evidence, and justify connections between claims and evidence (Sandoval, 2003). However, science learners have trouble with all of these practices. For example, when learners describe objects and phenomena, they may not notice important details or they may confuse description and explanation (Bell, 1997; Driver, Leach, Millar, & Scott, 1996; Gallas, 1995; Songer&Linn, 1991).When they discuss causality, learners may omit justifications or reasons (e.g., Bell, 1997; Kuhn, 1993; Sandoval & Reiser, 2004).” (Quintana *et al*., 2004, p. 369 – 370).

Strategies
7a: Provide reminders and guidance to facilitate productive planning

7b: Provide reminders and guidance to facilitate productive monitoring

7c: Provide reminders and guidance to facilitate articulation during sense-making

7d: Highlight epistemic features of scientific practices and products

Appendix C

The interview scheme of the focus groups.

Scheme C1. Final interview scheme for the focus groups. Interview questions are loosely based on Blekman's (2020) and Nikandros' (2020) interview questions.

Questions
1. What did you think of the experiment? Why?
2. What did you like the most of the experiment? Why? How?
3. What was the most difficult of the experiment? Why? How? An example?
4. What did you think of the material of the experiment? Why?
5. What did you think of the (difficulty) level of the experiment? Why? An example?
6. Did you feel that you had to come up with a lot yourself, for this experiment? How was that? Why? An example?

Appendix D

Coding-scheme for Competence, Autonomy and relevant scaffolding categories.

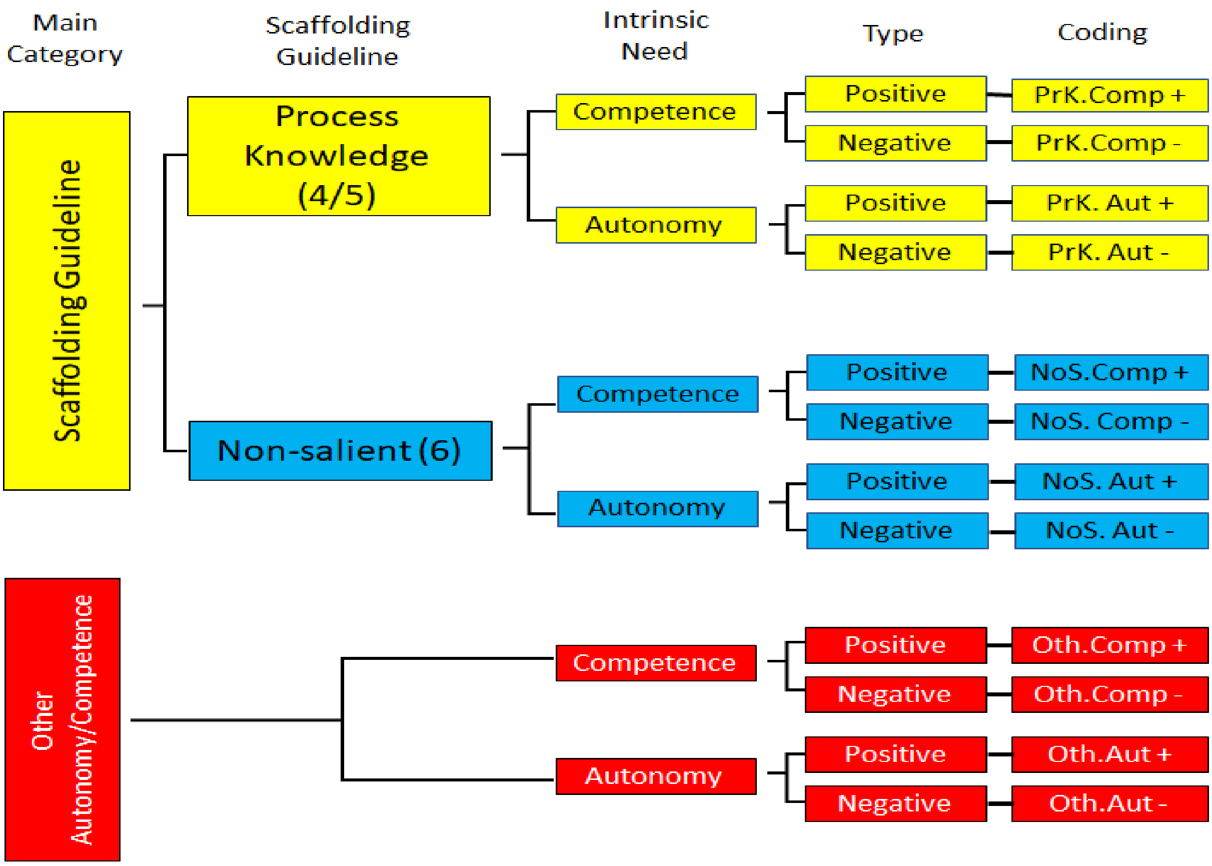


Figure D1: Coding-scheme for competence, autonomy, and the scaffolding guidelines Process Knowledge and Nonsalient Tasks. The 'positive' type stands for a supporting remark, whereas 'negative' type stands for a thwarting remark. This coding scheme was used for the coding of the focus-group transcriptions, after the first and second design cycle.

Appendix E

Chart with over and under competence of student remarks, after first design cycle.

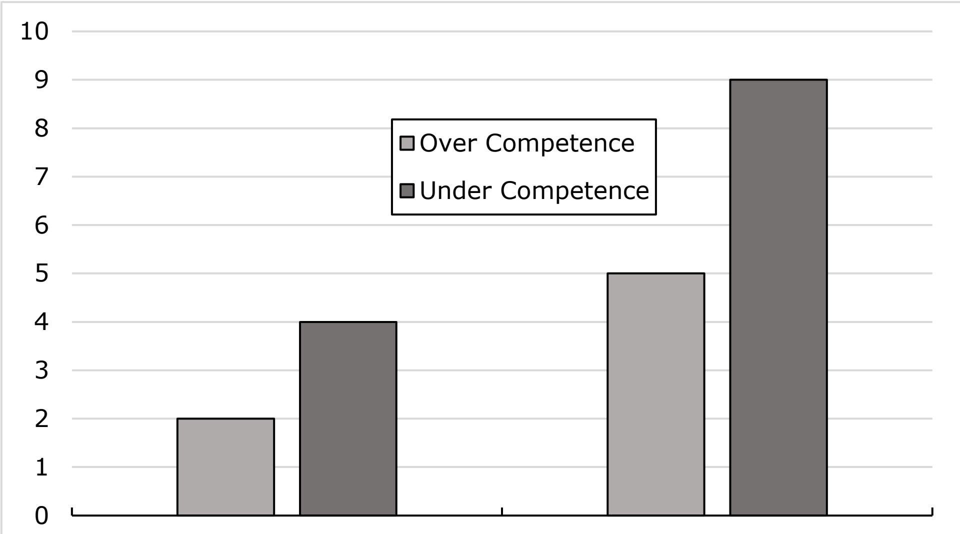


Figure E1. Frequency of competence thwarting remarks of students, after first design cycle iteration. Remarks coded for Process Knowledge and Nonsalient Tasks, based on guidelines of Quintana *et al.* (2004), as well as type of competence thwarting (Under Competence or Over Competence).

Appendix F

New design of ISP sheets

Figures F1, F2 and F3 illustrate the new designs of the sheets, after the first design cycle.

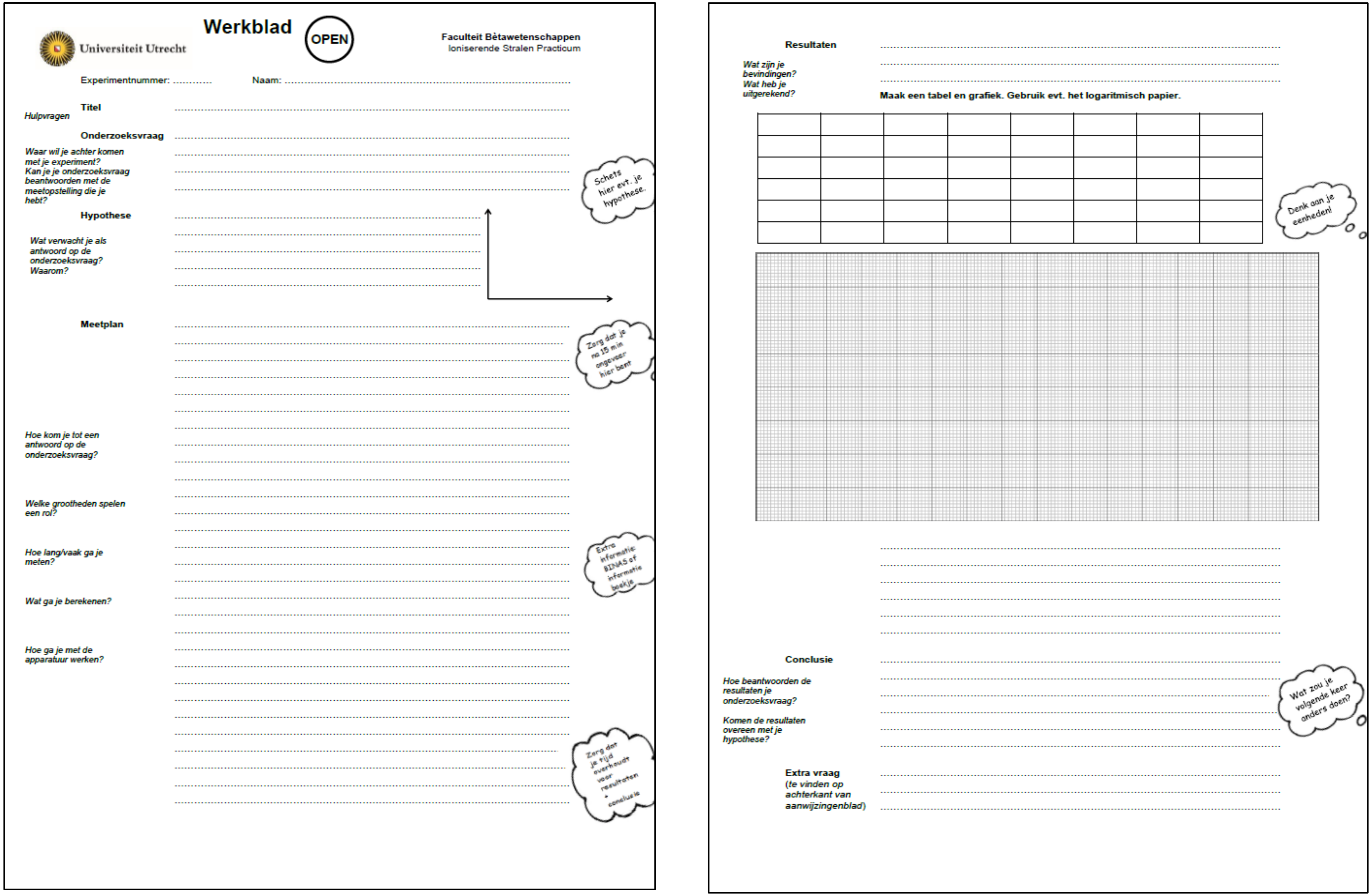


Figure F1. Newly designed worksheet after first design cycle. Changes include labelling the worksheet as worksheet (‘Werkblad’ in Dutch), guiding questions on the left side of each page, tips/suggestions on the right of each page, and the suggestion to fill in the table and graph in the results section (‘Resultaten in Dutch).

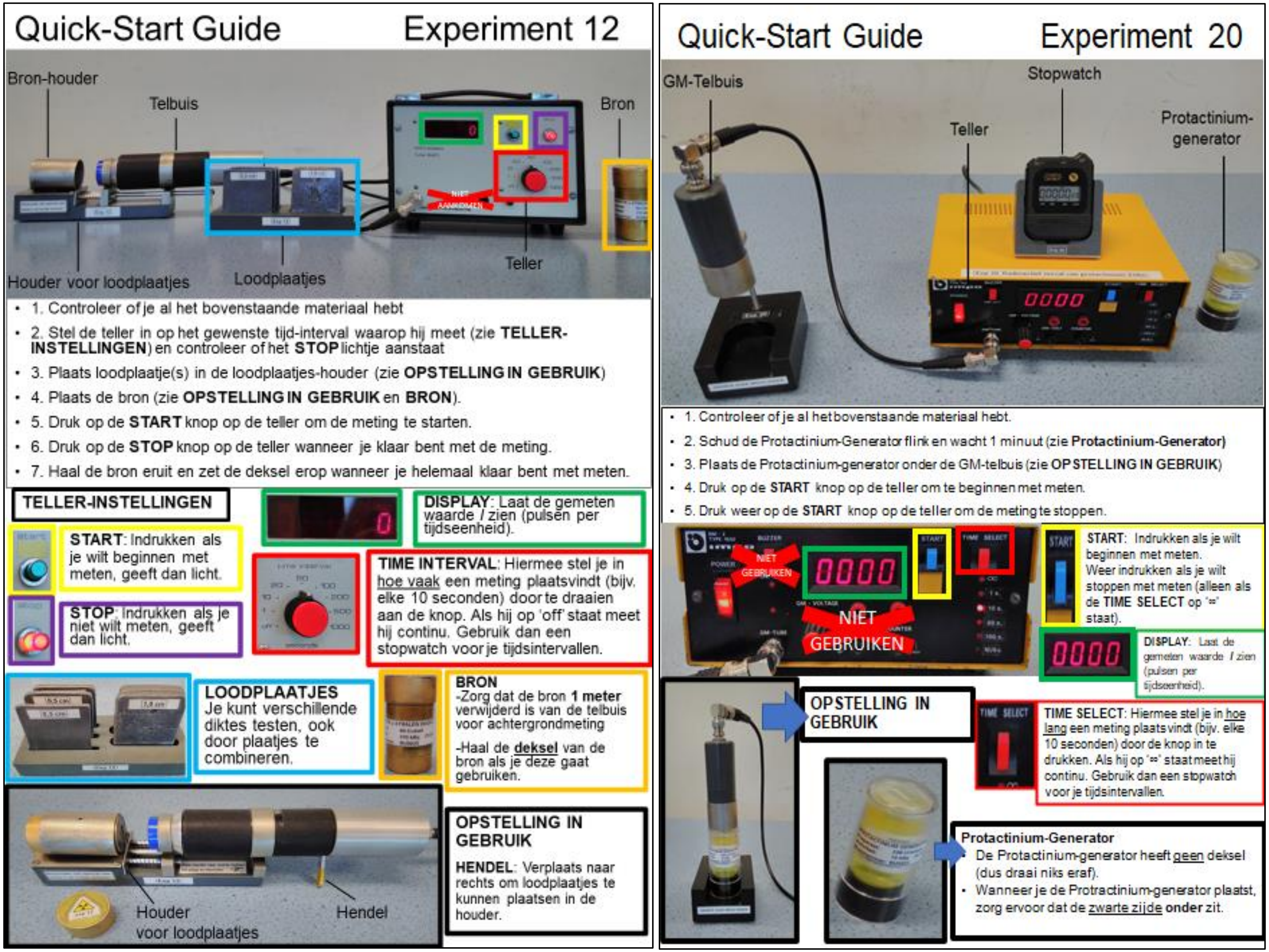
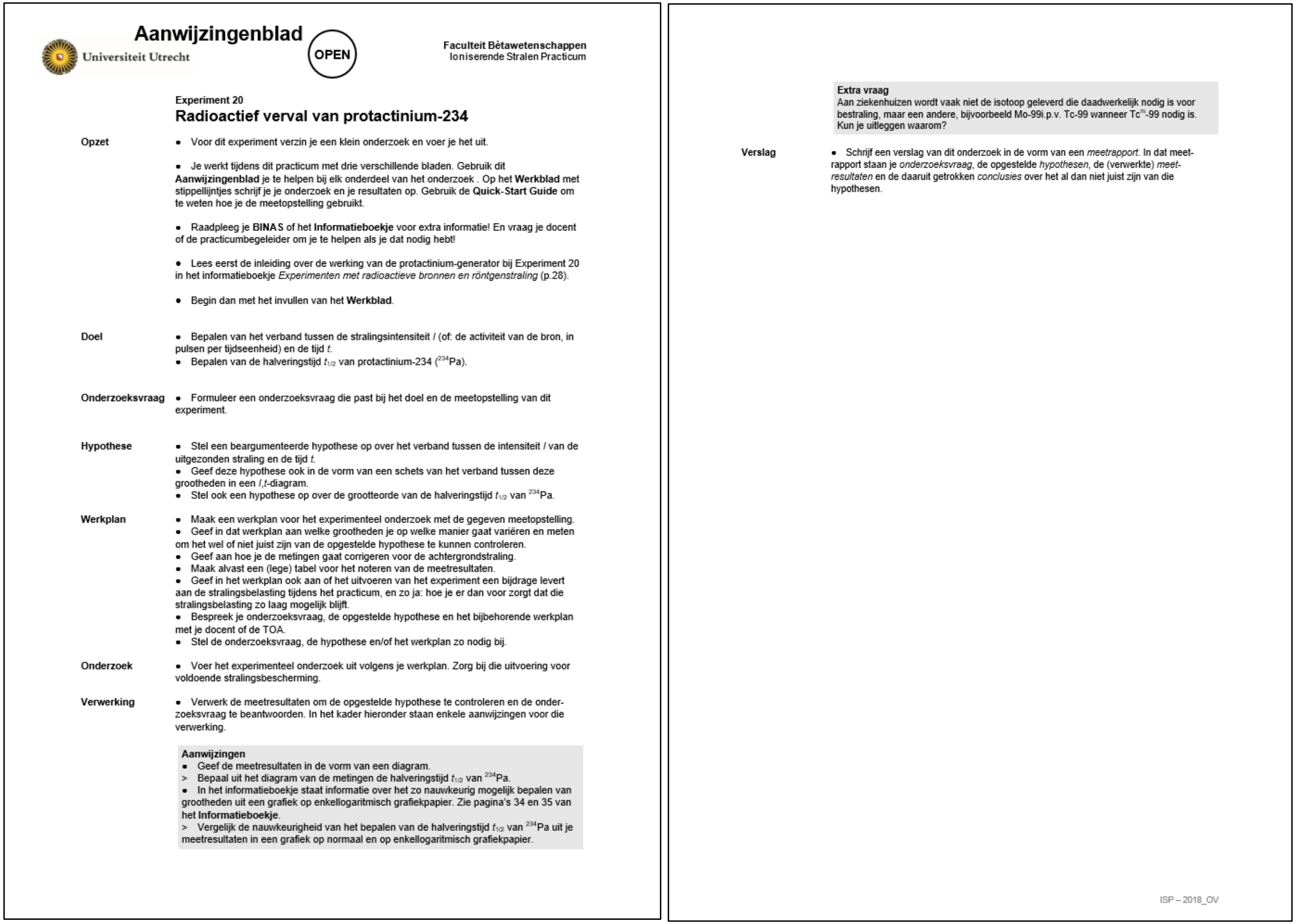


Figure F2. Quick-start guide for experiments 12 (left) and 20 (right), design after the first design cycle. The Quick-start guides have replaced the text and diagram explanation previously used in the 'suggestion sheet' of the respective experiments (see Figure G3).



Aanwijzingenblad

Universiteit Utrecht

OPEN

Faculteit Bètawetenschappen
Ioniserende Stralen Practicum

Experiment 20

Radioactief verval van protactinium-234

Opzet

- Voor dit experiment verzin je een klein onderzoek en voer je het uit.
- Je werkt tijdens dit practicum met drie verschillende bladen. Gebruik dit **Aanwijzingenblad** je te helpen bij elk onderdeel van het onderzoek . Op het **Werkblad** met stippellijntjes schrijf je je onderzoek en je resultaten op. Gebruik de **Quick-Start Guide** om te weten hoe je de meetopstelling gebruikt.
- Raadpleeg je **BINAS** of het **Informatieboekje** voor extra informatie! En vraag je docent of de practicumbegeleider om je te helpen als je dat nodig hebt!
- Lees eerst de inleiding over de werking van de protactinium-generator bij Experiment 20 in het informatieboekje *Experimenten met radioactieve bronnen en röntgenstraling* (p.28).
- Begin dan met het invullen van het **Werkblad**.

Doel

- Bepalen van het verband tussen de stralingsintensiteit I (of: de activiteit van de bron, in pulsen per tijdseenheid) en de tijd t.
- Bepalen van de halveringstijd $t_{1/2}$ van protactinium-234 (^{234}Pa).

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 intensiteit I van de uitgezonden straling 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 grootteorde van de halveringstijd $t_{1/2}$ van ^{234}Pa.

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 hypothese te kunnen controleren.
- Geef aan hoe je de metingen gaat corrigeren voor de achtergrondstraling.
- 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 hypothese en het bijbehorende werkplan met je docent of de TOA.
- Stel de onderzoeksvraag, de hypothese 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 ^{234}Pa.

- In het informatieboekje staat informatie over het zo nauwkeurig mogelijk bepalen van grootheden uit een grafiek op enkellogaritmisch grafiekpapier. Zie pagina's 34 en 35 van het **Informatieboekje**.

> Vergelijk de nauwkeurigheid van het bepalen van de halveringstijd $t_{1/2}$ van ^{234}Pa uit je meetresultaten in een grafiek op normaal en op enkellogaritmisch grafiekpapier.

Extra vraag
Aan ziekenhuizen wordt vaak niet de isotoop geleverd die daadwerkelijk nodig is voor bestraling, maar een andere, bijvoorbeeld Mo-99i.p.v. Tc-99 wanneer Tc^{m}-99 nodig is. Kun je uitleggen waarom?

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.

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Figure F3. Newly designed suggestion sheet of experiment 20. Changes include the omission of the textual and diagram explanation of the equipment (replaced by Quick-start guide; Figure G2), the suggestion to look up information from two different sources: BINAS (Verkerk *et al.*, 2004) and the information booklet they are provided with, a more elaborate overview section ('Opzet' in Dutch) with reference to the different sheets, and a label for this sheet as being the suggestion sheet ('Aanwijzingenblad' in Dutch).