Chapter 1

General introduction
CHAPTER 1

Introduction

In our society, data and statistics have become pervasive (Gravemeijer, Stephan, Julie, Lin, & Ohtani, 2017). These data can be used for inferential reasoning (i.e., the process of drawing a conclusion based on evidence or reasoning). However, for drawing adequate conclusions, it is fundamental that the evidence is credible and the inferential reasoning process sound (Dewey, 1910/1997). In daily life, this might not be the case; for example, a newspaper reports that “commuters sick of crowded, dirty train” (Pel, 2016). The newspaper thus makes a suggestion about Dutch commuters in general, while the sample contains only people who filed a complaint about train hygiene. In some instances, the role of empirical evidence in drawing conclusions seems to be left out altogether (Viner, 2016). In 2016, the Oxford English Dictionaries Word of the Year was “post-truth,” where “objective facts are less influential in shaping public opinion than appeals to emotion and personal belief” (Word of the Year 2016, 2016). In the Netherlands, for example, encountered crime decreases at a slower rate than recorded (Statistics Netherlands, 2018). Thus, in a time where the importance of data and inferential reasoning increases, citizens need to be able to assess the validity of inferences. Also, in the workplace, the importance of inferential reasoning is likely to increase because such reasoning is a skill not easily substituted by automated technologies (Liu & Grusky, 2013).

One of the primary purposes of education is to help children become qualified members of society, both today and in the future (Biesta, 2009). Since inferential reasoning is an important skill in this society, primary education could introduce children to inferential reasoning. To this end, teachers could introduce primary school students to informal statistical inference (ISI) (Groth & Meletiou-Mavrotheris, 2018). ISI can be defined as “a generalized conclusion expressed with uncertainty and evidenced by, yet extending beyond, available data” (Ben-Zvi, Bakker, & Makar, 2015, p. 293).

If primary school teachers are to introduce their students to ISI, they need to have appropriate content knowledge of ISI (ISI-CK) themselves. However, research suggests that many primary school teachers lack the content knowledge to teach ISI (Batanero & Díaz, 2010; Groth & Meletiou-Mavrotheris, 2018). Moreover, the literature provides few successful examples of how the
ISI-CK of pre-service primary school teachers\(^1\) can be fostered (Groth & Meletiou-Mavrotheris, 2018; Leavy, 2010). In particular, no research has been reported about contexts where limited time was available for interventions to foster pre-service teachers’ ISI-CK. This restriction in intervention length is relevant for our setting of Dutch teacher college education, where it is typical that little time is reserved for statistics. Therefore, the aims of this thesis are to extend the evidence about what ISI-CK pre-service primary school teachers actually have and to investigate how interventions of limited length can foster the ISI-CK of pre-service primary school teachers. The overall research question of this thesis is: What is the ISI-CK of pre-service primary school teachers, how does their ISI-CK develop during an intervention of limited length, and what ISI-CK do they show during teaching ISI in primary school?

**Informal Statistical Inference**

ISI could be a suitable form for introducing primary school students to inferential reasoning because the statistical reasoning involved in ISI tends to be of lower complexity than in formal statistical inference. This difference in complexity varies in a number of applications (Makar & Rubin, 2018). For instance, while formal statistical inference might use quantitative expressions of uncertainty, such as p-values, ISI permits qualitative expressions of uncertainty, such as “I am quite sure.” Second, inference in ISI can be based on (hands-on) simulations rather than closed-form formulas based on probability theory (J. D. Mills, 2002). For example, an ISI activity could have students first draw samples individually and then have them compare their results, thus simulating a sampling distribution. Third, ISI allows for a diversity of images of distributions, such as dot plots that highlight individual samples in sampling distributions (Makar & Rubin, 2018).

The following is an example of how, in ISI, multiple statistical concepts are used as statistical arguments to support the inference (Makar & Rubin, 2009; Watson, 2001): Confronted with a particular sample and its distribution,

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\(^{1}\) This dissertation concerns pre-service primary school teachers, which we often abbreviate as “pre-service teachers.”
someone notes the high level of variance in the sample and argues that the sample is too small and possibly biased and, therefore, expresses the inference with a high degree of uncertainty. In this example, the statistical concepts of sample size, bias, sampling methods, and variance are arguments in the inference.

For our studies among pre-service teachers, we used the ISI framework of Makar and Rubin (2009), which covers the key themes of ISI identified in the literature (Makar & Rubin, 2018; Rossman, 2008; Zieffler, Garfield, delMas, & Reading, 2008). We conceptualized the three components of this framework as follows:

1. Data as evidence, subdivided into two subcomponents:
   a. Using data: The inference is based on available data and not on tradition, personal beliefs, or personal experience.
   b. Describing data: Before the data can be used as evidence within ISI, one first needs to descriptively analyze the sample data by, for instance, calculating a mean (Zieffler et al., 2008). The resulting descriptive statistic then functions as an evidence-based argument within ISI (Ben-Zvi, 2006).

2. Generalization beyond the data: The inference goes beyond a description of the sample data by making a probabilistic claim about a population, an individual not included in the sample, or a mechanism that produced the sample data.

3. Probabilistic language: Due to sampling variability and the degree of sample representativeness, the inference is inherently uncertain and requires using probabilistic language. For the correct usage of probabilistic language, the origins of uncertainty in inferences must be understood. Therefore, we divided this component into four subcomponents:
   a. Sampling variability: The inference is based on an understanding of sampling variability; it is expressed from an understanding that the outcomes of representative samples are similar and that, therefore, under certain circumstances, a sample can be used for an inference.

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2 In this dissertation, “to make inferences” and “to make generalizations (beyond the data)” are used interchangeably.
b. Sampling method: The inference includes a discussion of the sampling method and the implications for sample representativeness.

c. Sample size: The inference includes a discussion of the sample size and the implications for sample representativeness.

d. Uncertainty: The inference is expressed with uncertainty and includes a discussion of what the sample characteristics, such as the sampling method employed and the sample size, imply for the certainty of the inference.

We used this framework in several ways. First, the framework was used to analyze and describe the pre-service teachers’ ISI-CK. For example, Chapters 2 and 3 show that many pre-service teachers appear to be able to use common descriptive statistics (subcomponent “describing data”), such as the mean, while at the same time, many tend to only describe the data without engaging in making generalizations beyond the data (component “generalization”). This finding led us to design tasks that put less emphasis on the subcomponent “describing data” and more emphasis on the component “generalization” in Chapters 4 and 5. The “describing data” subcomponent, therefore, no longer features in the ISI framework of the later chapters. Second, the framework was used to operationalize the learning objectives for pre-service teachers (Chapters 3 and 4). The attainment of these learning objectives was expected to give them sufficient ISI-CK to teach ISI in the upper grades of primary school. Third, the framework’s components helped us to formulate conceptual mechanisms that explain how the activities used in the intervention may scaffold the participants’ reasoning toward the attainment of the learning objectives (Simon, 1995). For example, the first activity of the teacher college intervention in Chapter 4 had the pre-service teachers search the media for a news item that made a claim about a population based on a sample in order to create awareness when inferential reasoning is used (component “generalization”).
ISI in Primary Education

In most countries, as in the Netherlands, ISI is not part of the (mathematics) curricula of primary schools (Makar & Rubin, 2018). It is hypothesized, however, that an introduction to ISI in the upper grades of primary school has several potential benefits (Makar, 2016; Makar, Bakker, & Ben-Zvi, 2011). A first benefit might be that, because it has been shown that understanding the statistical concepts underpinning statistical inference is challenging (Shaughnessy, Garfield, & Greer, 1996), an early introduction of ISI allows students to be repeatedly exposed to the statistical concepts involved in ISI over an extended period of time (Watson & Moritz, 2000). Second, it is conjectured that ISI can facilitate the transition to formal statistical inference, as students will gradually understand the processes involved in inferential reasoning (Zieffler et al., 2008). Third, ISI can offer a unified framework for learning multiple statistical concepts because ISI involves a reasoning process in which multiple statistical concepts are used as reasoning tools, as the example of ISI in the section on ISI shows. So it is conjectured that, by being engaged in ISI, students learn statistics in an integrated way (Bakker & Derry, 2011).

The potential benefits of introducing ISI in primary school can only be reaped if ISI is in the zone of proximal development of primary school students; that is, if primary school students can be successfully engaged in meaningful ISI activities while being supported by a more knowledgeable other, which, in a school setting, is often the teacher (Vygotsky, 1978). Successful engagement of students in ISI requires them to have some intuitive notions of chance, as one to needs to have a sense that sampling results usually vary from sample to sample (Chance, delMas, & Garfield, 2004; Saldanha & Thompson, 2002). Piaget and Inhelder (1975/1951) showed that, around seven years old, primary school students start to show intuitive notions about uncertainty. Recent evidence suggests that even babies as young as eight months “are sensitive to statistical patterns” (Gopnik, 2012, p. 1625). Babies tend to watch for a longer period of time when a sample of mostly white balls are drawn from a box of mostly red balls than when the sample is composed of mostly red balls. The researchers thus suggest that babies possess intuition about the likelihood of events.
Also, recent research evidence in the field of statistics education suggests an early introduction of ISI is possible (Ben-Zvi, 2006; Ben-Zvi et al., 2015; Makar, 2016; Meletiou-Mavrotheris & Paparistodemou, 2015; Paparistodemou & Meletiou-Mavrotheris, 2008). Leavy (2017) showed that kindergarten children demonstrated some initial ability to make inferences based on given data. Although far from being perfect, some inferences based on the data (component “data as evidence”) were expressed tentatively, using expressions such as “I think,” “maybe,” and “probably” (component “probabilistic language”). While it may be that primary school students cannot be expected to develop mature understandings of inferential reasoning, their emergent and incomplete understandings can provide a valuable foundation for later education (cf. the spiral curriculum Bruner, 1960; Makar et al., 2011). Chapter 4 provides an example of a meaningful introductory ISI activity that served as an example for pre-service teachers how ISI could be introduced to primary school students. These were hands-on activities that required little descriptive analyses (Arnold, Pfannkuch, Wild, Regan, & Budgett, 2011) and involved a tangible population and sample.

**ISI and Pre-Service Primary School Teachers**

**Pre-service teachers’ knowledge of ISI**

If primary school students are to be introduced to ISI, their future teachers must be well prepared to conduct this introduction (Batanero & Díaz, 2010) and, therefore, need to possess a thorough knowledge of ISI (Groth & Meletiou-Mavrotheris, 2018). Teachers’ content knowledge impacts their students’ learning achievements (Fennema & Franke, 1992; Rivkin, Hanushek, & Kain, 2005) and may facilitate the development of the teachers’ pedagogical content knowledge, which is, in this case, the knowledge of how to teach ISI (Burgess, 2009; Groth, 2013; Leavy, 2010; Shulman, 1986). This content knowledge must extend beyond what their pupils will learn. Teachers need to have knowledge about the place of the particular content in the curriculum (horizon content knowledge) and specific knowledge that is relevant for teaching the content (specialized content knowledge) (Ball, Thames, & Phelps, 2008). Given the importance of teachers’ ISI-CK for primary school students’
learning, our studies aimed to contribute to the scientific evidence about how to foster pre-service teachers’ ISI-CK.

For teachers, the foremost reason for learning ISI-CK is to use this knowledge in their teaching. It is, therefore, important to investigate how teachers’ ISI-CK “plays out” in teaching (Rowland, Turner, Thwaites, & Hurst, 2009), as “teacher knowledge can only be understood in the context in which they work” (Petrou & Goulding, 2011, p. 20). So, while Chapters 2 and 4 describe ISI-CK using an online questionnaire, and Chapters 3 and 4 investigate pre-service teachers’ ISI-CK when engaged in ISI activities in teacher college sessions, the focus of Chapter 5 is on the ISI-CK of three pre-service teachers “in action” while teaching an ISI lesson.

A review of the literature suggests that few studies have reported on pre-service teachers’ ISI-CK (Ben-Zvi et al., 2015). For example, the knowledge of pre-service teachers in the (sub-)components “using data” and “generalization beyond the data” have hitherto not been investigated. This implies that there is also no overview available that integrates pre-service teachers’ knowledge of all ISI components. Therefore, our first study, reported in Chapter 2, aimed to comprehensively describe pre-service teachers’ ISI-CK by surveying 722 first-year pre-service teachers from seven teacher colleges across the Netherlands.

The limited available evidence about pre-service primary school teachers’ ISI-CK suggests that many pre-service teachers have difficulty making inferences and lack an understanding of representativeness and sampling variability (Groth & Meletiou-Mavrotheris, 2018). The evidence on the “probabilistic language” component suggests that many pre-service teachers show a limited understanding of sampling methods, sample size, representativeness, and sources of bias in the case of self-selection (Groth & Bergner, 2005; Meletiou-Mavrotheris, Kleanthous, & Paparistodemou, 2014; Watson, 2001). Concerning the “sampling variability” subcomponent, Mooney, Duni, VanMeenen, and Langrall (2014) report that a substantial proportion of the teachers they examined understood that sample distributions are likely to be different from the population distribution. However, an understanding of the implications of variability for the actual sample proved to be more difficult. Watson and Callingham (2013) found that only half of the teachers they interviewed could conceptualize that a smaller sample has greater variability.
No studies have so far been conducted on how pre-service teachers use descriptive statistics in the context of ISI. However, the literature on pre-service teachers’ understanding of descriptive statistics in general has shown this understanding to be generally superficial (Batanero & Díaz, 2010; Chatzivasileiou, Michalis, Tsaliki, & Sakellariou, 2011; Garfield & Ben-Zvi, 2007; Jacobbe & Carvalho, 2011; Koleza & Kontogianni, 2016). More specifically, only a minority of teachers attend to both center and spread when comparing data sets (Canada & Ciancetta, 2007), while understanding of the mean, median, and mode is mostly procedural (Groth & Bergner, 2006; Jacobbe & Carvalho, 2011). In sum, this research suggests there is a need to develop at least some components of pre-service primary school teachers’ ISI-CK.

Interventions to foster pre-service teachers’ ISI-CK
In order to investigate how to foster pre-service teachers’ ISI-CK, we aimed to design an intervention that would be useful in mathematics education curricula of Dutch teacher colleges. In these curricula, there is usually little time reserved for statistics, and attention to ISI is likely to be absent altogether (Van Zanten, Barth, Faarts, Van Gool, & Keijzer, 2009). We, therefore, did not expect that teacher colleges would consider implementing lengthy ISI courses in their mathematics education courses. To obtain ecological valid results, we designed relatively short interventions (Chapter 3: one session; Chapter 4: five sessions) that could be implemented in the current mathematics education curriculum.

To date, the literature has not provided other examples of such short interventions, and very few studies have investigated how to foster pre-service primary school teachers’ ISI-CK (Ben-Zvi et al., 2015; Groth & Meletiou-Mavrotheris, 2018). The only study to date, Leavy (2010), showed a tendency among pre-service teachers to focus on data collection and analysis at the expense of inferential reasoning. This tendency is ascribed to the pre-service teachers’ inexperience with conducting statistical investigations themselves. Furthermore, pre-service teachers have severe problems designing lessons that provide opportunities to discuss ISI with students (Leavy, 2010; Makar & Rubin, 2009).

In designing the interventions reported in Chapter 4, we incorporated these findings by using activities that elicit awareness of inferences and by
providing pre-service teachers with a pre-designed lesson plan rather than having them design their own.

**Theoretical Framework**

As the above discussion revealed, there are no examples of interventional studies that show how to foster the ISI-CK of pre-service teachers within a limited time frame. Therefore, the second aim of this thesis is to design such interventions and study the development of pre-service teachers’ ISI-CK. This section sets out which theories on learning and teaching were used in designing the interventions.

The activities used in our studies are predominantly based on inquiry-based teaching, where the learning involved is defined as guided co-construction of knowledge (Dobber, Zwart, Tanis, & van Oers, 2017). For students in general, inquiry-based learning environments have been shown to be effective in developing their ISI knowledge (Makar et al., 2011). In such learning environments, a driving question is typically posed to motivate students to engage in inquiries (Garfield & Ben-Zvi, 2008; Groth, Bergner, Burgess, Austin, & Holdai, 2016). In the case of ISI, such a question would elicit the need to conduct statistical investigations as a means of finding an answer to the driving question (Garfield & Ben-Zvi, 2008; Groth et al., 2016). It is expected that such environments help to construct knowledge of key statistical topics (Ben-Zvi, Gravemeijer, & Ainley, 2018; Cobb & McClain, 2004). Chapters 3 through 5 report on pre-service teachers or primary school students being engaged in statistical investigations.

Inquiry-based teaching is well aligned with the Dutch mathematics primary school curricula given that these curricula are typically based on realistic mathematics education (RME), which originates from the work of Hans Freudenthal (1973). For example, guided reinvention, which is one of the central tenets of RME, resembles the idea of guided co-construction of knowledge: Students reinvent mathematical and statistical tools for solving problems under the guidance of the teacher and the materials (Freudenthal, 1991). An educational designer could incorporate activities that use students’ informal solution strategies as starting points for the reinvention process. In
this thesis, the principle of guided reinvention underlies the growing samples activity (Bakker, 2004) employed in Chapter 3 as well as the activities in Chapter 4.

For effective inquiry-based learning, appropriate teacher guidance is essential (Dobber et al., 2017). In particular, the teacher plays an important role in providing scaffolds, in being a role model for conducting inquiries, and in establishing the cultural norms of statistical inquiry (Makar et al., 2011). An important task of the teacher is, thus, to enculturate students into such practices. Although stemming from a different theory on learning, direct explanations can be useful for teachers to employ in inquiry-based teaching when such explanations build on pre-existing knowledge and are provided when students are aware of what they do not know (Hmelo-Silver, Duncan, & Chinn, 2007). The demonstration of a simulated sampling distribution in Chapter 4 provides an example of such a “just-in-time” explanation.

Inquiry-based learning can be linked to sociocultural learning theories such as situated cognition theory, which posits that knowledge is contingent upon how and where it was learned (Putnam & Borko, 2000). From this theory, we highlight three issues that are relevant for our research. First, we assume that learning activities, or practices, need to be authentic and make sense to the students. We follow the view of Brown, Collins, and Duguid (1989) of authentic practices in the sense that these are practices that professionals would be engaged in as well. From the perspective of ISI, this implies that students conduct statistical investigation themselves (Garfield & Ben-Zvi, 2008) and work with real, or realistic, datasets (Cobb & McClain, 2004) to experience real statistical research (see Chapters 3 and 4). From the perspective of teacher education, teaching internships in placement schools are used to offer authentic practices (Putnam & Borko, 2000). In our research, we had the participating pre-service teachers teach an ISI lesson based on meaningful problems (Chapter 5).

Second, we acknowledge the situated nature of knowledge. Therefore, we assume that what pre-service teachers can do and how they think depends on the context (Ball, 1997). As mentioned in Section 3.1, we, therefore, do not look only at the knowledge in contexts outside the practice of teaching (during tests and during teacher college sessions, in Chapters 2, 3, and 4) but in Chapter 5,
we also investigate how their ISI-CK is displayed in their teaching (Rowland et al., 2009) – which is the ultimate goal of learning ISI.

A third and related point is that successful use of knowledge in new situations is facilitated by a high degree of similarity with the context where the knowledge was learned (Carter & Doyle, 1989; Putnam & Borko, 2000). So, to facilitate the use of the pre-service teachers’ ISI-CK in primary classrooms, we aimed for close links between the teacher college activities and the teaching practice in primary school by, for example, modeling a lesson that the pre-service teachers could teach themselves in their placement schools (Chapter 4) and by integrating content knowledge and pedagogical content knowledge (Groth, 2017).

Finally, our research was also informed by cognitive learning theories such as conceptual change theory. We follow Cobb (1994), who argued that enculturation of practices presupposes an actively constructing student and that different constructions can result for different students. We assume that learners have to actively construct their knowledge (Ben-Zvi et al., 2018; Freudenthal, 1973; Mickelson & Heaton, 2004). Therefore, all interventions are primarily activity based.

**Methodological Approach**

The following methodological tenets guided the design and legitimatization of the research and the interventions.

**Agency**

The concept of agency was important in designing the research, in particular in terms of the content of Chapters 4 and 5. Agency can be defined as “the actual ways situated persons willfully master their own life” (van Oers, 2015, p. 19). For our research, agency implies that the pre-service teachers are motivated to participate in the intervention and experience a sense of ownership about their own learning and use of ISI and the task of teaching an ISI lesson. Pre-service teachers who express such agency could, for example, prepare the ISI lesson in such a way that they tailor the lesson to their students’ needs while simultaneously ensuring the underlying ideas of ISI are maintained. Such an
attitude is opposed to pre-service teachers who teach as executors of a course of actions prescribed in a lesson plan.

A first reason why agency is important in our research is that the pre-service teachers’ motivation to participate in the intervention was necessary for a proper functioning of the intervention’s activities and, thus, for obtaining good research data. A second and more important reason is that, in their role as teachers, they need to be able to show their primary school students the relevance of ISI and motivate them to engage in ISI. This task can only be done successfully if the teachers are motivated to engage in ISI themselves.

Dutch pre-service primary school teachers are likely to be unfamiliar with ISI and inquiry-based teaching, which may have affected their development of agency. Historically, Dutch primary mathematics curricula spent little time on statistics, and to date, ISI is not part of Dutch primary education curricula (Van Zanten et al., 2009). Moreover, an inquiry-based teaching approach appears to be at odds with mainstream teaching practices in Dutch primary schools.

Although Dutch mathematics curricula are mostly based on RME (Freudenthal, 1973), Gravemeijer, Bruin-Muurling, Kraemer, and van Stiphout (2016) speculate that actual teaching practices are characterized by “the tendency to link learning to the ability of students to successfully carry out well-defined tasks and by ‘getting right answers’” (p. 36). Most pre-service teachers will have encountered this procedure-oriented mathematics in their placement schools. These schools have been argued to be “powerful discourse communities” in which “patterns of classroom teaching and learning have historically been resistant to fundamental change” (Putnam & Borko, 2000, pp. 8-9). As a result, we expected that the historical context of procedure-oriented mathematics teaching and the institutional context of placement schools could lead to doubts about the relevance of ISI and lead to teacher reluctance to adopt the openness and uncertainty of an inquiry-based teaching approach (Engeström, 2011; Penuel, 2014; Putnam & Borko, 2000).

Another factor that could lead to reluctance to participate in the intervention might be that when pre-service teachers were themselves primary school students, they may have been taught with a similar procedure-oriented approach. Since their experience as learners influences their perceptions of what good teaching entails (Lortie, 1975), they may be reluctant to accept an inquiry-based teaching approach.
The possible resistance of pre-service teachers to ISI and inquiry-based teaching made it essential to search for ways to foster the participants’ agency. We first approached this possibility with the initial activity used in the teacher college intervention (Chapter 4), which had the participants search the media for reports where claims were made based on a sample. It was hypothesized that this activity would help them see the relevance of ISI. Second, we stressed their position as key actors in translating what was offered at teacher college to their own classrooms. Third, we emphasized their role as research informants, whose information was necessary for our research purposes. For example, we stressed that the purpose of teaching an ISI lesson was not that their students would learn ISI, but rather that we could investigate the possibilities of having inexperienced teachers teach ISI. We hypothesized that this role of test case would alleviate possible feelings of anxiety. In Chapter 6, I will discuss to what extent we were successful in fostering the pre-service teachers’ agency.

Practice-oriented research

As mentioned above, we aimed to design interventions that could be incorporated with relative ease into the mathematics education curricula of primary education teacher colleges. As such, the interventional studies discussed in Chapters 3 through 5 are examples of practice-oriented research (A. J. Mills, Durepos, & Wiebe, 2009). The first approach to increase the usability of the interventions was by embedding relatively short interventions in existing teacher education courses. This stands in contrast with other interventional studies in the domain of statistics education for teachers, which often involved semester- or summer-long interventions (e.g. Groth, 2017; Leavy, 2010). Second, the intervention was implemented in existing classes of pre-service teachers enrolled in a regular curriculum for primary education rather than in classes with teachers specializing in mathematics or statistics education or among high-ability pre-service teachers. Third, the activities were designed in such a way that teacher educators, as well as teachers, could apply the activities with relative ease in their own classrooms. The activities require little organization and mostly involve hands-on activities (Pratt & Kazak, 2018) in lieu of using educational statistics software such as Tinkerplots (Konold & Miller, 2011). The use of such software requires a considerable time and financial investment, which could make teacher educators and teachers
reluctant to use the activities in their own education. These methodological choices were expected to foster the ecological validity and transferability of the results (Lewis & Ritchie, 2003).

**Qualitative and mixed-methods research**

Given that there is limited previous research related to our research aims, the study in this thesis is predominantly explorative. Qualitative and mixed-methods research designs are particularly well suited (Ritchie, 2003) for exploratory research. Both types of designs are also commonly used in statistics education research (Petocz, Reid, & Gal, 2018).

The studies reported in Chapters 2 and 4 used mixed-methods designs. The questionnaire study in Chapter 2 used open questions that allowed the respondents to give their own answers without steering them in a particular direction, while the subsequent statements to be evaluated allowed for probing for information that was not provided through the initial questioning. These different perspectives thus yield complementary information with the effect of describing a more complete picture of pre-service teachers’ ISI-CK (Schoonenboom & Johnson, 2017). Chapter 4 covers a study using an abbreviated and slightly adapted version of the questionnaire from Chapter 2 as a pretest and posttest. The results from these sources were primarily used for providing quantitative overviews of the development of the participants’ ISI-CK. Qualitative data from the open-ended questions and from classroom observations helped us gain deeper knowledge of pre-service teachers’ reasoning and argumentation about ISI. The latter data also helped us gain insight into which, and in what way, activities were useful for fostering the pre-service teachers’ ISI-CK (Garfield & Ben-Zvi, 2008).

**First-person perspective**

In the two interventional studies (Chapters 3 and 4), I combined the roles of designer, researcher, and teacher educator. This combination of roles was expected to have several benefits. First, as a researcher, I was well acquainted with the ISI literature, and as a teacher educator, I was familiar with the particular teacher education context. This combination helped me design ISI activities that were framed by the results in the literature but that were also tailored to the specific context. Second, because ISI is not part of Dutch teacher
college curricula, Dutch teacher educators are usually not familiar with ISI and would have to be instructed about it. This might lead to a loss of instructional quality. Moreover, it would make the study unnecessarily complex by introducing a third layer of interaction between researcher and teacher educator, on top of the interactions between teacher educator and pre-service teachers, and between pre-service teachers and primary school students. Third, being also a teacher educator helped me to experience from the inside the workings and effectiveness of the activities (Ball, 2000). Furthermore, I knew the pre-service teachers I was working with well because I was their regular mathematics teacher educator. This helped me to interpret their discussions and mannerisms, and it allowed me to use our shared history and experiences in teaching ISI.

However, this combination of roles could threaten the reliability of the observations and the validity of the conclusions. Therefore, in Chapter 6, I will discuss in what ways I tried to separate the roles and to what extent the threats to the reliability and validity were counteracted.

**Outline of this Thesis**

The overall research question was, What ISI-CK do pre-service primary school teachers have and how does their ISI-CK develop during interventions of limited length? To answer this question, four studies were conducted:

**Chapter 2** reports on a study that surveyed 722 first-year pre-service primary school teachers from seven teacher colleges across The Netherlands in order to describe the ISI-CK of first-year pre-service teachers. The results informed the design of the interventions to foster pre-service teachers’ ISI-CK.

Research question, Chapter 2: To what extent do first-year pre-service primary school teachers have appropriate ISI-CK?

**Chapter 3** reports on an exploratory study of pre-service teachers’ reasoning processes about ISI when they were engaged in a growing samples activity, to study how this heuristic supported pre-service teachers’ development of reasoning about ISI.
Research question, Chapter 3: What reasoning about ISI do first-year pre-service primary school teachers display when they are engaged in a growing samples activity, and what is the quality of their reasoning?

Chapter 4 reports on a case study investigating ISI-CK development in a class of 21 pre-service primary school teachers who participated in a short intervention consisting of several activities aimed at fostering their content knowledge and pedagogical content knowledge of ISI.

Research question, Chapter 4: In what respect does the ISI-CK of pre-service primary school teachers develop during a teacher college intervention, and what role do the activities used during the intervention play in this development?

Chapter 5 reports on an embedded case study of three pre-service teachers who participated in the study discussed in Chapter 4 as they demonstrated their ISI-CK by teaching an ISI lesson.

Research question, Chapter 5: What ISI-CK do three pre-service primary school teachers express while teaching an ISI lesson in primary school?

The four studies were separately published or submitted in different places. Therefore, each study necessarily had to discuss the practical relevance and the theoretical background. As a consequence, the chapters are to some extent repetitious with regard to these issues.

Expected Contribution to Research and Practice

This thesis aims to extend the body of scientific knowledge about ISI-CK of pre-service primary school teachers and demonstrate how this knowledge can be developed as a result of teacher college education. These results may inform other researchers, instructional designers, and teacher educators who wish to study ISI in the context of pre-service teacher education or to implement ISI activities in teacher training.

Although this thesis offers grounded examples of ISI education in only one Dutch teacher college, it may reveal characteristics of learning processes among
pre-service teachers that could be applicable in other contexts as well. The results may, thus, contribute to the formation of a domain-specific theory of learning and inquiry-based teaching of ISI (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006), in particular, for pre-service teachers, but also for other types of learners. The data from the different studies in this thesis resulted in a list of provisional design heuristics that could be part of such a domain-specific theory of ISI (see Chapter 6).

As some of the teacher college activities used in our research are explicitly designed to be used with relative ease in primary education, these activities may be useful for those wishing to design and study ISI learning environments for primary education. Furthermore, the results of our research may reveal how recommendations for statistics education in general (Cobb & McClain, 2004) can be applied in the context of ISI and whether adaptations to these recommendations are required when applied in ISI education. Finally, this thesis also contributes to the conceptualization of ISI for pre-service teachers and how ISI-CK can be measured (Chapter 2).
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