An exploration of how social science students utilise an opportunity to learn about simulation-based research methods: A design-based study

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Abstract

At the core of this thesis lies an exploration of how social science students utilise an opportunity to learn about Modeling and Simulation (M&S)-based research methods. The study is framed within the Cultural Historical Activity Theory (CHAT). The thesis also utilises local theories such as the community of practice theory, the theory of objectification, and the theory of semiotic representation, and these are used to analyse, interpret and discuss the data generated in the study. During the analysis, boundary-crossing, boundary objects, tension and contradictions within and between activity systems were identified. Metaknowledge underpinning Modelling and Simulation (M&S) research methodology and mathematics, process and product mathematics, and epistemological analysis of simulation-based educational tools are explicated to interpret the data generated and explore students' meanings and anchor the discussion presented in the dissertation.

The study aims to understand how social science students utilise opportunities to learn about M&S-based research methods to study social dynamics. Further, to achieve the goal, the research also explores how students utilise metaknowledge while learning about M&S-based research methods.

The study uses a design-based intervention approach to implement an M&S-based research methods curriculum module for students on social sciences programs. The design-based research processes were cyclic and iterative, with each component of the intervention affecting the others. This dissertation includes four independent papers (published or submitted for publication). The overall study resulted in the development of an M&S-based research methods module that was informed by and evolved throughout each intervention. My Paper 1 reports the outcome of intervention study I, which set out to explore the feasible and practical design of an M&S-based research methods module with the students of religion. Precisely, Paper 1 laid an empirical foundation of the study that made it possible to increase the intensity of the M&S-based research methods module in the following iteration with the students of Development Studies.

Paper 2 reports intervention study II, which investigates how Development Studies students can gain metaknowledge about M&S-based research methods: its rationale, background knowledge, and opportunities and limitations of the research

methods. Using the results of intervention studies, I and II, the next iteration, intervention study III, set out to explore how undergraduate students of religion utilise an opportunity to learn about the M&S-based research method. Paper 3 reports on formative evaluation of 'meet-the-expert' event, an element of the M&S-based methods curriculum module implemented through seminars and workshops. Moreover, Paper 4 deals with the pedagogical aspects of M&S-based tools and reveals how such tools can facilitate students' evolutionary process of mathematical and social science sense-making during their interaction with the social simulation applet.

The design-based research approach was significantly helpful in designing and implementing innovative M&S-based research methods module by creating a new learning environment to explore future possibilities in teaching, learning, and development of research methods curriculum module. The study's findings showed that students' engagement in the M&S-based research methods curriculum module was explorative, informed, and persistent. This study contributes to the literature on teaching, learning and research in curriculum development in higher education, primarily, in three ways: (i) offering empirical-based M&S-based research methods curriculum module development, (ii) providing an epistemological analysis tool to exemplify how such tools are helpful to analyse learners' engagement with software or technological tools in teaching, learning or research in higher education (iii) the study additionally reveals how students need to utilise mathematical knowledge in apparently non-mathematical contexts.

Contents

1 Introduction

This research is a part of a project titled Learning about Simulation as a Research Method (LaSiRM), an interdisciplinary project at the University of Agder between the Department of Mathematical Sciences and the Department of Humanities and Social Sciences. Within the LaSiRM project, we study students of humanities and social science and how they utilise the opportunity to learn about simulation-based research methods to study social dynamics. The LaSiRM project is an adjoining project of the MODRN (Modeling Religion in Norway) project, in which social researchers conduct a scientific study of religious, social conflict.

Research in the social sciences has traditionally been limited to methods such as literature reviews, interviews, ethnographic observations, and survey analysis. In recent years, many social scientists have begun to embrace more novel and interdisciplinary methods. One of these is computer modelling and simulation (M&S)-based research methods. M&S-based methods offer opportunities to run experiments repeatedly, making possible investigations of ethically sensitive and socially challenging areas (e.g., exclusion and migration) that are not easy to examine by using traditional research methods.

M&S-based methods provide opportunities to create virtual worlds of social phenomena, which imitate real-world processes (Gilbert & Troitzsch, 2005). Virtual worlds enable social scientists to run social experiments or to see what future scenarios could possibly occur. Consequently, social scientists can use M&S-based research methods to generate useful insights, enhance theoretical consistency, relate theories to data more effectively. Thereby, there opens the potential to deepen the understanding of the varied phenomena studied (Whitehouse, Kahn, Hochberg, & Bryson, 2012; Wildman, Fishwick, & Shults, 2017).

The PhD program is within the Department of Mathematical Sciences. However, the research is not about the teaching and/or learning of mathematics; instead, it is about utilising mathematics as a tool in learning about M&S-based research methods in studying social dynamics. The study is interdisciplinary and has connections to social aspects of mathematics. First, it deals with the mathematisation (Jablonka & Gellert, 2007) of knowledge as research in the social sciences increasingly employs mathematical techniques to create models and simulations.

Second, the study touches on the demathematisation (Jablonka & Gellert, 2007) in society (black-boxing of mathematics) as the interfaces of simulations hide the underlying variables and calculations. The term demathematisation refers to "the trivialisation and devaluing of the development of mathematics that occurs when, for instance, the software is used to carry out a calculation or mathematical procedure" (Vecchia, Maltempi, & Borba, 2015, p. 56).

1.1 Aims of the study

Social dynamics are behavioural processes carried out by human beings. These human interaction processes include both experimental and behavioural aspects, which are accessible by examining linguistics and humanistic symbols (Mennell, 1990). Some examples of social dynamics are birthdays, marriages, voting patterns, domestic violence, drug use, job migrations, religious violence, and so forth. It is also possible to observe some newly emerging social dynamics as modern society continues to develop—for instance, social media use in cyber-socialising and criminality.

The study has two aims, (i) to study how students utilise the opportunity to learn about M&S-based research methods to understand social dynamics (ii) to study how students utilise metaknowledge (including mathematical knowledge) while learning about M&S-based research methods. By learning about M&S-based research methods, students have the opportunity to develop an understanding of assumptions, simplifications, and comprehension of how the simulated social phenomena assist researchers in their investigation of social dynamics.

In the following, I adopt a definition of metaknowledge of mathematics offered by Trouche (2005). He defines metaknowledge is "knowledge linked to gaining access to mathematical knowledge, and knowledge about own mathematical functioning" (p. 206) (more detail of this follows in Chapter 3). Furthermore, learning about M&S-based research methods can enable students to consider using the M&S-based research method for their own project and research tasks or even as a future career option.

In this study, two types of students were selected as participants. The first group are students of Religious Studies[1], who utilised their opportunity to develop a sense of researchers' motivation for using M&S-based research methods. In doing so, students would have the opportunity to develop an understanding of how researchers utilise such methods for the scientific study of religion. Further, students could experience how researchers, consequently, discover new insights and new tools that could inform the formulation of more effective policies for reducing religious radicalisation, violence, and extremism (Shults et al., 2018). The second group are students from Development Studies, who also utilised their opportunity to learn about how researchers use M&S-based research methods to study complex socio-economic analysis. For example, Subramanian & Qaim (2010) used household survey data and a micro-social accounting matrix model that enable researchers to run simulations to study the broader socio-economic impacts of genetically modified crops in rural India. They found that genetically modified crops (i.e., Bacillus thuringiensis cotton) might contribute to poverty reduction and rural development and, particularly, that technological innovation in farming contributes to positive socio-economic effects in the economy of small farmers.

1.2 Background of the study

In all social science study programs at the University of Agder, students are required to take research methodology courses. Those courses demand a basic level of quantitative as well as qualitative reasoning skills. However, research methodology courses that include quantitative methods risk losing students who have anxiety about mathematics or do not feel comfortable with methodology courses because the statistics (mathematics) are difficult and do not engage the students' interest. According to Oldmixon (2018) and Bernstein and Allen (2013), undergraduate research methodology courses need improvement, with an emphasis on conceptual and analytic tools to reduce anxiety concerning methodology courses. They propose:

[1] Formally, students of Religious Studies are within the Faculty of Humanities, and not within the Faculty of Social Sciences. However, their curriculum includes topics on social dynamics and the research methods thereof, which enabled me to include them into my study. As overarching term I use the term "students in the social sciences", which includes any student studying social dynamics, irrespective of institutional affiliations.

(1) the use of overarching teaching themes to keep students engaged and to contextualise the material; (2) beginning with qualitative components and then moving into the quantitative materials gradually, helping students to develop confidence in their research abilities; and (3) the use of computer-supported tools. For this reason, several studies have shown that a simulation-based learning environment supports student learning. Two separate studies, conducted by Case et al. (2019) and Mills (2002), revealed that simulation-based learning environments better engage students in contrast to the traditional methods of teaching statistics.

Simulation-based teaching tools are becoming increasingly more important in education. Interactive simulations can provide virtual environments to engage students in developing their conceptual understanding and analytical skills. For example, Clarke-Midura, Pope, Maruca, Abraham, and Meir (2018) implemented a simulation-based module for undergraduate biology students for teaching about evolution and natural selection. The findings of the study exposed that the simulation-based module not only improved students' expression of critical concepts but also helped them to overcome targeted misconceptions. Further, the study demonstrates how a design-based study can contribute to evidence-based instructional practices in university classrooms.

Another set of articles of this kind emphasises computer simulation's role to create opportunities to observe scientific models to understand concepts (Hulshof, Eysink, & Jong, 2006; Thacker & Sinatra, 2019). For example, Thacker and Sinatra (2019) documented the contribution of online simulations to create mental models of climate change. They implemented design-based research to understand how online climate change simulation helps promote scientific understanding of the greenhouse effect. They also explored ways to incorporate such simulation-based methods into instructional practices. The study's findings demonstrate that the visual representation of the greenhouse effect improved students' perceptual inferences. Further, the intervention enabled students to develop a sense of causal relationships that culminated in discussing how climate change works.

There have been several endeavours to demonstrate interactive computer simulation methods to render more accessible abstract university curricula. For instance, Stephens, Carverand, and McCormack (2014) utilise computer simulation-

based educational tools to teach a statistical inference course. In the same vein, Marriott, Tan, and Marriott (2015) used computerised stock market trading simulation in teaching finance concepts in business education. Lee, Hairston, Thames, Lawrence, and Herron (2002), for example, used computer simulations in a college biology course to illustrate the story of the potato famine in Ireland in 1800 in teaching science processes and skills in the course. They reported that the interactive simulation-based educational tools were helpful to exemplify abstract scientific concepts.

In the intervention study reported in this dissertation, I aimed to introduce an M&S-based research methods curriculum module using simulation-based educational tools within Social Science Study Programs. However, students are not only learning about the dynamical phenomena being simulated but also learning simulation-based research methods to study such dynamics. In doing so, this research will fill a gap in the field by exploring ways to introduce simulation-based research methods to the students of social science disciplines.

No courses in either the Religious Studies or Development Studies program at the University of Agder offer the M&S-based research methods. However, these methods are growing in usage among experienced researchers in these fields (e.g., Gore, Lemos, Shults, & Wildman, 2018; Shults et al., 2018). In this study, my questions are concerned with how one might fill a gap in methodology courses and what could be ways to introduce simulation-based research methods to the students of social science disciplines. In this connection, practitioner-researchers and educators also envisage possibilities to train social science students about M&S-based research methods. For example, Wildman and his colleagues (2017) pointed out that university curricula could raise awareness about the methods, opportunities, and limitations that might prompt students to consider applying M&S methods in their future practices.

I start from the assumption that students from Religious and Development Studies can utilise the opportunity to learn about M&S-based research methods. I divide this study into two interconnected strands. Strand one is to study how students utilise the opportunity to learn about M&S-based research methods. The other strand is to understand how they utilise metaknowledge of mathematics (a

more detailed explanation follows in Chapter 4). I embarked on a three-year design-based study to implement an M&S-based research method curriculum module. In addition to the research goals, the study evaluates the effectiveness of the iterative modules; in this, I hope to formulate recommendations for future possibilities of developing such a course.

1.3 Study context

The research project LaSiRM (Learning about Simulation-based Research method) is based in the University of Agder located in southern Norway. I chose two types of students as participants of the study: bachelor's degree students of religion and masters' students within the Department of Development Studies.

1.3.1 Students of religion

The University of Agder offers a three-years undergraduate religious studies program with approximately 30 students every year. In the fall semester of 2018, I implemented an M&S-based research methods as an optional part of the curriculum to supplement the core course' Religious radicalisation, extremism and violence' (UiA course code, REL 206). The REL 206 course aims at two main objectives, these are:

> (i) To serve students to understand and develop a conceptual understanding of religious fundamentalism, radicalisation and violence, and they will demonstrate an ability to apply this knowledge to current problems that involve religious extremism,
>
> (ii) To provide theoretical knowledge on sociological perspectives of religious change in modern societies emphasising globalisation, the processes for radicalisation and religious violence, how discrimination and stereotyping of minority population leads towards segregated (Source: https://www.uia.no/studieplaner/topic/REL206-1[2])

The course also aims to introduce recent theoretical as well as empirical studies of religious radicalisation, extremism and violence. Moreover, the course content has

[2] The updated course named as 'Global trends in the field of religion: radicalization, violence, and populism'

an extended scope, which intends to support students to develop an understanding of religious radicalisation, extremism and violence within Islam, Hinduism, and Christianity. Graduates from the religious studies program employment in community development, social workers, municipal counsellors.

Students of religious studies are critical readers of research reports while gaining information about various research methods through lectures, group discussion and available audio-visual resources. The highlight of the course reading list includes a recent scholarly debate on relationships of religion and violence such as fundamentalism, religious violence from psychological perspectives, a cosmic war in religious traditions, violence, and non-violence at the heart of Hindu ethics etc. The curriculum also incorporates topics that are helpful to analyse the relationship between violence and religion through various perspectives such as sociological, political sciences, psychological and evolutionary perspectives.

In his book chapter "Can we predict and prevent religious radicalisation?", Shults (2018) discusses the causal relationships between religion and radicalisation by introducing the application of computer modelling and simulation techniques to study social dynamics. This provides us with an example of the use of M&S-based research methods in social research practices. Shults highlights the M&S-based research methods as an approach that enables social science researchers an opportunity to explore new insights and new tools that could inform the development of more effective policies for reducing religious radicalisation, violence and extremism. The M&S-based methods enable researchers by running simulation experiments to understand religious phenomena "insights into the micro-level mechanisms that can lead to macro-level phenomena, such as higher average religiosity among members of minority groups" (Shults, 2018, p. 12). A similar study from Kenya revealed that "radicalisation is strongly related to individual-level psychological trauma". The study suggests a "model of radicalisation that emphasises process-oriented and psychological factors rather than macro-level political or economic grievances" (Rink & Sharma, 2018, p. 23). These are representative examples of literature that students critically read, reflect, and discuss throughout the semester programs.

As described in the literature, social researchers utilise computer simulation models (i.e., the virtual world) to run social experiments. Computer-simulation models create virtual worlds in which the researcher or students can manipulate to create different conditions that match their experiences in the real world and monitor the scenarios as they evolve in the virtual world. The dynamic interaction with the virtual worlds not only provides instant feedback but also takes students beyond the static presentation of information in the textbooks. Thus, the simulation-based environment transports students into a dynamic virtual world where the consequences of conditions in society are experienced as if alive. Thus, M&S methods go beyond static information, as presented in textbooks and lectures. M&S-based methods are also relevant to the students of religion as they create opportunities to understand how researchers in their field utilise such methods.

1.3.2 Students of Development Studies

The University of Agder also offers two years of masters' program in development studies. The program provides opportunities to explore development issues such as social, environmental, economic, and political obstacles to development. The program aims to include learning about theories and findings concerning development and exploring ways to solve problems. The course content comprises various disciplines such as economics, management, political science, sociology, anthropology, and geography. The program's syllabus also incorporates issues regarding local, international private business, non-government organisations, central and local governments. The program graduates find employment opportunities in sustainability, social responsibility, refugee support and immigration management, and UN systems. However, the current study program did not include M&S-based research methods.

Increasing numbers of researchers in development studies utilise M&S-based research methods to simulate complex social, economic, environmental, and demographic issues. For example, Thapa and Murayama (2012) use a predictive model to examine the urban development patterns and optimise the spatial patterns of future growth of Kathmandu Valley, Nepal. Their predictive model provides crucial information on land availability, biophysical characteristics, socio-economic conditions, neighbourhood interactions, and transportation accessibility that are

useful for future policy and planning. The M&S-based research practices are not only helpful in policy and planning practices but also in practices in which ethical considerations in socially sensitive issues are central.

Atkinson et al. (2018), for example, conducted a literature review concerning the advantages and limitations of M&S-based methods in supporting decision making during pediatric drug development; they found that M&S-based methods were received as useful tools that allow the individualisation of drug therapy in children that improve risk-benefits. M&S-based methods demonstrate benefits in two ways. First, they avoid children's unnecessary exposure to a clinical trial involving actual drug use, with the concomitant risk of harm. Second, they support policymakers by providing data and evidence sources to understand complex problems better.

The above examples showed that M&S-based research methods are getting the attention of some development practitioners and researchers. Thus, I see the relevance of M&S-based research methods to the students of development studies to enable them to understand how researchers in their field utilise such methods. Further, M&S-based research methods courses can help students to develop an understanding of the opportunities, limitations, and challenges of utilising M&S-based research methods in their field.

1.4 Structure of the dissertation

This dissertation is divided into seven sections. Chapter 2 outlines the theoretical framework for this study. This is followed in Chapter 3 with a discussion of M&S-in higher education. The chapter covers an overview of the M&S-methods, a review of literature that reports studies on M&S-based methods in higher education curricula. The remaining section of Chapter 3 includes a description of the Schelling applet and its epistemological analysis and structure of a novel M&S-based research methods curriculum module designed for social science students. Chapter 4 presents a detailed account of the methodological considerations for this study. Chapter 5 offers a concise summary of each of the publications used as part of this thesis. This is then followed by addressing this study's research questions that integrate findings from the papers (published and unpublished) in Chapter 6. Finally, I present a

discussion of the theoretical, empirical, and methodological implication of this research, alongside its limitations, and a conclusion in Chapter 7.

2 Theoretical Background

In this chapter, I elaborate on the theoretical perspective that undergirds this study. I begin Section 2.1 with an introduction to Cultural-Historical Activity Theory (CHAT) to establish the features most relevant to my research. Section 2.2 describes how I frame this study within CHAT. Then, Section 2.3 presents the CHAT framework as a lens for analysing students learning about the M&S-based research method. This section also describes the role of boundary-crossing, boundary-objects, tensions and contradictions within and between activity systems. The section includes a brief presentation of some concepts from communities of practice theory relevant to the analysis. The section concludes with brief outlines of Radford's theory of knowledge objectification (Radford, 2002, 2003) and Duval's theory of resisters of semiotic representations (Duval, 2006, 2017), both of which are used to analyse data generated.

2.1 Introduction to Cultural-Historical Activity Theory

Cultural-Historical Activity Theory (CHAT) is one of the so-called "grand theories", which provides a principled explanation of, or a lens through which to focus on, issues of learning, cognition, and development within the socially embedded and culturally created context. The foundation of *Activity Theory* was laid by Vygotsky and his colleagues Alexander Luria and Alexei Leont'ev, who established the cultural-historical school of Russian psychology, aiming to study the cultural-historical roots of thinking and learning (Engeström & Miettinen, 1999; Sannino, Daniels, & Gutiérrez, 2009). The foundation of Vygotsky's psychological theory is an attempt to interpret and apply Marxist dialectic philosophy to learning and development. The approach enabled Vygotsky and those who follow him to develop an explanation of learning that accounts for how socio-cultural roots of thought become internalised by the individual learner.

Vygotsky's account of learning is an attempt to explain how human learning is mediated by cultural tools and artefacts and therefore contrasts with learning that can be described in terms of behavioural changes, which can also be observed in lower forms of life. Further, Vygotsky's account of mediation is dependent upon the learner's appropriation of cultural tools and signs, principal among these being

language. Therefore, it differs from the constructivist account of learning that was being developed in Europe around the same time, by Piaget and others. In the latter, human learning is also a product of a form of mediation. However, the mediation is referred to as interpretation, and the mediator is the individual's model of the experienced world.

Leont'ev further developed Vygotsky's ideas with a collective model, which is referred to as "second-generation activity theory". Collaborating with Luria, Leont'ev studied the cultural, historical, and political processes of learning and development. Rooted in Vygotsky's work, Leont'ev extended activity theory to understand the development of human consciousness (Engeström, 1999a; Leont'ev, 1978). Leont'ev's (1978) version of CHAT emphasises understanding how collective action by social groups mediates the activity as well as providing the principal explanation of consciousness, thereby cognition and learning. CHAT comprises the notion of activity and motive. The activity takes place in a historical human context, that is, it takes place over time. More importantly, activity is a cultural expression of humans, and thus, it is also a product of culture rather than nature. Leont'ev explains:

> "Activity is a molar, not an additive unit of the life of the physical, material subject. In a narrower sense, that is, at the psychological level, it is a unit of life, mediated by psychic reflection, the real function of which is that it orients the subject in the objective world. In other words, activity is not a reaction and not a totality of reactions but a system that has structure, its own internal transitions and transformations, its own development" (Leont'ev, 1978, p. 50).

Further, Leont'ev's notion of activity, action, and operation depicts the structure of human activity as three different levels. At the top level, the activity takes places across time and is driven by a motive to achieve some objective. At an intermediate level, the activity is realised as actions of limited duration that are occurring within time and directed towards achieving goals. At the lowest level and below a level of consciousness, actions emerge as operations that are carried out within a range of personal and contextual conditions, such as competences and available resources. Activity is a human enterprise, and there is always a motive that drives social engagement in the activity to achieve an object of activity. Moreover, "activities are

distinguished on the basis of their motive and the objective towards which they are oriented; actions on the basis of goals; and operations on the basis of conditions in which they are carried out" (Nilssen & Klemp, 2020, p. 76). In an intervention study such as LaSiRM, students are engaged in the activity of university studies (i.e., participants in the M&S-based research methods seminar and workshops), researchers are engaged in the activity of knowledge creation and understanding society better (e.g., publishing articles). Likewise, professionals are engaged in the activity of workplace context (e.g., social workers, city planners, schoolteachers), and individuals are engaged in the activity of regular citizens (e.g., consumers, voters, migrants).

From the CHAT perspective, one should perceive that students engage in university education as a cultural-historical activity. The object of the activity is to become highly educated, critical, culture-sensitive individuals who will be future community leaders, teachers, or professionals. University education emerges as various forms of actions, for example, lectures, seminars, workshops, and writing essays, all activities directed to achieving students' object. Students engage in the actions to achieve relatively short-term goals, such as learning about "M&S-based research methods". Whereas "activity" generally lies above a level of consciousness, students will be conscious of their actions in which they engage because they seek to achieve the goal (Leont'ev, 1978). In this sense, an activity is a bridge by which an individual student's mind is connected to the community of M&S-based research practitioners in their field (Wertsch, 1991).

In their actions, students explore M&S-based tools intending to enter into professionals' situations. More so, students apply their metaknowledge of mathematics as a mediating artefact in their learning about M&S-based research methods. Mediating tools (e.g., M&S-based tools) play a crucial role in connecting social science students with the object of their activity and with other people in the university community. The mediating "tools relate to the level of operations, where methods or material object are crystallised" (Nilssen & Klemp, 2020, p. 77). As such, they usually are applied below the level of consciousness, thus posing a challenge to the researcher to expose and analyse them.

Engeström (2001) introduced the third generation of CHAT in which he proposes a nested triangular model of extended activity system to draw attention to the issue of tensions and contradictions within and between activity systems. Karl Marx, 100 years earlier, had drawn attention to the fundamental contradictions between use value and exchange value, as he explained the notion of economic materialism. Building on Vygotsky's (1978) and Leont'ev's (1978) conception of socio-culturally mediated and object-oriented activity, several scholars (See Cole & Engeström, 1993; Engeström, 1987; Roth, 2014; Roth & Radford, 2011; Sannino et al., 2009) advocate the perspective of CHAT, both for designing change and development when tensions and contradictions are recognised.

In sum, this study adopts CHAT to investigate university students' activities in learning about M&S-based research methods. Further, CHAT focuses on interacting systems of activity: the intersecting systems of M&S-based research methods curricula, M&S-based tools and students' future professional goals. Also, taking account of socially situated inter-relations, the CHAT framework is useful to examine how M&S-based tools have transformed the workplace practices of M&S-based researchers. The following subsection elaborates on how CHAT addresses these issues.

2.2 Framing the study within Cultural-Historical Activity Theory (CHAT)

At the outset, I anticipated students in the social science study programs did not see a connection between the research methods curricula in university studies and the professional practices of their future workplaces. CHAT offers an approach to an understanding of the theory-practice gap in the context of the university curricula and professional practices in the workplace context. "Because CHAT addresses the troubling divides between individual and collective, material and mental, biography and history, and praxis and theory (e.g., Cole, 1988), we believe that it is deserving of wider currency in the educational community" (Roth & Lee, 2007, p. 191). More specifically, CHAT provides a framework to analyse how humans utilise tools and symbols in a multifaceted social context to achieve specific objectives that lead towards anticipated outcomes (Fenwick, Edwards, & Sawchuk, 2011; Vygotsky, 1978). This study focuses on simulation-based educational tools and symbols,

mostly in the form of language. The objectives are learning about M&S-based research methods and the outcome of being graduates who had exposure to M&S-based research methods.

Several studies have shown that a CHAT framework has enabled researchers by providing an appropriate approach to questions of education, such as in the development of academic practices and practice-based research (Hsu, van Eijck, & Roth, 2010; Roth, 2004). In doing so, CHAT can "… deal with the complexity in education systems" (Jaworski & Potari, 2009, p. 222). In the present study, CHAT offers language, structure or categories to understand contextual features that shape and mould changes in the M&S-based research methods curriculum module.

The CHAT framework was perceived as an approach that allows identifying objects that motivate the student's activity and the innovative pedagogical tools or artefacts that will equip them for their future professional careers. Further, the framework offers a language to identify and describe students' interactions with M&S-based tools, M&S-based experts and peers within which they participated. The theoretical framework helps identify the members of the community, their roles, and the manner in which students take up their 'opportunity to learn'[3] about M&S-based research methods (Roth, Tobin, Zimmermann, Bryant, & Davis, 2002). CHAT, as a theoretical framework, is also helpful to articulate a research methodology curriculum that can be used to explore how a study program can be founded on, informed by, and infused with research and development (R&D).

In this present study, I assume there will be issues of boundaries between university studies' academic practices and professionals' workplace context. CHAT can be characterised as a "cross-disciplinary framework for studying how humans purposefully transform natural and social reality, including themselves, as an ongoing cultural and historically situated, materially and socially mediated process" (Roth, Radford, & LaCroix, 2012, p. 1). In this regard, the CHAT framework allows researchers to investigate university studies' educational phenomena such as teaching and learning of M&S-based research methods curriculum module within

[3] In this study, M&S-based research methods curriculum module is being designed to extends students opportunities to learn about M&S-based research methods. In this sense, teaching about M&S-based research methods provide a context in which students utilise their opportunity to learn for a student to learn.

social science study programs. Also, the framework helps explore intended future professional opportunities and challenges envisaged by M&S-based research methods curriculum modules. In the university context, the relational agency of students engagement is developing future professional knowledge, skills, and mindsets as an "expansion of their control over life conditions and action possibilities" (Roth & Radford, 2011, p. 106). Thus, CHAT is an appropriate framework to analyse students' activities within a university study context in which students act, negotiate, and learn activities embedded in a system of tool-mediated, rule-defined, object-oriented action without diminishing individual and collective features of human activities.

In my study, I anticipate tensions and contradictions between the academic norms of social science study programs and workplace practices of M&S-based professionals. The notion of contradiction in an activity system is perceived as the outcome of multifaceted processes rooted in the accumulation of tensions over time. Additionally, an activity system is not static, but "it is inherently a dynamic structure, continuously undergoing change in its parts, in its relations, and as a whole" (Roth, 2004, p. 4). The CHAT framework alerts the researcher to see the possibilities mentioned above. Therefore I needed to frame my study in such a way that I could generate data that enabled me to see the contradictions and tensions as they emerge.

Several studies have revealed that CHAT is a useful theoretical framework for researchers engaged in socio-culturally informed and designed based developmental study, which involves designing learning interventions in a real-world context (e.g., Bakker, 2018; Cole & Engeström, 2006; Cole & Packer, 2016). In this vein, for Bakker (2018), the design and research are complementary and interconnected, "the design is research-based, and the research is design-based" (p. 4). Hence, utilising the promise of the CHAT framework enabled the design of an M&S-based research methods module that is a crucial part of the research. The module would be composed of engagement with M&S-based educational tools and other activities to promote learning. The description of the design of the series of interventions is presented later in chapter four. Using a design-based methodology, the present study

was framed within the CHAT framework to examine how students utilise the opportunity to learn about M&S-based research methods.

2.3 CHAT framework as a lens for analysing the opportunity to learn about M&S-based research method

CHAT provides a language or structure to study human activity, and activity emerges as actions directed towards achieving goals by utilising mediating artefacts. According to Roth (2014) "cultural, historical activity theory is a *process* theory for understanding the human life form generally, and its concrete manifestations in human activity more specifically" (p. 4). CHAT enabled me as a researcher the means to develop a lens to focus on and analyse the relationships between the interconnected elements within an activity system (like a university seminar or students meeting with experts). More so, CHAT "illustrate[s] structures, process, patterns, and configurations that are usually ignored or invisible" (Roth, Lee, & Hsu, 2009, p. 147). This study framed students' thinking and behaviour as co-constituent of collectively organised, historically evolving, culturally mediated, and object-oriented activity systems as the basic unit of analysis (Roth & Lee, 2007).

2.3.1 Mediation, cultural tools, and artefacts

Tools and signs, as mediating artefacts, are an essential part of the activity systems. These tools can be physical (e.g., simulation-based educational tool), conceptual artefacts (i.e., simulation and visualisation of social phenomena) or cultural artefacts, such as signs (i.e., language). All artefacts are deployed in actions directed towards achieving the participants' 'goals' (Vygotsky, 1978). For example, in the university students' activity system, 'subject' refers to the students of religion and development studies (i.e., novices) who participate in a research methods seminar, tutoring sessions, and meetings with experts. Students thus utilise the opportunity to learn about M&S-based research methods ('object').

2.3.2 Mediation, subject, and object

Students' opportunity to learn about M&S-based research methods is mediated by artefacts or tools (e.g., M&S-based research methods module, M&S-based educational tools), which play a collaborative role between subject and object and

include social others (Yamagata-Lynch, 2010). For example, students participate in the activity utilising an opportunity to learn about M&S-based research methods, leading to their individual and collective motives to develop a sense about their future career options. While students are utilising their opportunity to learn about M&S-based research methods in their discipline, they utilise their object, opportunity to learn about M&S-based research methods as raw material. Further, students engaged in their learning activities are directed towards their 'future-oriented actions', direct their journey from students to researchers to professionals in their field (Engeström, 2001).

2.3.3 Mediation, community, rules, and division of labour

Further, individual students' utilisation of their opportunity to learn about M&S-based research methods cannot be well understood without examining the functioning of M&S-based research practices in their workplace context. According to Kaptelinin and Cole (2001), individual students' utilisation of opportunity to learn about M&S-based research methods and their participation in a meeting with M&S-based researchers (i.e., experts) are "different aspects of the same phenomena" (p. 1). Therefore, students are members of a community, and collective activities materialise within this community, and this involves rules and the division of labour, represented by the distribution of responsibilities and tasks and the hierarchy of power within activity systems (Cole & Engeström, 1993). The outcome (e.g., graduate who had exposure to M&S-based research methods) of this activity system is the development associated with interacting elements, that is, "an evolving, complex structure of mediated and collective human agency"(Roth & Lee, 2007, p. 198).

2.3.4 Mediation facilitates change and development

The CHAT framework provides a useful way of systematically describing students' activities and is of particular resonance in creating opportunities to learn about M&S-based research methods**.** In this sense, the framework helps devise new elements such as the M&S-based research methods curriculum module within the existing research methods curricula. The design and development of the M&S-based research methods curriculum module are facilitated by introducing new tools (i.e.,

M&S-based educational tools, mathematics). In this study context, an M&S-based educational tool and mathematics are the means of mediating actions. In this regard, mathematics is bound into students' action, for example, when manipulating imaginary people's behaviour while interacting with M&S-based tools (i.e., Schelling applet) (more details in Section 3.4.2). However, the student's activity does not include algebraic equations or arithmetic. As described by Triantafillou and Potari (2010), invisible mathematical relationships and mathematical processes have been historically crystallised in the M&S-based researchers' community who utilised M&S-based tools.

2.3.5 Role of boundary-crossing and boundary-object within and between activity systems

The notion of boundary-crossing facilitates the problematisation of novices and expert practitioners by bringing "academic/theoretical practices and practical/vocational work practices together, integrating the two types of knowledge" (Swanson & Williams, 2014, p. 196). In an educational context, boundaries occur between domains of the university, work, and everyday life context. At this juncture, boundary-crossing is a critical concept for describing the "efforts by individuals or groups at boundaries to establish or restore continuity in action or interaction across practices" (Bakker & Akkerman, 2014, p. 225). This feature is also emphasised in the work of Roth and Radford (2011, p. 153) "the boundary-crossing concept is a way of rethinking the question of 'transfer' of 'knowledge' and 'skills' between situations". To strengthen the transfer of learning and knowledge, the notion of boundary-crossing "draws attention to a wider range of relevant processes involved in integrating different types of knowledge to be learned and used in different contexts" (Bakker & Akkerman, 2014, p. 224). The boundary between problem-solving in university studies and the workplace is an example of boundary-crossing between the university and professional lives. The knowledge gained in the university context cannot be assumed to be transferred smoothly unless the workplace does not have crucial context markers. In this sense, learning is situated, dynamic and appears context-dependent.

I anticipate a crucial challenge for social science students is to develop a link between university research methods curricula and workplace professional contexts.

As described by Jurdak (2016), learning at university and workplace practice are "two types of purposeful human activities (Leont'ev, 1981) in which the actions toward realising their purposes are mediated by the use of cultural artefacts"(p. 137). However, the workplace culture of an M&S-based researcher is influenced by sophisticated artefacts such as computer software and applets. On the one hand, learning activity in the university context is mediated by symbolic and material artefacts such as language, mathematics, computer simulations. On the other hand, workplace activity is mediated by technological tools (i.e., computer software, applets) and semiotic artefacts, where mathematics is embedded or black-boxed (Williams & Wake, 2007). For example, in a self-service checkout counter of a supermarket, we rely on computer software to calculate the amount due, and the underlying mathematics is hidden in the so-called "black box".

The CHAT framework coupled with the construct of boundary-crossing provides the tools I need to analyse issues in the M&S-based research methods curriculum module to explore the relationships across the curriculum of university study programs and outside of the university contexts.

Suppose university students and M&S-based researchers interact with each other within and beyond their designated practices: between novice learner and workplace context. This will be achieved by creating an opportunity for students to meet with active social science researchers that use M&S methods. Their communication may entail dialogue, written texts, simulation and visualisation, signs, symbols, or gestures. However, students and researchers may introduce boundary objects as potentially shared or jointly constructed objects of two different yet interacting activity systems (Engeström, 2001). It is essential to note the term "object" is distinct from the notion of an object as the motive of activity: the boundary object referred to " those objects that both inhabit several communities of practice and satisfy the informational requirements of each of them" (Bowker & Star, 1999, p. 297). In the same vein, within communities of practice theory, boundary objects are defined as:

> "artefacts, documents, terms, concepts, and other forms of reification around which communities of practice can organise their interconnections...They enable coordination, but they can do so without actually creating a bridge between the

perspectives and the meanings of various constituencies" (Wenger, 1998, pp. 105-107).

To facilitate the interaction between two different but interacting communities of practice, Star & Griesemer (1989) identified a term "boundary object" to refer to mediating artefacts facilitates between two different but interacting activity systems. Star (1989) explains:

> Boundary objects are objects that are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use and become firmly structured in individual-site use.
> Like a blackboard, a boundary object "sits in the middle" of a group of actors with divergent viewpoints. Crucially, however, there are different types of boundary objects depending on the characteristics of the heterogeneous information being joined to create them (Star, 1989, pp. 46-47).

CHAT and its focus on activity systems are helpful to analyse the processes of university students learning when they are challenged to link theoretical knowledge to the workplace of M&S-based research. This framework promotes the view that learning is an evolving process, and it emerges in dynamic movements of interacting activity systems such as university studies and workplace practices. Examples of boundary objects include geographical maps, expert software for web page construction, and scholarly journal articles. There are many artefacts that can form a bridge between university studies and workplace contexts. It remains to be exposed through the analysis of data generated in this study what artefacts the students and expert researchers introduce to span the boundaries between their different practices (cf. Paper 3).

2.3.6 Role of tensions and contradictions within and between activity systems

According to Gedera (2016), tensions and contradictions are visible as obstacles, conflicts, and gaps. However, contradictions are typically taken as essential components of practice-oriented activity systems. In this connection, Roth and Radford (2011) identified the contributions of contradictions to learning.

> "The individual needs to be able to experience that there is more to learn than what is available to them on the basis of their current knowledge and understanding. In other words, they have to experience the dialectical contradictions that are situated at the epistemological level of the [classroom] activity (Roth & Radford 2011, p. 107).

To unpick this further, as Roth and Lee (2007, p. 210) argue, "… human beings are not merely at the mercy of extant institutional contexts but that they are endowed with the power to act (agency), which allows for critique and revision". As described above, any tension and contradiction exert an influence on the individual and the whole community within the system, as I explain below.

I anticipate there will be tensions between the division of roles between students, teachers, and M&S-based researchers in the course of implementation of the M&S-based research method module. The utilisation of M&S-based tools interferes with the traditional norms of lecture-based curricular practices of research methods study programs by introducing active learning expectations. From the CHAT perspective, Westberry and Franken (2015) argue "learning is viewed as participation with others within a particular socio-cultural context rather than learning as the acquisition of individual cognitive processes" (p. 302). In this regard, learning is an evolving process, and it is not possible to acknowledge the emergence of tensions and contradictions ahead of time. I also expect the utilisation of M&S-based tools within the social science study programs contradicts some hidden rules that regulate the tools and artefacts, such as social science study programs rarely offer computer programming and mathematics. In this connection, Fenwick et al. (2011, p. 9) propose that "learning is explained as the construction and resolution of successively evolving tensions or contradictions in a complex system that includes the object or objects, the mediating artefacts, and the perspectives of participants (Engeström, 1999b)". In this regard, an M&S-based educational tool is an innovative pedagogical device for the M&S-based research methods module that may contradict the culture of lecture-based teaching methodology.

CHAT and its focus on interactive activity systems help characterise events within and between activity systems, such as the activity systems of university classrooms and those of the workplace, as well as the contradictions that emerge

between them (Potari, 2013; Williams & Wake, 2007). In particular, CHAT provides a language and conceptual framework that theorises tensions and contradictions and recognises how they offer some explanation for changes in social practice. For example, students and M&S-based researchers are participating in an M&S-based research methods module from two different points of view. On the one hand, students are learning about M&S-based research methods by exploring the possible solution to societal problems they are experiencing. On the other hand, M&S-based researchers' engagement is to understand social dynamics utilising social simulation that entails relationships and constructions of the social world. In this sense, M&S-based researcher's models "cannot be read as an objective representation of the world because no simulation is an objective representation" (Heidelberg & Desai, 2015, p. 10). However, the M&S-based tool function as an instrument that facilitates researchers' investigation about social dynamics.

In this way, CHAT functions as a means of exposing tensions and contradictions and bringing these to the foreground for analysis. CHAT also provides a language and conceptual framework that facilitates the analytic process. Further, these tensions and contradictions serve to make explicit the alternative practices of M&S-based research methods curricula within social science study programs.

2.4 Communities of practice

The communities of practice framework emphasise transformation through social interaction; in contrast, the CHAT focuses on how participants "make sense of, interpret and construct their world through practical action" (Arnseth, 2008, p. 291). In this sense, individuals engaged in their practice, part of everyday activity, to translate their learning and understanding into meaningful action. However, both theoretical frameworks emphasise that learning (and teaching) takes place in social, historical and material contexts. Lave and Wenger (1991) propose that "a community of practice is a set of relations among persons, activity, and world, over time and in relation to other tangential and overlapping communities of practice" (p. 98). In this framework, it is the *practice* that is goal-oriented, not the individual, and the individual is not considered strongly as a category of analysis. Drawing from the social learning theory, Lave and Wenger (1991) offer a conceptualisation of situated learning, communities of practice and legitimate peripheral participation. While

traditional learning theories separate learning from practice and advocate learning as a one-way transmission of existing knowledge from teacher to learner, situated learning theory describes learning as a process of understanding in a socio-cultural context and knowledge is distributed amongst the community of practice (Lave & Wenger, 1991). In this sense, practice is associated with doing and knowing "in a historical and social context that gives structure and meaning to what we do" (Wenger, 1998, p. 47). Situated learning theory emphasises "learning as legitimate peripheral participation (meaning) learning is not merely a condition for membership but is itself an evolving form of membership" (Lave & Wenger, 1991, p. 53).

Students in the university context are the legitimate peripheral participants in a community of practice that includes their teachers, M&S-based researchers, and M&S-based professionals in their field. The students' participation and learning in this community can benefit themselves in learning about M&S-based research methods. The participation can be formal and informal activities. More specifically, the practice is about learning. For the students, it means learning about M&S-based research methods, whereas for the researchers, it means learning more about the world through M&S research methods. Neither can be considered regular real-world applications of the methods to solve experienced societal problems. The foundation of legitimate peripheral participation is linked to Vygotsky's (1978) notion of the zone of proximal development, which "refers to the gap between what a given child can achieve alone, their potential development as determined by independent problem solving, and what they can achieve through problem-solving under adult guidance or in collaboration with more capable peers" (Wood & Wood, 1996, p. 5).

The notion of learning as participation is helpful to characterise "the evolution of practices and the inclusion of newcomers…[and]… the vehicle for the development and transformation of identities (Wenger, 1998, p. 13). On that account, it is necessary to analyse students' engagement in learning about M&S-based research methods, which can be observed through the four interconnected components. First, learning as *belonging* happens as students sign up for M&S-based curriculum module and build a relationship that enables learning from each other. Second, learning by *doing* as students engage in the module course work, talking and

interacting with M&S-based tools. Third, learning by *meaning-making* as students learn about the abstract concept of social in/exclusion through an experiential approach. Fourth. Students learn as a process of *identity* formation or evolution as a learner or knower of M&S-based research methods (Wenger, 1998, p. 5). To unpick this further, Wenger (1998) defined the concept of a community of practice by the following features:

- "mutual engagement, participation and reification;
- a joint enterprise can create relations of mutual accountability […];
- shared histories of engagement can become resources for negotiating meaning making processes (e.g., ways of doing things, routines, words, tools)" (Wenger, 1998, p. 83).

In this sense, learning/knowing is devised to act with a community of practice (Arnseth, 2008) and the analysis of learning/knowing inseparable from practice (Wenger, 1998). In this fashion, the communities of practice theory provide a framework for analysing students learning about M&S-based research methods in the workplace context (i.e., the context of M&S-based professionals in their field).

2.5 The theory of knowledge objectification

The theory of objectification (TO) is linked to the dialectical approach proposed by Hegel (1977) is part of Leont'ev's (1978) version of *cultural, historical activity theory* (CHAT) that "provides analytic tools for understanding in greater details the historical, cultural, and semiotic dimensions of mathematical, thinking and learning" (LaCroix, 2014, p. 160). For Presmeg, Radford, Roth, and Kadunz (2016) "the theory of objectification is an attempt to understand learning not as the result of the individual student's deeds (as in individualist accounts of learning) but as a cultural-historical situated process of knowing and becoming" (p. 16). In this regard, Roth et al. (2012) describe the dimensions of *cultural, historical activity theory* by triads: activity, culture, and history. In the approach, activity does not mean merely to do something; instead, it is a social form of collective action. Further, the TO provides a framework for a systematic analysis of the relationship between; semiotic representations, mathematical objects and meaning/concepts. In this regard, Santi (2011) cites, "to understand the meaning of signs, we cannot reduce them to what

they represent, but we must understand the kind of activity they accomplish" (p. 286). Thus, the analysis emphasises students' utilisation of semiotic representations in the system of practices. In this connection, in his recent publication, Jurdak (2016) reflected in its name CHAT:

> The theory implies that human activity is temporal because it consists of an event that can be only understood in the local context in which it occurs. It is historical because its meaning can only be understood in terms of the events that shaped the activity up to this moment. It is cultural because it is embedded in mediating artefacts which are, by their nature, cultural tools (p. 53).

As a researcher, for example, I am looking for something connected to the student's life. More specifically, I "do not look for subjects or tools or objects, and so on. [I] Look for something that is an event-activity. Something has to happen" (Roth et al., 2012, p. 6). It shows that the CHAT framework equipped researcher can observe students' actions (activity) mediated by artefacts (culture) and the events that shaped the activity up to the moment (history).

According to Radford (2002, 2003), the theory of objectification provides means to analyse the evolution of students' sense-making activities. In Radford's (2002) term, objectification is "a process aimed at bringing something in front of someone's attention or view" (p. 15). In the present study, the students' sense-making activities mediated reflective activity directed to the mathematical objects that are the social processes of becoming aware of cultural and historical ways of thinking and learning. In this regard, TO is helpful to characterise students discourse concerning their choice of natural languages, semiotic means of objectification, and reification of mathematical and social science concept/ meaning. In this process, the semiotic means of objectification may include mathematical sign/symbol, objects, language, and the teacher, and so on. In doing so, knowledge cannot be transmitted; instead, it evolves progressively across the cultural-historical modes of thinking and learning. In this sense, learning /knowing is developing perspectives or forms of thinking in objectification processes. It is also seen as a system of ideas and materialised in the form of consciousness.

The cultural-historical conception of mathematical knowledge is not as an object but as an evolving process. For Radford, "to learn is to objectify something" for this reason, he named this process objectification (Radford, 2005 p. 116). Radford asserts to objectify is to learn about something abstract, a concept. Further, objectify means knowing mathematical objects which are not easy to apprehend by human senses. Further, mathematical objects need to be expressed by signs or other semiotic means such as linguistic expressions, pictures, or gestures (Radford, 2002). In the theory of objectification, learning is perceived as a conscious act. More so, learning is not merely about knowing something; instead, it is also about becoming (Radford, 2008). In this regard, Radford described the semiotic means of objectification as "objects, tools, linguistic devices, and signs that individuals intentionally use in social meaning-making processes to achieve a stable form of awareness, to make apparent their intentions, and to carry out their actions to attain the goal of their activities" (Radford, 2003, p. 41). In this approach, students' sense-making appears in three modes of generalisation: through students' action, through mathematical sign/symbol and language. In such a manner, the theory of objectification framework for analysing students' interaction with cultural artefacts through gestures and language to build up mathematical sense-making/knowing.

2.6 The theory of resisters of semiotic representations

Mathematical objects such as concepts or procedures are abstract knowledge objects. The function of mathematics illuminated by a simulation-based educational software or tool is abstract, and "the only way to have access to [mathematical objects] and deal with them is using signs and semiotic representations" (Duval, 2006, p. 107). According to Duval's theory of semiotic representations, several registers of knowledge representations such as graphic, algebraic, arithmetic, pictographic, and natural language are relevant to the mathematical activity. The theory suggests two types of transformations of semiotic representations: *treatment* (i.e., manipulating representations within the same register) and *conversion* (i.e., translating representations in one register to those in another). He describes that:

> Treatments are transformations of representations which happen within the same register: for example, carrying out a calculation while remaining strictly

> in the same notation system for representing the numbers, solving an equation or system of equations, completing a figure using perceptual criteria of connectivity or symmetry, etc.
>
> Conversions are transformations of representation which consist of changing a register without changing the objects being denoted: for example, passing from the algebraic notation for an equation to its graphic representation, passing from the natural language statement of a relationship to its notation using letters, etc. (Duval, 2006, pp. 106-112).

To appreciate this approach, I consider a few examples. *Treatment* can be exemplified as students' interaction with the simulation-based educational tool by manipulating parameters to get the desired effect in the form of visualisation and simulation. Simultaneously, a *conversion* would be involved in transforming symbolic representation in a particular "slider bar" to visualisation. For example, controlling input by using a slider bar (i.e., a digital means for controlling the value of a variable by adjusting the position of a pointer along a line marked with a numeric scale) results in output in the form of visual representation (i.e., an image in the output screen), in other words, the transformation of one semiotic representation into other semiotic representations. Thus, treatment represents mathematical transformations within a representation system, whereas conversion signifies between the representations systems. At this juncture, my argument is that the theory of multiple representations helps to analyse how students "interpret and deal with the semiotic representation of mathematical object without confusing the object" (Gulkilik, Moyer-Packenham, Ugurlu, & Yuruk, 2020, p. 1).

I anticipate students sense-making /knowing processes take place through their perceptual actions such as interaction with the tool, gesturing or looking at the representation in a particular, conscious, and cultural way (Radford, 2010). More so, these sense-making actions transform their learning/knowing from the situation of not knowing mathematical objects in the tool to one in which they identify them and their concept/meaning. Students' sense-making activities are not merely operational or logical activity but both knowing and becoming, that is, semiotically mediated social processes of becoming and critically aware of systems of ideas, a form of thinking, cultural meanings etc. (Radford, 2013b). In this regard, Iori (2017) argued

that Duval's *semio-cognitive* (semiotic and cognitive) approach is an operational or logical-discursive analysis that characterises mathematical objects and the semiotic activity. For Duval (1995), "objectification" "means becoming aware of something for oneself and only for oneself (not for communication)" (as cited in Iori, 2017, p. 283). However, in the semiotic-cultural approach, Radford (1998) proposed the term "representation" is "to some extent (…) as a synonym for a sign" (p. 288), and it is "a conceptual tool used to interact with our culture" (p. 289).

The above discussion explicitly revealed requirements of epistemological analysis[4] of the simulation-based educational tool distinguishing what sign and symbol 'stand for' (i.e., semiotic function) and what it refers to' (i.e., meaning and concept) (see more details in Chapter 3 and in paper 4). Paper 4, in this research study, the epistemological analysis of simulation-based educational tool was helpful to characterise the operationalisation of students' interaction with the tool.

2.7 Chapter Summary

In this chapter, I have outlined the theoretical background that undergirds this study. This chapter provides a foundation and historical overview of the CHAT theoretical framework. Then, this chapter describes the role of boundary-crossing, boundary-objects and tension and contradictions within and between activity systems. Following this, the chapter presents local theories such as the community of practice theory, the theory of knowledge objectification and multiple representations theory as useful lenses to analyse students learning about M&S-based research methods.

In the following chapter (Chapter 3), I present an overview of M&S-based methods in higher education and research questions that guide this study.

[4] It will be explained later that the analysis I refer to here as "epistemological" might be described by others as "semiotic".

3 Modeling and Simulation in Higher Education

This chapter presents an overview of M&S-methods in higher education. I begin with defining key terms and reviewing some literature that reports studies on M&S-based methods in higher education curricula. Further to this, I present an introduction to the Schelling applet that is introduced to the students in the research reported here and epistemological analysis of the Schelling applet and the structure of an M&S-based research methods curriculum module designed for social science students. The chapter concludes by stating the research questions that guide this study.

3.1 Models, modelling, and simulation

3.1.1 Models

Models are useful devices for the understanding of complex phenomena. In a science lesson, a student may develop a mental model of an atom or a model of electric current. However, except through verbal and pictorial descriptions and explanations, those mental models are inaccessible to other collaborators such as colleagues, teachers, and non-specialists. Based on their purposes and uses of models, we can categories them into several different types. For examples, mental (i.e., atom), physical (i.e., globe), verbal (i.e., solar systems suggest models of atomic structure), symbolic (i.e., mathematical equation), virtual model (i.e., computer simulation), iconic models (i.e., images, pictures, diagrams and graphs). These are a few examples of categories of models, and there may also be other types. According to Lehrer and Schauble (2010) “models are analogies in which objects and relations in one system, the model system, are used as stand-ins to represent, predict, and elaborate those in the natural world” (p. 9). Models are helpful to negotiate meaning connecting theory and observations. For Held and Wilkinson (2018) “models are simplifications of real systems that are easier to study and understand because they focus on essential aspects of a system without distracting detail” (p.380).

The simplified representations of real-world processes such as transportation, railway design, business structure, health care systems, or social phenomena are

used to communicate, evaluate, and improve the systems for future purposes. A model is a formalised representation of real-world phenomena, a system, or a set of processes with some specific purposes. Joshua Epstein (2008), one of the pioneers of agent-based modelling, in his landmark article 'Why model?' succinctly explained that the model's primary goal is not for prediction; instead, it describes future scenarios. He stated 16 reasons for utilisation of modelling and simulation as tools in the following manner: models are used to:

1. explain (very distinct from predict);
2. guide data collection;
3. illuminate core dynamics;
4. suggest dynamical analogies;
5. discover new questions;
6. promote a scientific habit of mind;
7. bound (bracket) outcomes to plausible ranges;
8. illuminate core uncertainties;
9. offer crisis options in near-real-time;
10. demonstrate trade-offs/suggest efficiencies;
11. challenge the robustness of prevailing theory through perturbations;
12. expose prevailing wisdom as incompatible with available data;
13. train practitioners;
14. discipline the policy dialogue;
15. educate the general public;
16. reveal the apparently simple (complex) to be complex (simple)

(Epstein, 2008, pp. 2-3)

The above list illustrates how useful it can be for training social scientists (or, in general, those studying social dynamics that can be modelled and simulated, such as in/exclusion, migration etc.).For instance, social simulation-software (for detail in section 3.4.1 below) is a useful way to explain, illuminate core dynamics or discover new questions about social dynamics (e.g., 1,2 &3 from the above).

3.1.2 Modelling

In a sense used here, a model represents phenomena, which could be a system or a set of processes, that is often used to support learning. The model and modelling process provides opportunities for learners to explore patterns and relationships in the represented phenomena. The representational forms of models (i.e., pictures, diagrams, physical replicas, maps, computer simulations, mathematical formula) are commonly used in educational settings. In this regards, Lehrer and Schauble (2010) describe, "Modelling is a form of argument that is central to science, and that has other instructional advantages as well: it renders student thinking visible to teachers and peers, it fosters representational competence" (p. 20). In this sense, modelling is a tool that mediates students' sense-making about a phenomenon by utilising existing resources. The representational form of models not only engages learners to develop an interpretation of an object but also enables their co-construction of meaning. In this regards, Knuuttila and Boon (2011) describe *models as epistemic tools* that will allow novices to engage in the process of interacting and manipulating them.

3.1.3 Simulations

Digital simulation is defined as a "method for using computer software to model the operation of real-world processes, systems, or events" (Davis, Eisenhardt, & Bingham, 2007, p. 481); a simulation provides an opportunity for studying various phenomena. Gros (2007) highlights the digital simulation that re-creates a situation or phenomena and enables users to achieve a specific goal such as solve problems, gain insights. It is possible to run a computer-simulated process, observing its behaviour over time, and relate the effects of different initial conditions and other inputs (Gilbert, 1999). Simulations are useful for many different purposes, such as prediction, performance, training, entertainment, education, and discovery.

Computer-generated simulation and visualisation enhance the representation of phenomena that provides an opportunity to interpret its outputs in the form of visualisation. Many computer simulations include the possibility of human interaction. Moreover, interactive visualisation enables users to manipulate and explore the role of parameters in models. The interactive processes with

visualisations can influence users understanding of the issues (represented by the parameters) as well as the usefulness of visualisations of systems (Zudilova-Seinstra, Adriaansen, & Van Liere, 2009). In particular, simulation and visualisation purposefully engage users in interacting with visual outputs and communicating insights. Further, they provide an opportunity to improve learners' actions because a digital visualisation "provide(s) an opportunity to experience and reflect upon probabilistic behaviour. It allows mimicking such behaviour in a real-world system, answering questions about that system, and making predictions of future outcomes" (Aridor & Ben-zvi, 2017, p. 41).

The following section introduces some examples of M&S-based research practices that contribute to advancing physical, natural, and social sciences.

3.2 Modelling and simulation (M&S)-methods in research practice

3.2.1 Physical and natural science

Modelling and Simulation (M&S)-methods enable researchers to explore assumptions, rules, and behaviour to gain insights over complex phenomena. In this sense, modelling and simulation appear as a tool for creating virtual phenomena for researchers to conduct experiments to understand the physical dynamic without using laboratory experiments. Several studies showed that M&S-based research methods have been implemented in the field of physical and natural sciences. I cite two examples of M&S-based methods used in practice: One is Longman and Miles (2019). They built an M&S-based programming library called DESaster to model the housing recovery process, such as the distribution of funds and labourers in the community after the 2015 Nepal earthquake. Their work added value to the available research literature on the post-disaster recovery model. Further, their simulation models inform individual homeowners and facilitate them to understand the complexities of reconstruction and resource needs. DESaster assists in managing the reconstruction systems by identifying and testing strategies that would benefit state agencies and individual homeowners.

The second example I offer is from a review article highlighting the advantages and limitations of M&S methodologies in supporting decision making during paediatric drug development. Bellanti and Pasqua (2011) conducted a review of

relevant publications on the use of model-based approaches in paediatric drug development, therapeutics and the related decision-making processes. They revealed that M&S-methods were useful as a tool that enabled them to develop drug therapy individualisation while improving the drug risk-benefit ratio in their population sample.

A significant advantage of M&S-based methods is that professionals can run simulation-based experiments to observe presumed causal relationships between the variables within the virtual phenomena to understand better and examine the system's behaviour.

3.2.2 Social science

M&S-based research method enables social science researchers to build realistic models of the real-world phenomena they are investigating. Held and Wilkinson (2018) argued that M&S-based research "is not a competitor to other research methods, but a complement" to help researchers solve problems by constructing virtual social dynamics to understand behaviour. The virtual social dynamic is also helpful to researchers by engaging with M&S-based tools in a wide range of intellectual processes such as changing parameters to see their effects in outcomes virtually.

Further, M&S-based research methods are considered a new type of research approach that enables realising connections between micro and macro-world by constructing models based on the individual units called agents. I offer four examples of utilising M&S-based tools in practice. The first example is the work of Grimaldo, Lozano, Barber, and Guerra-Hernández (2012). They implemented the Jason Multi-modal Agent Decision Making (J-MADeM) library to construct a model to represent urban mobility to understand decision making aspects of inhabitants of a city regarding their decision to get to work, e.g., by sharing a car, public transport, etc. By creating a virtual society, Grimaldo et al. (2012) compared outcomes of different scenarios such as agents representing an egalitarian and individualistic society, transportation use, average time, and the amount of CO_2 emitted into the environment.

The second example is about how M&S-based research methods illuminate the changing scenarios of religiosity and secularisation dynamics among individuals over time. Gore, Lemos, Shults and Wildman (2018) utilised social simulation models to predict religiosity and existential security changes. They conducted a multi-faceted analysis of the Human Development Report (HDR) of wellbeing on the critical dimensions of human development, including long life, a healthy life, and a decent standard of living. The interpretive design study revealed an increase in religious practices after natural disasters such as earthquakes and flooding as the natural disaster results in an increase in existential insecurity. Gore et al. (2018) suggested exploring additional mechanisms that may help clarify these religiosity changes and the possible adaptive role of secularisation. The study shows how the use of M&S-based tools can facilitate conceptual clarification of social phenomena and investigation of religious, social behaviour.

The third example illuminates how researchers are utilising M&S-based methods to avoid the obstacles of cost, ethical issues, and time factors. In this regard, M&S-based methods have helped researchers create virtual societies as reasonable substitutes for live experiments. It is possible to carry out investigations using a virtual community where individuals are not actual people but virtual entities. Researchers can then experiment with scenarios that would be unethical in the real world with real people. For example, Hébert, Perez, and Harati (2018) studied Syrian refugees migration pathways. They developed a dynamic model of the decision steps of the migrants, and they found that the validated model could be a helpful tool for humanitarian agencies to prepare to receive refugees arising from forced migration.

The fourth example concerns the usefulness of M&S-based research methods in educating policymakers. For instance, Seifu et al. (2018) utilise an M&S-based research approach to educate Baltimore City policymakers and other stakeholders about the effects of childhood obesity prevention policies even though policymakers have a limited understanding of how the model was developed. They concluded that the M&S-based research methods benefited policymakers by adding value when: (a) applying for grants, (b) increasing evidence for decision-making, (c) piloting programs and policies, and (d) visualising data. This example showed that research

collaborators utilised one of the strengths of the M&S-research approach, particularly visualisation and communication techniques, to educate policymakers and other stakeholders to ensure actionable changes in childhood obesity prevention, policy, and practice.

3.3 M&S-based methods in education

M&S-based methods are helpful to develop demonstrable concepts such as how a railway transport system functions, the effect of gravity, how virtual human agents segregate themselves based on individual biases of colour or race. Several studies revealed that M&S-based tools are proving to be useful learning resources for a variety of learners. For example, Sassa et al. (2017) recently created the 'Landslide Interactive Teaching Tools' for stakeholders and users of the International Consortium on Landslides (ICL) through their global collaboration promotion of understanding and reducing landslides disasters. They utilised computer simulations to create landslide dynamics to demonstrate the motion and hazards of landslides virtually. This material aimed to disseminate the scientific and technological progress and practical use of disaster management tools across many countries, regions, and communities.

For science, technology, engineering and mathematics (STEM) students, computer simulations can provide practical ways to learn theories by conducting '*what if*' experiments and practice higher-order thinking processes (De Jong, 2010; De Jong & Van Joolingen, 1998; Falloon, 2019; Leonard, Barnes-Johnson, & Evans, 2019). Hogstad, Isabwe and Vos (2016), for example, researched engineering studies documenting students' communications using a simulation-based educational tool, Sim2Bil.[5] They claimed that Sim2Bil is a useful device that provides four ways for visualising engineering content: formula, graph, simulation, and menu window. The interpretive study reveals that simulation methods offer opportunities to visualise mathematics and connect different mathematical representations and applications.

[5] Sim2Bil is a simulation and visualisation tools in mathematics education for engineers.

M&S-methods are useful for virtual training of scientific knowledge, conceptual clarity on scientific phenomena and acquisition of practical skills in a virtual world that is readily transferable to real-world contexts. In this sense, students can relate their observations in the virtual world to their real-world experiences and enhance their conceptual understanding. Heck, Uylings and Kędzierska (2010), for example, exhibited a study about understanding the physics of bungee jumping using simulations as a part of an orchestration of classroom approaches. The study used experiments within a design environment. These researchers illustrated that the simulation mediated learning environment that provided a dynamic computer model allowed students to compare results from experiments, models, and theory with each other. The researchers also claimed that M&S supported students in an inquiry-based approach to STEM (Science, Technology, Engineering and Mathematics) education.

In medical science education, M&S-methods are claimed to be helpful to ensure competencies and safe practice of the diagnosis, treatment, and nursing. The approach offers an opportunity to learn about clinical reasoning skills, develop self-efficacy, provide virtual experience, reduce training errors, and embrace ethical benefits (Padilha, Machado, Ribeiro, Ramos, & Costa, 2019; Ziv, Small, & Wolpe, 2000).

Unlike disciplines such as medicine and STEM, where theoretical ideas can be demonstrable through practical activities, there is relatively limited scope for social science disciplines. However, M&S-based methods offer something different and an attractive approach to engaging students in learning about complex social theories. One example in which M&S-based methods are useful for learning complex theories and how learners acquire practical skills is by conducting 'what if' experiments within the simulation-based learning environment. Hulshof, Eysink and Jong (2006) utilised an interactive computer program called ZAPs (self-contained computer programs). ZAPs is an "interactive approach that enables students to engage with subject matter through exploration, experience, and discovery of psychology (p. 39). Hulshof et al. (2006) found that the experimental methods supplemented the introductory psychology course, and, interestingly, the participants' role was transformed from a student into a researcher. In this sense, M&S-methods provided

an opportunity to experiment in the virtual world when it was impossible to access the real-world context or a context that does not exist.

To summarise this sub-section, M&S-methods are useful for organising researchers' and educators' support mechanisms. Based on the above discussion, the M&S-methods have the potential to create an enhanced learning environment in which students can develop mastery of some concepts and, potentially, the ability to integrate knowledge in interdisciplinary fields. Moreover, the M&S-based learning environment offers a middle ground between academic lecture-based learning and learning by doing or experiment. Through M&S-methods, students can make risk-free errors that can help them develop understanding; potential risks can be imagined and run through simulations. In this way, a learner can think about the best possible strategies to overcome the issues that are hardly possible in real-world experiments. In theory, this should better prepare them for working in out-of-college professional practices.

3.3.1 Leveraging and repurposing M&S-methods in higher education curriculum

M&S-based educational tools are gaining popularity in instructional practices and innovative interventions in higher education study programs. I draw attention to further examples of curricula that leverage and repurposes the M&S-methods in higher education.

In their recent work, Holter and Schwesinger (2020) report on the utilisation of digital reconstruction through M&S-methods as a teaching tool in their graduate study program at Humboldt University of Berlin. They argue that an M&S-based approach is useful to create an interdisciplinary connection between digital technology and archaeology studies; the study revealed that the digital tools "mediate and communicate archaeological research for a broader public" (p. 168). Emphasising the importance of mediational tools, M&S-based educational tools in the Masters in Urban Development curriculum offer a similar opportunity to learn about complex urban phenomena. For example, Szczepanska, Priebe and Schröder (2020) document their newly introduced masters' program to train future

professionals to deal with complex urban dynamics. A 3 ECTS[6] point course within a master's program teaches future leaders of urban change to deal with changing scenarios of complex urban dynamics. The master's program module entails a series of sessions covering topics such as the reason for modelling, introduction to emergence and macro-micro paradigms in M&S-method, complex relationships between the physical, socio-cultural, and informational fields of urban systems. Besides, the course module entails hands-on learning activities utilising computer simulations and the presentation of modelling ideas.

In the same vein, M&S-methods are useful to teach complex science concepts through a computer-simulated learning environment. For example, Lee and her colleagues (2002) introduced M&S-methods to teach an introductory college biology course to engage, explore, explain and evaluate the methods of developing concepts in science. Lee et al. (2002) utilised computer simulations in the biology laboratory course to illustrate the story of the potato famine in Ireland in the 1800s. The course module emphasises the content, attitudes, and science process skills in the context of a constructivist learning environment. The highlight of the module was group work utilising computer simulation, formulating hypotheses, poster presentation etc. They conclude that the M&S-methods "allowed learners to practice [content] as cooperative learning groups with a variety of situations that resemble "real-life" problems" (Lee et al., 2002, p. 40).

Other fields such as finance education have utilised M&S-methods to enhance students' understanding of complex finance concepts, stock market systems and linking financial theory with practice (Marriott et al., 2015; Smith & Gibbs, 2020; Wolmarans, 2005). For instance, Marriott et al. (2015) report their intervention of introducing M&S-methods into Business Schools' Finance curricula utilising M&S-methods as an instructional tool. The post-graduate curriculum module's unique attraction was the adoption of the computerised stock market trading simulation to involve students in active learning techniques to enhance their participation. The study showed that the M&S-based learning approach improved students' learning

[6] European Credit Transfer System, 60 ECTS points is equivalent to one year of full-time study

experiences, stimulated interest, and increased deeper reflection and understanding of complex finance concepts.

The M&S-based method is substituting the traditional learning environment in graduate study programs of Master of Public Administration (MPA) and Master in Public Policy (MPP) curricula offering an opportunity to learn how to manage complex problems in the public sector (Ku, MacDonald, Andersen, Andersen, & Deegan, 2016; McFarland et al., 2016). Ku et al. (2016), for example, introduced M&S-based methods in the MPA curriculum module to educate future and current policy decision-makers to tackle the rapidly changing complex world. They implemented a semester-long study program in MPA classes in policy and analytic modelling methods at the Rockefeller College of Public Affairs, State University of New York. A ten-week M&S-based curriculum module aimed to enhance students' competence to deal with complex and analytic problems in public policy decision making. The M&S-based curriculum module entails: preparing for the simulation and stochastic uncertainty, introducing computer-based simulation models, connecting analytic complexity to socially constructed complexity, learning dynamic complexity, learning detail complexity, and proposing solutions to a complex real-world problem etc. The evaluation of the module revealed that the M&S-based curricula increased students' intrinsic motivation and facilitated system thinking. Further, Ku and colleagues also stated that the interface of computer simulation models (i.e., CoastalProtSIM) could "promote and stimulate students' interest in learning about dynamic complexity in public policy within a challenging and enjoyable learning environment"(p. 62).

Complementary to the Marriott et al. (2015) and Ku et al. (2016) studies, Hostetler, Sengupta, & Hollett (2018) documented how simulation-based educational tools encourage future teachers to discuss socio-political issues in the classroom. They implemented a semester-long course in 'Social Studies Teacher Education Curriculum' modules, including spatial thinking, individual and community mobility, social justice, civic and community engagement, geospatial representation and analysis and social change. Their choice of an M&S-based education tool of ethnocentrism and racial segregation allowed students to "discuss critical socio-political issues in the classroom without forcing them to reveal their

personal experiences or assumptions" (p. 145). They utilised a ViMAP[7] simulation, an agent-based computational representation of socio-political dynamics, aimed to encourage preservice teachers to discuss critical socio-political issues in the classroom. Hostetler and colleagues argue that once the learner locates themselves as "one of the agents (or agent-types) in the simulation or on the map, the remaining agent-types that represent people of a different colour can take on the role of the other" (pp. 145-146). Their results suggest that the M&S-based tools afford opportunities for the learner to "build discourses that include critical perspectives, debate relevant conflicts, and develop nuanced understandings of the underlying socio-political-economic mechanisms that may be responsible for the emergence of ethnocentric behavior" (p. 140). Hostetler and colleagues claim that teachers were deeply engaged in model-based reasoning about social dynamics without avoiding the issues of face, power, and diversity.

In this way, M&S-methods are proving to be active learning and teaching resources for students of diverse background. The M&S methods facilitate conceptual clarification of complex phenomenon, which plays an essential role in learning and teaching in educational contexts. Furthermore, the M&S-based methods facilitate understanding of complex systems (e.g., stock market), increasing intrinsic motivation and enabling students to take a more objective stance in examining social issues. More importantly, such methods create the opportunity to interact with virtual systems by extending the possibility of decreasing or controlling complexity that enables them to focus on critical issues.

3.4 The Schelling Applet

In this current study, I chose to use an applet (i.e., social simulation) based on Schelling's model of Social Segregation (McCown, 2014) to present some basic ideas about a social phenomenon such as the social in/exclusion, segregation,

[7] ViMAP program integrates computer modeling and programming practice in science and math classrooms. ViMAP is designed to introduce a complex form of computational thinking through a user-friendly interface that is easy grasp for students and teachers.

without making the simulation overwhelmingly complicated for novice learners. I refer to this as the Schelling applet. Frank McCown (2014) created Schelling applet's online version (Segregation Simulation) see Figure 2. The Schelling applet is designed in such a way that it provides a visualisation of Schelling's (1971) model of segregation. The American Economist Thomas Schelling introduced the Schelling model of segregation to illustrate how and why a small individual bias can produce collective segregation in any urban residential city.

The Schelling applet is a visual simulation of the *Schelling Model for Segregation*, which expands possibilities for understanding how residential patterns emerge when individuals have small preferences in selecting their housing. The Schelling applet,

> "… illustrates the random distribution of two types of recognisable "agent," which are indicated by blue and red squares. The agents (squares) represent a type of community element that share, to some extent, a critical social character (represented by the colours red or blue). Agents can move or relocate (have agency) when the number of neighbouring agents sharing the same characteristic (colour) is unfavourable to their tolerance of "otherness." (reproduced from my paper 4, p. 3)

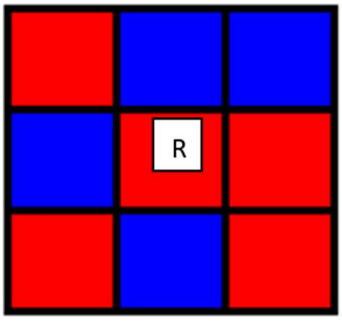


Figure 3.1(a)

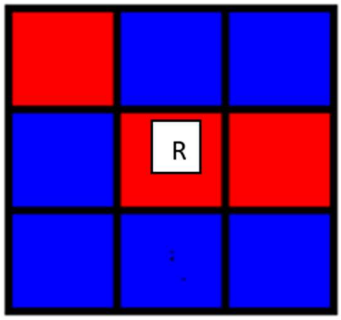


Figure 3.1(b)

In Figure 3.1(a), for the R block (as indicated in the figure), 4 neighbours share the same characteristic (colour). In this sense, the block has eight neighbours, and 4 of them are red. The rational number $\frac{4}{8}$ represents the proportion of whole sharing the given characteristic.

> "Depending on an agent's choice regarding whether to live within a neighbourhood of the same colour (in other words, the tolerance of an agent for living with neighbours from the other group), the agent may or may not relocate. Consider, for example, that agents are satisfied when at least half of their immediate neighbours share the same crucial characteristic (red or blue) in the Figure 3.1(a) above, the condition preferred by the "red" centre square (community element) is satisfied because 50% of its neighbours are also red ($\frac{4}{8}$), [50%≥t, where t = threshold tolerance for each block]. In Figure 3.1(b), the condition is not satisfied because only 25 % ($\frac{2}{8}$) are similar [25% < t]" (reproduced from my paper 4, p. 4)

The Schelling applet is an example of M&S-based tools developed to create representations of urban racial segregation that offer learners the opportunity to take on others' perspectives. Further, the applet is an example of an agent-based model of racial segregation that enables learners to discuss conditions under which household blocks (i.e., agents) may be discontent with the characteristics of the immediate neighbours.

In Figure 3.2, the threshold condition for similarity tolerance is set to 30%, which means that an agent is 'satisfied' when at least $\frac{3}{10}$ of their neighbours share the same colour (red or blue). If the number of same-coloured neighbours falls below this threshold, the agent will seek to move to a vacant square (a white block) with a higher proportion of same-coloured neighbours.

> "Also, in Figure 3.2(b), 3.2(c) and 3.2(d), the illustrations of the Schelling applet show the distributions after running the applet based on agents' threshold intolerances from a very low to a very high level. At higher (74%) in Figure 3.2(d), middle level (50%) in Figure 3.2(c), or lower (11%) in Figure 3.2(b) threshold, similarity segregation was more, medium, or less visible in the visualisations. In these applet trials, the higher the threshold (level of intolerance), the higher the likelihood that the community of household blocks get segregated" (reproduced from my paper 4, p. 5)

Figure 3.2(a) illustrates the applet before running the simulation, i.e., an initial condition of the Schelling applet with imaginary household blocks (i.e., agents). The satisfaction level of each agent is 0% which indicates they are discontent with the characteristic of their immediate neighbourhood.

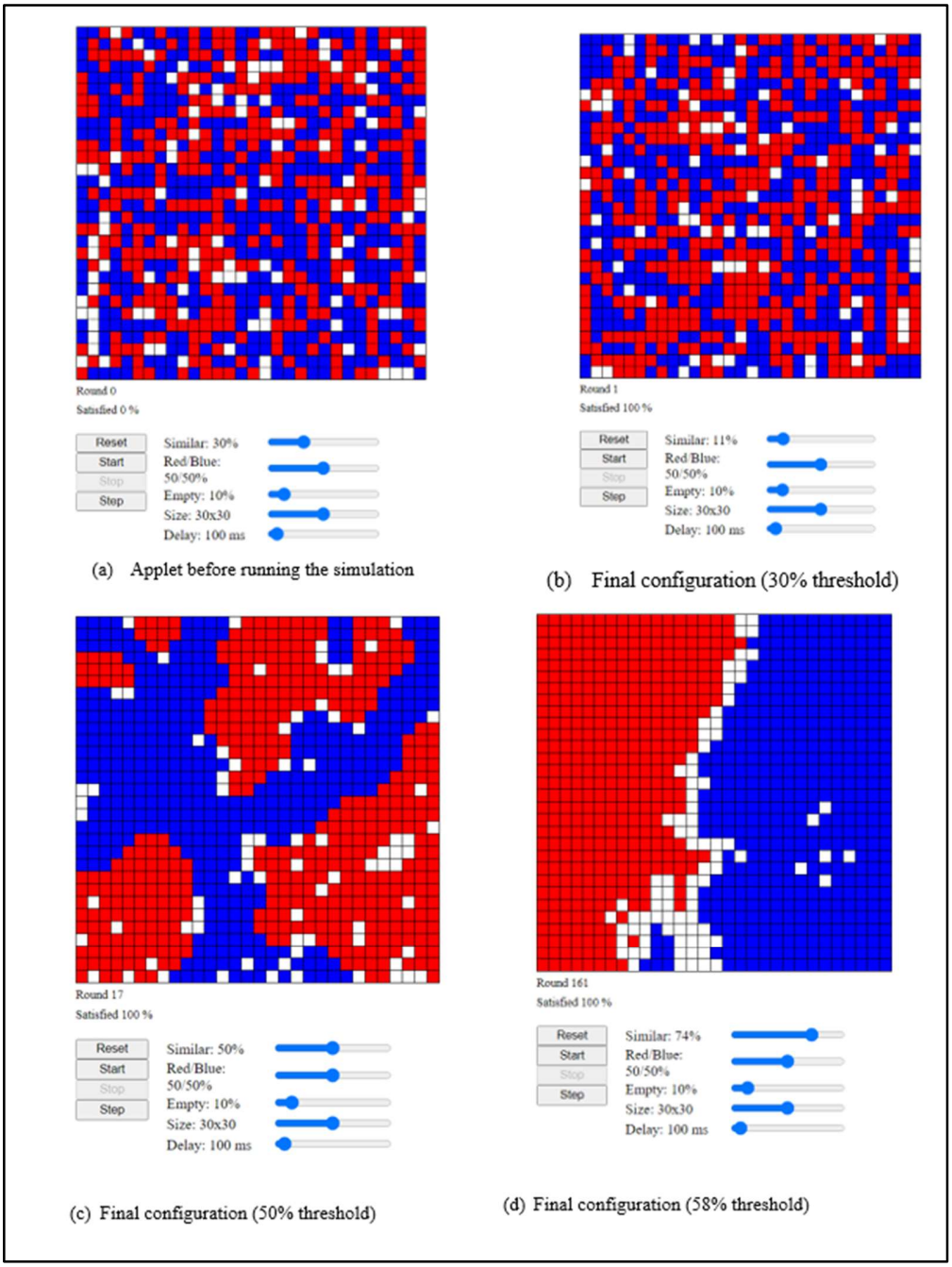


Figure 3.2: The result of the Schelling applet (figure reproduced from Paper 4, p. 4)

3.4.1 The Schelling applet is an educational tool

The Schelling applet is an educational tool that enables students to experiment with behaviour patterns of a virtual city populated by people with definable social attitudes through simulations. The computer experiments "can be done by running the simulation many times under different conditions (settings) to study its behaviour and compare the results. In this way, the behaviour of the systems is examined and understood" (Held & Wilkinson, 2018, p. 382). The Schelling applet as a mediational tool extends possibilities of students' engagement in interaction about complex social issues such as racial segregation, social in/exclusion. The Schelling applet interface allows a student to manipulate the behaviour (i.e., tolerance, intolerance, colour) of imaginary people and run the experiment, which is impossible in real-life. The epistemological significance of the Schelling applet is that individual students can be made aware of individual preferences or choices based on attitudes that are presented can be the root cause of segregation or in/exclusion.

3.4.2 Epistemological analysis of the Schelling applet

As described above, the Schelling applet is a visual simulation of the Schelling Model for Segregation. The visualisation and simulation embedded in the applet offer a method of seeing the unseen by inviting students to 'see' what appears in the output screen (Arcavi, 2003). In this regard, the characterisation of the applet is consistent with Presmeg's characterisation, "broad enough to include product and process, visualisation [and simulation] as an artefact (as in the number line as a tool of learning), as well as the meanings constructed by individual learners" (Presmeg, 2014, p. 152).

The interface of the Schelling applet:

> "…consists of two areas: input parameters at the bottom, controlled by sliders, and a visualisation area at the top. The display area illustrates, after running the simulation, the results of the inputs in the form of visual representation. The operation of parameters entails signs and symbols, such as percentages or fractions, spaces, colour indicators, sliders, underlying

model, start and stop keys, and empty boxes" (reproduced from my paper 4, pp. 6-7).

The Schelling applet enables students by providing them with an opportunity to use and reflect on sign and symbols (i.e., sliders, spaces, colour indicators, underlying model, start and stop keys), animations, images, shapes appear on the output screen to share evidence, thinking about, and advancing understanding.

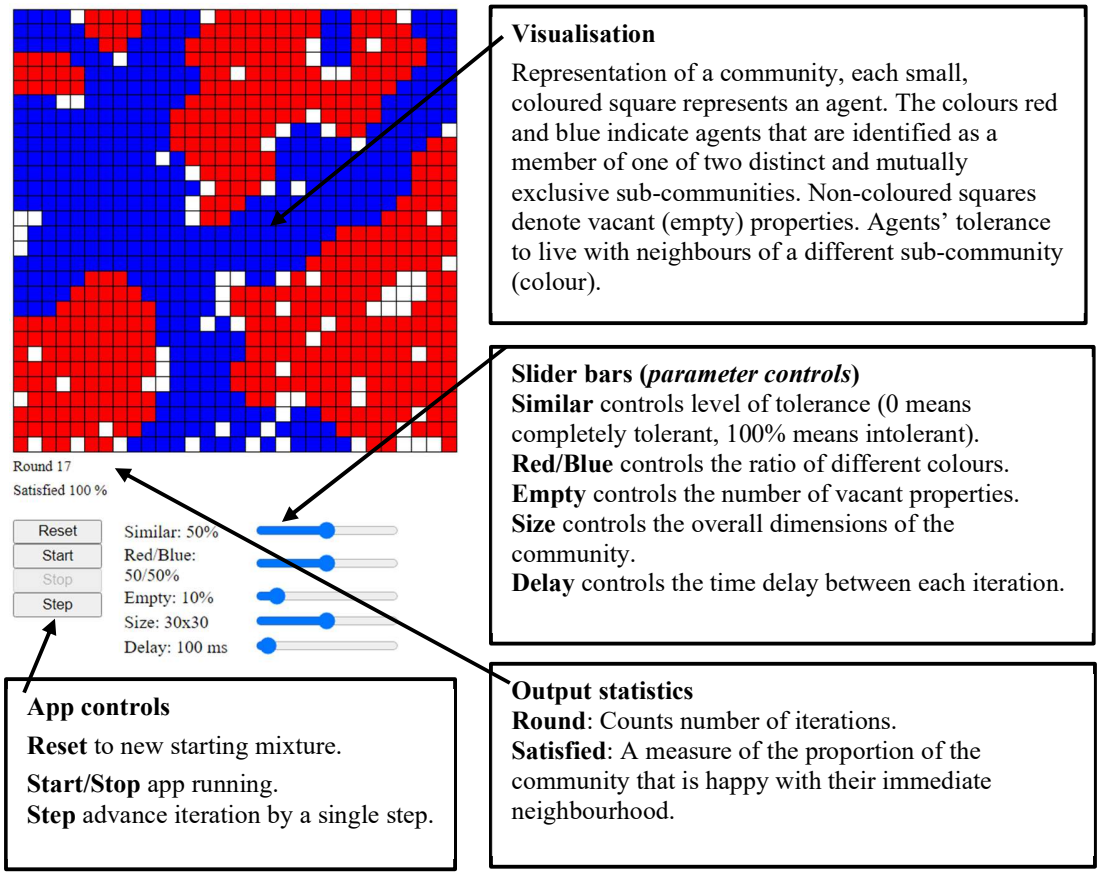


Figure 3.3: Components of the Schelling applet

According to Steinbring (2006), sign and symbol have two primary functions: (i) a semiotic function, "something that stands for something else," and (ii) an epistemological function, indicating "possibilities with which the signs are endowed as means of knowing the objects of knowledge" (p. 134). More specifically, the epistemological triangle (see Figure 3.4) is a theoretical instrument used to analyse the nature and development of mathematical sense-making processes, focusing on

the role of the sign, symbols, speech, visual image, and other ways of representing mathematical concepts. The Schelling applet's:

> "interface enables students to vary the input parameters, observing how the display (output) changes. The input parameters illustrate the representation of the mathematical concept in the form of a fraction or percentage that mediates the interaction between the virtual social phenomena of an urban neighbourhood using Steinbring's (1998) model, illustrated in Figure 3. 4. The epistemological triangle entails sign or symbol (fraction, percentage, squares, colour codes, sliders, press keys, empty boxes, underlying model), visualisation of the Schelling applet (referred to as an object or reference context), and the concept. The signs refer to both mathematical concepts and the visualisation of simulated virtual urban dynamics as a reference context (i.e., social science)" (reproduced from my paper 4, p. 7).

A summary of the Schelling applet's epistemological analysis that is useful to analyse students' interaction with the Schelling applet is illustrated in the following table 3.1(see Appendix 1 for Epistemological analysis of the Schelling applet).

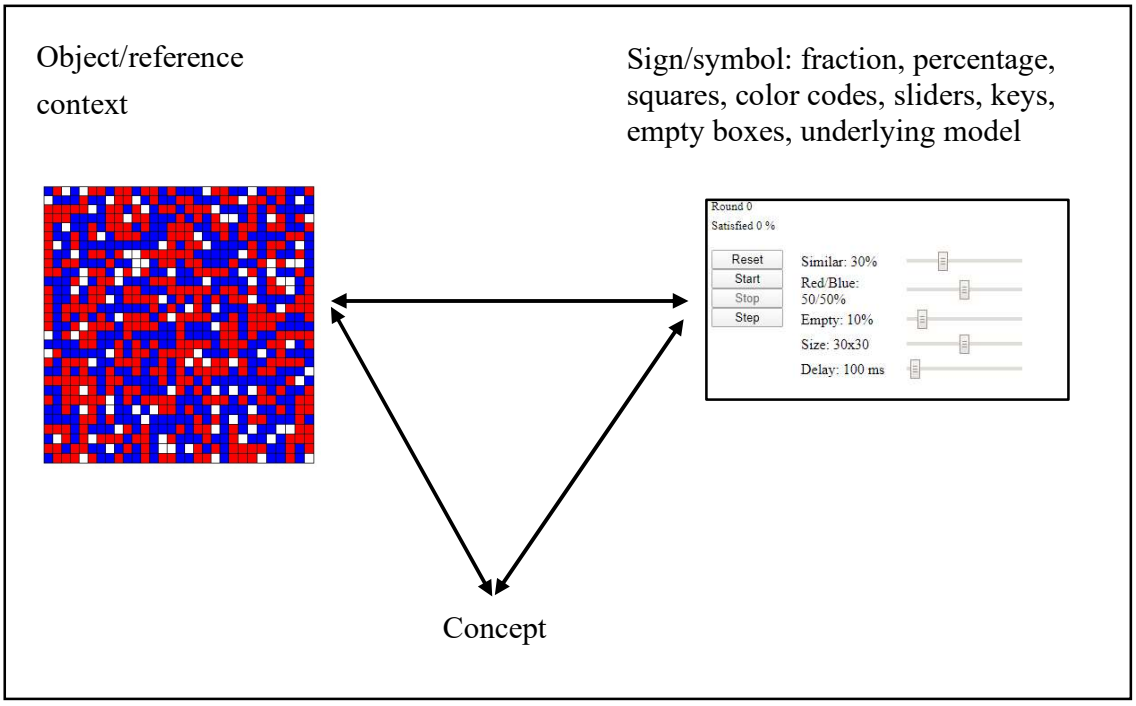


Figure 3.4: Epistemological analysis of Schelling Applet

Moreover, the concept is what students gain or reflect on the relationship between visualisation (object/ reference context) and sign/symbols. The Schelling applet,

> "as a tool (or cultural artefact), enables students' sense-making activities by connecting the physical world (i.e., interaction with the tools) and the conceptual world (i.e., mathematical and social science meanings). As Radford (2013a) argues, "artefacts do much more than mediate: they are a constitutive part of thinking and sensing" (p. 149). This approach sees artefacts as both physical and psychological tools that enable students' evolution of knowledge of mathematics and social science" (reproduced from my paper 4, p. 7).

The Schelling applet enables students by engaging them in the evolution of mathematical and social science sense-making processes. Thus, I anticipate students transform their observation from the concrete object (i.e., visualisation) to the conceived world (i.e., ghettoisation).

3.5 Setting the Schelling Applet and its educational use within the theoretical structure set out in Chapter 2

The Schelling Applet is an artefact or tool that mediates students' participation and interaction, aiming to understand and learn about M&S-based research methods. In the socio-cultural perspective, Danish (2014) argued the "notion of tools as mediators by focusing on the design of tools that both encourage individuals to engage with each specific activity's object and shape the user's perception in key ways that align with the chosen goals" (p. 106). For example, the Schelling applet is an example of a tool that is designed both to help the learner see specific aspects of the phenomena (i.e., social in/exclusion, segregation) and to help the learner appropriate a goal of understanding M&S-based research methods. Further, the applet mediates cultural-historical context of underlying categories of 'community' (structures and patterns of the population), "rules" (idiosyncratic regulations arising from personal and shared attitudes), and division of labour' (as devolution of an agency that enables an individual to choose, to some extent, the characteristics of the neighbourhood in which she/he lives). The Schelling applet is a basic example of a visualisation of an M&S-based approach utilised by M&S-based social researchers

Table 3.1: Epistemological analysis[8] of the Schelling applet

Procedural knowledge (i.e., pre-operational experience, getting ready to interact with the applet)	Operational knowledge (i.e., meaning that exists between control and what happens in the applet)	**An object in Schelling applet**	**Mathematics**		**Social Science**	
			Semiotic function "Stands for"	**Epistemological function "Meaning/concept"**	**Semiotic function "Stands for"**	**Epistemological function "Meaning/concept."**
		N (a number symbol e.g., "30")	In the app, it is used in the "cardinal" sense; that is, to represent "how many." It is used as a quantifier rather than an ordering or naming symbol.	Characterisation of phenomena with squares. A numeral (semiotic function) is used as an adjective as it quantifies the noun, tells how many of that "thing" are present. The meaning or concept is that it places the "thing" into a set in which all members share the same characteristic property of "quantity," the shared and equal "numerosity." However, on the slider bars, the ordinal meaning is also called on because the numbers increase uniformly as the slider is moved from left to right.	Agent A is an entity within the neighbourhood that shares a social characteristic with (A. In the applet, it is used in several contexts: It could stand for the number of squares surrounding a central square (which may share the same colour); it could stand for the dimensions of the whole square grid; it could stand for the proportion (%)	Agent (A) lives in a neighbourhood that shares, to some extent, a critical social characteristic. The characteristic is distributed throughout the neighbourhood, and agent A tends to prefer living with neighbours that share the same characteristic. The distribution of these units is not static and can change throughout time because the agent in those units (households) have an agency to move to another (more amenable) location if they find the surrounding community is not like one, they prefer to live in.

[8] I understand there is some variation in how the work of epistemology has been within mathematics education research. From a philosophical perspective, epistemology is a concern with the justification of knowledge. In this sense, I used epistemology here, which is consistent with Steinbring (2006) used the word. According to Steinbring, the epistemology relates more to what we know and how we know in the mathematical and epistemological analysis may be more accurately described as a semiotic analysis.

					of a community sharing a characteristic; etc. the numerical symbol stands for "how many."	The meaning of the numerical symbol can be linked to the density of the other units (households) in the neighbourhood that share the characteristic with A.
		Proportion/fraction	Symbolic representation of a part of a whole The proportion (in this context) will be a rational number.	The proportion of squares within a grid that share the same characteristic (colour) The whole may be divided into a given number (N) of equal parts; some (m) of these parts may be identified as sharing a characteristic not possessed by the remainder. The proportion of the whole sharing the given characteristic is represented by the rational number m/N	A quantity of "units" within a given community expressed as a fraction of all the "units" within the given community	The identified fraction/proportion of Agents (A) that share a characteristic which is not found in the remainder of the community. The characteristic is linked to the behaviour of Agent (A)
		%	The symbol for the proportion or fraction in which the whole is considered as 100 equal parts	Indicating that the numeral preceding this symbol represents the quantity of parts out of one hundred equal parts.	In a neighbourhood, the number of agents (A) out of every 100 surrounding that share the same social characteristic as (A)	Agent (A) is among a group that represents the proportion (expressed as a fraction of 100) of agents that share the critical social characteristics
		30%	30 out of every 100 parts of a phenomenon share a characteristic not possessed by the other 70	The proportion of squares (30 out of 100) bordering a single square that shares the same colour as the single central square. However, there are only eight squares that border a given square, so the eight squares are considered a single unit and then divided into 100 equal parts. Thirty of these parts are identified as sharing a characteristic not possessed by the others. Also, in the complete square grid, this would represent an approximation to the fraction of component squares that share (one of) the same colour.	In a neighbourhood, 30 out of every 100 agents surrounding an agent (A) share the same social characteristic as (A)	Agent (A) will want to relocate when the proportion of agents sharing the same critical social characteristic surrounding is less than 30%

in their field. The applet creates an opportunity for students to develop a sense of how large data might be used to create models of society (i.e., virtual society) that can be manipulated to answer several imaginary questions.

In the educational context, the Schelling Applet is a simulation-based educational tool (i.e., simulation and visualisation) that mediates the evolution of mathematical and social science sense-making processes utilising semiotic means of objectification (Radford, 2002). In this approach, a "student's interaction with the Schelling applet appears in three modes of generalisation: through mathematical sign/symbol, students' action, and language" (reproduced from my paper 4, p. 15). In this sense, the Schelling applet mediates the processes of generalisation of simulation, and visual patterns appear in the output screen. The applet brings the emergence of social segregation (emergence being somewhat slow and therefore a rather abstract process) into the shared conscious attention of the students.

The function of mathematics illuminated by the Schelling Applet is abstract, and "the only way to have access to [mathematical objects] and deal with them is using signs and semiotic representations" (Duval, 2006, p. 107) (reproduced from my paper 4, p. 9). In doing so, students engage with the Schelling Applet as they move within and between the different representations – enactive (moving slider bars), symbolic (changing values), iconic (figurative representations), and meaning (relation to the real-world).

3.6 The introduction of the Schelling Applet in an innovatory M&S-based research methods curriculum module

I am reproducing the following text from my Paper 3, pages 6-7.

> **"Implementation of the M&S-Based Research Methods Module**
> The M&S-based research methods module is intended for students of religious studies. The central hypothesis is that these students can develop knowledge of M&S-based research methods and understand the opportunities and limitations of using M&S-based methods in social research without having knowledge of mathematics or a programming language.
>
> **The Introduction Seminar**
> The 3 hours seminar was conducted in three parts. The first part was mainly a lecture-style presentation in which background information about conventional research methods, such as surveys, historical approaches, and ethnography, was

introduced. M&S-based research methods were introduced as an alternative research approach to study social dynamics in which subjects are not actual people but virtual entities. In this way, M&S-based research methods allow for conducting studies using imaginary scenarios and thus eliminates the risks entailed with human participants.

The second part of the seminar sought to answer the questions, "What is a simulation?" and "What is a model?" In this part, students were given the opportunity to obtain hands-on experience with a social simulation applet (i.e., Schelling Applet) related to a theme of religious studies: the social inclusion and exclusion of people. The Schelling Applet was developed based on Schelling's Segregation Model (Schelling, 1971); the animated applet is freely available at http://nifty.stanford.edu/2014/mccown-schelling-model-segregation/. The representation by the computer-simulated of Schelling's Model (i.e., the virtual world) imitates a real-world phenomenon and provides an opportunity to explore complex social dynamics through changing social/community characteristics.

The third part of the seminar included a discussion guided by probing questions such as "Why do researchers use simulation-based research methods?", "What questions could be answered by creating a virtual Norway?", "Will the ageing population affect tolerance in the community?", "What are the assumptions and limitations of these methods?" and "Are you interested in using M&S-based research methods in the future?"

After the seminar, students were asked to register suitable dates for the tutor session, which was planned accordingly. The author set students in different roles depending upon where they are in the sessions.

Tutor Session

The student–tutor session was designed as a small-group session in which there would be a discussion of the opportunities and challenges related to M&S-based research methods and the possibility to help students clarify the concepts associated with these methods. Moreover, the session was intended to help students who chose to write a short essay on M&S-based research methods. Each tutor session lasted about 1 hour, and they were guided by some questions for students' reflection:

I. What do you see as the most promising aspects of these methods?
II. What do you see as the most challenging aspects of these methods?
III. How might this approach be applied to other contemporary social issues related to religious, social behaviour?

IV. If mentorship were available to help you learn these methods, would you be interested in using it for your future research?

Meet the expert session

The setting of the expert meeting was a round-table discussion. Taking turns, the students posed questions to experts (M&S-based researchers) regarding the usefulness, opportunities, challenges and limitations of M&S-based research methods. The researchers' role was to take notes regarding the students' questions and coordinate the meeting. The duration of the expert meeting was one hour. This paper focuses on the "meet-the-expert" event, which was the specific design innovation of the third iteration of the M&S-based research methods module.

Essay about the M&S-based Research Methods Module

The students were asked to write a short (300-word) essay, which was to be submitted along with the end-of-semester essay. The task was voluntary. They were encouraged to write the essay based on the knowledge they developed at the seminar, tutor session and meet-the-expert session; the essay task's primary goal was to assess how students utilised the opportunity to learn about M&S-based research methods."

3.7 Defining metaknowledge in the context of the present study

Metaknowledge is defined as background knowledge about a phenomenon (a topic, an area, a discipline, artefact). In contrast to direct knowledge of a phenomenon, metaknowledge about a phenomenon may include knowledge about its history, purpose, rationale, opportunities, limitations, and learning trajectory that may lead to that direct knowledge. For instance, students are engaging in learning about research methodology within social science study programs. The research methodology course teaches metaknowledge about research methods such as M&S-based research methods, ethnography, survey methods. In this sense, the M&S-based research methods curriculum module intended to develop students' understanding of the M&S-based research methods, rationale, background knowledge, how it is conducted, and its opportunities and limitations.

3.8 Research questions

In this educational intervention study, students participate in the M&S-based research methods curriculum modules through lectures, seminars, or meeting professional practitioners. These are the educational opportunities offered to students to transform their learning experiences. In this sense, they utilise their opportunities to learn about M&S-based research methods; however, it does not necessarily mean learning happened, or all took advantage of learning. Thus, I choose the phrase "opportunities to learn" to formulate my central research question.

The following central research question guides this thesis:

How do students in the social sciences (i.e., Religious and Development Studies) utilise the opportunity to learn about M&S-based research methods?

To answer this central question, the following sub-questions are formulated:

1. To what extent and how do students develop a sense of social science researchers' motivation for using M&S-based research methods?
2. To what extent and how do students develop an understanding of the opportunities, limitations, and challenges by utilising M&S-based research methods?
3. What possibilities are there to expose the evolution of students' mathematical and social science sense-making?
4. What can be deduced about the evolution of students' mathematical and social science sense-making during interaction with the social simulation applet?

Paper 1, 2 and 3 in this study address sub-questions 1 and 2, and paper four address sub-questions 3 and 4. I explain which specific sub-questions the different articles in the summary of the articles (Chapter 5). As a standalone unit, the four articles provide the background for discussing the main research questions (chapter 6).

3.9 Chapter Summary

In this chapter, I have presented an overview of M&S-methods in higher education. Further, this chapter demonstrated a review of literature that reports; M&S-methods in research and educational practice and how M&S-methods has been helpful within higher education curricula. Following this, the chapter also presents the Schelling applet and epistemological analysis of the Schelling

applet. Then, the chapter ends by presenting research questions to guide this study.

The next chapter (Chapter 4) marks the methodological and theoretical rationale that lies behind this study.

4 Methodological consideration

In this chapter, I present methodological approaches developed to explore how social science students utilise their opportunity to learn about M&S-based research methods. I begin with the choice of research paradigm, the ontological and epistemological position that inform my study. Further to this, I present a rationale for adopting design-based research methods, research design, a detailed account of the design cycle, their connection to the research question, and data generation methods. The chapter concludes with an account of the data analysis techniques chosen in this study and strategies to maintain this thesis's quality standards.

4.1 Research paradigm

Patton (2015, p. 153) defines research paradigm as "a worldview—a way of thinking about and making sense of the complexities of the real world". Elaborated by Thomas Kuhn (1962), the term paradigm was very influential within social science research, it was used to stimulate discussion about the shared beliefs, values and generalisations of a community of specialists regarding the nature of reality and knowledge. As such, the term "paradigm" encompasses the deeply embedded philosophical assumptions or the basic sets of beliefs that guide the actions and define the worldview of the researcher (Lincoln & Guba, 2000). The above lines indicate that the term "paradigm" can refer to a philosophical position, a theoretical framework, and a methodological standpoint.

In any discipline, research is primarily affected by the researcher's worldview due to the fundamental assumptions about what constitutes reality (ontology) and what constitutes knowledge and truth (epistemology). Based on these ontological and epistemological frameworks, scientific and interpretive methodologies form two distinctive research traditions. On the one hand, quantitative research belongs to the positivist paradigm and is most often associated with natural sciences research. The positivist paradigm is closely linked with an objectivist ontology, wherein reality is seen as existing in and of itself, independent of the researcher. It is an epistemological stance that assumes "knowledge confirmed by the senses can genuinely be warranted as knowledge" (Bryman, 2012, p. 28).

On the other hand, interpretive research, in general, entails three main features: an interpretive epistemological position, a constructivist ontological

stand, and an inductive view of the relationship between theory and practice (Bryman, 2012). The constructivist stand assumes multiple, individual or socially constructed realities shared between a researcher and participants (Bryman, 2012; Guba & Lincoln, 1994). For example, an interview may initiate meaning-making activity within groups and between individuals. Following an inductive approach, a researcher begins by gathering data from participants that leads to developing themes, generalisations and then refers to the theories. In this connection, researchers who adopt the interpretive paradigm strive to understand and interpret the world according to its actors (Cohen, Manion, & Morrison, 2018). In this study, I adopt the interpretive paradigm as a means for understanding how students utilise their opportunity to learn about the M&S-based research methods and their interpretation of the approach in terms of their future careers. To explain the choices of research strategy, design, and methods, I start by making my ontological and epistemological stance clear in order to locate my study within the interpretive research paradigm. This gives me a foundational rationale for the methodology of the study.

4.2 Ontological position

In contrast to the view that 'reality is out there' and detached from society, my ontology favours the perspective that the nature of reality is socially constructed as the outcome of an interaction between individuals and their environment. I focus on the interactive environment with the M&S-based tools and others, which facilitates the understanding of the M&S-based research methods. Within this context, students are considered active individuals in the process of constructing their worlds. Students' opportunity to learn about the M&S-based research methods is mediated by the M&S-based tools through their interaction with peers, artefacts, or tools. For instance, I assume that students can think of M&S-based social simulations as a virtual world of social dynamics that imitate or reproduce real-world processes. They co-construct their reality by interacting with their peers and the 'virtual-world created by M&S-based tools' (i.e., social simulation applet) to understand segregation, ghettoisation, or in/exclusion.

CHAT, as an overarching theoretical framework of this thesis, frames the participating students as actors in their activity systems. In this regard, we cannot study individual students' opportunity to learn about M&S-based research methods by separating them from their social and cultural environment. Packer

and Goicoechea (2000) have made useful proposals about ontological foundations of socio-cultural and constructivist theories. According to them, "the socio-cultural perspective's notion of learning—gaining knowledge or understanding— is an integral part of broader ontological changes that stem from participation in a community" (p. 234) which endorse a non-dualist ontological assertion.

How, then, do 'community of practice', 'the theory of knowledge objectification', and 'theory of semiotic registers' on which this thesis builds stand concerning ontological assumptions? If we look at situated learning theory, Lave and Wenger (1991) argued that students' opportunity to learn about M&S-based research methods are distributed between the individual and his/her environment. From this perspective, learning is not seen as the acquisition of knowledge by individuals instead as a process of social participation. This accepts that "learning, as increasing participation in communities of practice, concerns the whole person in the world" (Lave & Wenger, 1991, p. 49). In socio-cultural scholarship, strong ties between learning/knowing and identity have been highlighted (Lave & Wenger, 1991; Packer & Goicoechea, 2000; Wenger, 1998); the phenomena underline the "characteristics of social participation, relationships (such as that between novice and expert, newcomer and old-timer), the setting of the activity, and historical change" (Packer & Goicoechea, 2000, p. 227). In this connection, Packer and Goicoechea assert learning/knowing to be more than just developing understanding and entails broader changes in being.

The theory of objectification (Radford, 2008) "relies on a non-rationalist epistemology and ontology, which gives rise, on the one hand, to an anthropological conception of thinking, and on the other, to an essentially social conception of learning" (p. 217). This latter means that learning/knowing cannot be separated from doing and being. Radford argues that knowing (epistemological) and being (ontological) are deeply intertwined phenomena and need to be studied together. The theory of knowledge objectification aims to account for participants' (i.e., student, teacher, expert) "embodied, sign-, and artefact-mediated interaction that includes both co-knowing and co-being" (Radford & Roth, 2011, p. 244). Then, artefacts, sign and symbol, and social interaction mediate students' knowing (objectification) and being and becoming (subjectification) that resolve the dichotomy between subject and object.

In the theory of semiotic representation, Duval (2006) argues from an epistemological point of view, “there is a basic difference between mathematics and the other domains of scientific knowledge. Mathematical objects, in contrast to phenomena of astronomy, physics, chemistry, biology, etc., are never accessible by perception or by instruments (microscopes, telescopes, measurement apparatus)” (p. 107). For Duval, the only way to access mathematical objects is through exploiting signs and semiotic representations and understood as a transformation of such representations. For example, students’ interaction with simulation-based educational tools (i.e., Schelling Applet) entails mathematical sign and symbols and the rules for producing them is associated with the existence of mathematical sense-making because there is a meaning to be explored both logically and ontologically.

4.3 Epistemological stance

The paradigm of interpretivism leads my inquiry towards understanding the activity of my participants during the seminars, workshops and meeting with an expert that is conducted for the empirical part of my study. My epistemological position emphasises understanding the social world by examining the interpretations of its participants (Bryman, 2012). Thus, I assume that the nature of knowledge is experiential, inter-subjective, and contextual. The student’s activities in a university context are a social setting intended to originate new thinking and reasoning. Burton (2002) argues that students’ behaviour being researched could only be understood within their environment, which needs to be explored and explained. Further, acknowledging students’ social and cultural diversity leads to multiple interpretations of reality/truth.

I assume that students will be able to imagine that virtual worlds can support M&S-based researchers to run social experiments or to see what future scenarios of social phenomena could occur. Students will participate in the activities to understand how researchers utilise M&S-based tools or instruments to run virtual experiments without the potential to cause harm to actual people, maintaining an acceptable standard of research ethics, and avoiding socially sensitive issues. My proposal is to understand the processes by which students utilise the opportunity to learn about M&S-based research methods and the relationships in which students and M&S-based tools are necessarily interpreted. I assume that students' thinking, reasoning, or sense-making emerge through practical activity in the

social environment and concern the cultural-historical context and M&S-based tools.

It is worth noting that this current study and that of most M&S-based researchers are in distinct paradigmatic traditions. Most M&S-based researchers (e.g., Gore et al., 2018; Shults et al., 2018) develop social simulations by utilising variables derived from 'objective' observation of the real world. For most M&S-based researchers, there is an objective reality, which they try to reflect in M&S-based virtual worlds. Most M&S-based research can thus be qualified as having an objectivist ontology, while I followed the interpretive notion of inquiry and methodology. The illustration in Figure 4.1 represents the epistemic distinctions between M&S-based researchers and me.

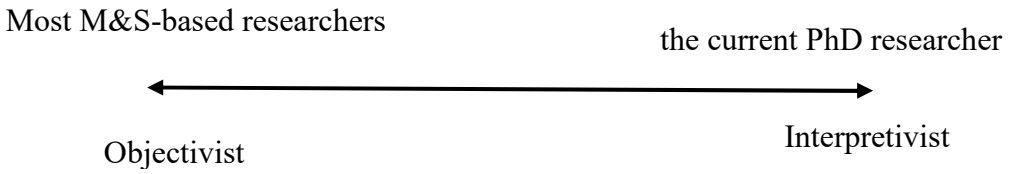


Figure 4.1: Epistemic distinctions between M&S-based researchers and the PhD researcher

In this study, I take a socio-cultural perspective, which supports a pluralistic view of research methodology curricula, aiming to design and explore an M&S-based research methods curriculum module within social science study programs. Students' learning within the socio-cultural framework is taken as multifaceted, participatory so that collective activities lead towards their goals. The design of this study aligns with what Bell (2004) described as a "folk (emic) research orientation that investigates the manifested meaning of an intervention from the point of view of the participants of the research as interpreted through their activity and their accounts" (p. 248). For Bell, design-based research (DBR) is a folk (emic, i.e., from within the social group researched) research orientation which is an alternative approach to theory-driven (etic, i.e., from outside the observed group). I anticipate DBR helps investigate the manifested meaning of the M&S-based research method module intervention from the participants' perspective (i.e., social science students). Further, DBR allows participants to

influence both the intervention and framing lens to understand whether students utilise the opportunities to learn about the research methods.

At this point, I argue that design-based research (Bell, 2004; The Design-Based Research Collective, 2003) is appropriate to design and explore a range of innovations within the research methods curriculum practices. The design-based research approach offers practical solutions to the problems regarding a research methods curriculum both from the perspectives of participating students and researchers involved in the design, implementation, and evaluation.

In the following sub-section, I describe design-based intervention as a research method.

4.4 What is design-based research?

Design-based research involves the iterative development of solutions to complex problems in educational contexts (McKenney & Reeves, 2012; Van den Akker, Bannan, Kelly, Nieveen, & Plomp, 2013). The design-based research approach offers the opportunity to start an educational intervention with a small scale of participation and enables researchers to increase its range and complexity (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). Furthermore, this research genre is generally characterised as intervention-centred, iterative, and adaptive, theoretically informed, practice-oriented, pragmatic, and composed of mixed modality (Reinking & Bradley, 2008). In this study, I use the definition outlined by The Design-Based Research Collective (2003):

> "Design-based research is an emerging paradigm for studying learning in context through the systematic design and study of instructional strategies and tools….design-based research can help create and extend knowledge about developing, enacting, and sustaining innovative learning environments" (p. 1).

I prefer an interactive and reflective educational intervention that focuses on the "systematic examination of data and refinement of theory" (Schoenfeld, 2006, p. 193) instead of (quasi-) experimental methods with controlled variables. Further, DBR involves analysing the problem situation, designing, and organising lectures for teaching and learning, evaluating the process formally, and then planning to repeat the intervention with new groups of students iteratively. The design leads to a product that guides the learning and teaching of

the M&S-based research methods curriculum module within methodology courses in social science studies. Hence, DBR combines research, design and implementation in a learning context; this is important when designing and developing a new curriculum module on M&S-based research methods within the social science study program.

The advantage of taking a DBR approach is that it eliminates the boundary between design and research (Edelson, 2002). Moreover, other researchers widely adopted the approach due to its practical contribution in developing empirical-based, prototypical learning trajectories in their fields (Bakker, 2018; Plomp, 2013; Van den Akker, Branch, Gustafson, Nieveen, & Plomp, 2012). The DBR approach is beneficial in research around the design of new educational practices in which new content is taught (Plomp, 2013; Vanderhoven, Raes, & Schellens, 2015). Design-based researchers emphasise the concept of artefacts that are not necessarily concrete, such as computer software or applets; however, it might be described as documenting development, challenges or learnings of "activity structures, institutions, scaffolds and curricula" (The Design-Based Research Collective, 2003, p. 6).

The DBR approach emphasises the process and features of artefacts (i.e., curriculum recommendation for M&S-based research methods) and educational knowledge (i.e., theory) development (Edelson, 2002). Moreover, design researchers seek a potential solution for a problem in education by exploiting available resources such as new technology for teaching and learning. In this connection, DBR methods are suitable for creating a new learning environment to explore future possibilities in teaching, learning and development of M&S-based research methods. This feature underpins the work of Vygotsky's (1987) view on teaching " *The teacher must orient his work, not on yesterday's development in the child but tomorrow's"* (p. 211; emphasis in the original). In this regard, the DBR approach "has its roots in Russian teaching experiments" (Kelly, 2003, p. 3) and the research approach aims to employ both educational and scientific methods, in which the researcher acts as an educator (Kelly, 2003).

4.5 Why design-based research?

DBR shares many principles with other research genres, such as evaluation research, community-based participatory research, implementation research, and action research (Fishman, Penuel, Allen, Cheng, & Sabell, 2013). In this case, an

alternative to DBR could be action research. According to Bryman (2012), "action research can broadly be defined as an approach in which the action researcher and members of a social setting collaborate in the diagnosis of a problem and the development of a solution based on the diagnosis" (p. 397). Action research is, therefore, a pragmatic co-creation of scientific and practical knowledge concerning the problems identified by the practitioner's research, which is facilitated by the researcher within the context, who makes informed decisions as a result of enhanced understanding (Koshy, 2005; Mertler, 2019). In order to assist the research process, a practitioner who takes the initiative for the research activity also acts as a researcher.

Table 4.1 Commonalities and differences between DBR and action research (Bakker, 2018, p. 15)

	Design-based research	**Action research**
Commonalities	Open, interventionist, a researcher can be participants, reflective cyclic process	
Differences	The researcher can be an observer Design is necessary Focus on instructional theory and improved design	The researcher can only be a participant Design is possible Focus on action and improvement of a situation

In contrast, DBR "involves active and thoughtful consideration of what has come together in both research and development (including theoretical inputs, empirical findings, and subjective reactions) with the aim of producing new (theoretical) understanding" (McKenney & Reeves, 2012, p. 151). As stated in the above table, both DBR and action research are cyclic in nature, interventionist, conducted in a real-world setting and intend to bridge theory and practice (Bakker, 2018). Both research approaches aim to improve practice; however, the essential difference between DBR and action research is that DBR is primarily aimed at generating design principles and developing new interventions (Bannan-Ritland, 2003; Plomp, 2013; Van den Akker et al., 2012). In this line of thought, Bakker (2018) argues: "in design research, the design is a crucial part of the research, whereas in action research the focus is on action and

change, which can, but need not, involve the design of a new learning environment" (p. 15). In this connection, the learning environment may include design and use of software (i.e., social simulation applet) in designing a model of practice to characterise a future "outcome" or "product" (diSessa & Cobb, 2004; Kelly, 2004).

Action research is a suitable approach in situations where the educational practice is already in place instead of starting a new intervention. This current study, however, requires new interventions in M&S-based research approaches within the research methodology courses in the social sciences. I can imagine, for example, when the M&S-based research methods are included in methods courses in the social science programs. I assume the teachers of the M&S-based methods can initiate action research to improve teaching and learning practices further. Thus, I reject action research for this current study and apply the interventionist approach of design-based research DBR (i.e., designing intervention in a real-world setting).

4.6 Research design

Having presented above the short introduction to DBR, and the rationale for adopting the DBR approach, the purpose of this short section is to briefly describe how my work is placed within the design-based tradition. My study

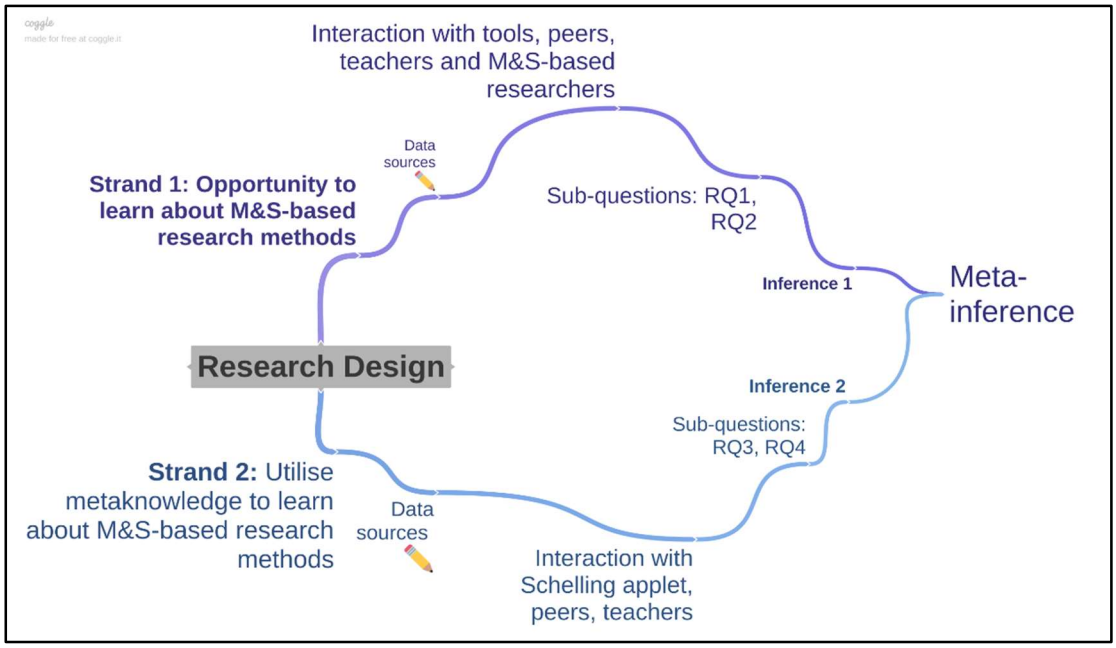


Figure 4.2: A sketch of my research design

entails designing with two interconnected strands, one being students' opportunity to utilise M&S-based research methods and the other, students' utilisation of metaknowledge (including mathematics) in learning about M&S-based research methods. Strand 1 was designed to address the first two sub-research questions and is reported in articles 1-3 (Sub-research questions 1 & 2, more details in chapter 6). The data sources incorporated in strand 1 are students' interaction with M&S-based tools, peers, teachers, and M&S-based researchers. The data collection methods involve; participant observation, audio, and video recording of interaction between M&S-based tools, peers, and M&S-based researchers.

Strand 2 is designed to address the other two sub-research questions reported in article 4 (Sub-research questions 3&4). The data sources incorporated in strand 2 are students' interaction with M&S-based tools, peers, and teachers. The data generation methods entail the recording of activities to capture students' voices and screen actions. Details about the data collection methods presented in Table 4.2 (below in Section 4.7) and the overall data processing and analysis strategies are presented in this chapter's following section.

4.7 The sequence of the design cycle and their connection to research questions

In this current study, the intervention consists of the seminar, workshop, tutor session, and meeting with experts to introduce students to an M&S-based research methods module. The DBR approach helps to incorporate recommendations derived from the formative evaluation of previous interventions. For instance, I improved the seminar's content for Religious Studies students in 2018 (ReliStud2018) based on the formative evaluation of the previous seminar as a pilot study (ReliStud2017). Likewise, the seminar designed for students of Development Studies in 2018 (DevStud2018) was the improved version of the seminar designed for Religious Studies students in 2017. Besides, I could extend the one-hour student tutor session and meet with experts for the Religious Studies group in 2018 to provide learning opportunities for interested students.

This design-based study investigates: How can students in the social sciences (i.e., Religious and Development Studies) utilise the opportunity to learn about

M&S-based research methods? Table 4.2 (below) illustrates the sequence of interventions and their connection to research questions.

Table 4.2: The sequence of intervention studies and their connection to research questions

Sequence of study	**Aim of the study**	**Connection to the study research question**
Intervention study I	To study the effectiveness of the design of lessons as well as developing a better understanding of the learning processes.	1. To what extent and how do students develop a sense of social science researchers' motivation for using M&S-based research methods? 2. To what extent and how do students develop an understanding of the opportunities and limitations of M&S-based research methods?
Intervention study II	To study how students of development Studies can gain metaknowledge of M&S-based research.	
Intervention study III	To undertake a formative evaluation of a 'meet-the-expert' event which was an element of the third iteration of M&S-based research methods curriculum module.	
	To explore what ways simulation-based educational tools can facilitate students in the evolutionary processes of mathematical and social science sense-making during the interaction between the social simulation applet.	3. What possibilities are there to expose the evolution of students' mathematical and social science sense-making? 4. What can be deduced about the evolution of students' mathematical and social science sense-making during interaction with the social science simulation applet?

4.7.1 Intervention study I: Student of Religious Studies Learning about M&S-based Research Methods

The intervention study II took place during the implementation of the M&S-based research methods module in the fall semester of 2018. As part of the preparation for intervention study II, I conducted a pilot study (intervention study I) at the beginning of September 2017. The pilot study was exploratory. The pilot

study's two main aims were: to explore the strong and weak points in my educational designs and understand the learning processes (how students interact with the M&S-based educational tools).

In the first iteration of the M&S-based research methods module, in colloboration with senior researchers and project leaders I created a learning context that consists of a 3 -hour seminar in which students of the Religious Studies program could participate voluntarily. A professor experienced in research methodology conducted the seminar. Following a participant observation approach (Bryman, 2012), my role as a researcher was to observe students' interaction between M&S-based tools, peers, and teacher and collected data by video-recording and field notes.

4.7.2 Intervention study II: Student of Development Studies Learning about M&S-based Research Methods

The second intervention study was designed for the students of Development Studies at the University of Agder, aiming to understand how this group of students gain metaknowledge of M&S-based research methods. My hypothesis was that students could understand how social simulation tools are useful to academic as well as professional researchers in their field.

In this iteration, the M&S-based research methods module was re-designed according to the core curriculum of the research methods in their study programs. Three Nepali students from a master's program in Development Studies were participants in this study. I was the leader of the 3-hours seminar on "Using simulation in development studies" (see Appendix 2 for a summary of the session plan). The recording of participants' interactions was done by the video camera to capture the overall activities of the seminar. Kaltura's CaptureSpace Desktop App was used to record the students' interaction with M&S-based tools, peers, and teacher. In this intervention study, I concentrated on students' engagement and their understanding of how and why researchers in their field utilise M&S-based tools.

4.7.3 Intervention Study III: Student of Religious Studies Learning about M&S-based Research Methods and Evolution of Mathematical and Social Science Sense-making

In the fall semester of 2018, I implemented the 'M&S-based research methods

module' aiming to gather evidence of how students of religion utilise their opportunity to learn about M&S-based research methods. The module was re-designed to incorporate the lessons learned from the previous interventions, modules I and II. The participants of the study were in their second year in the undergraduate program in religious studies.

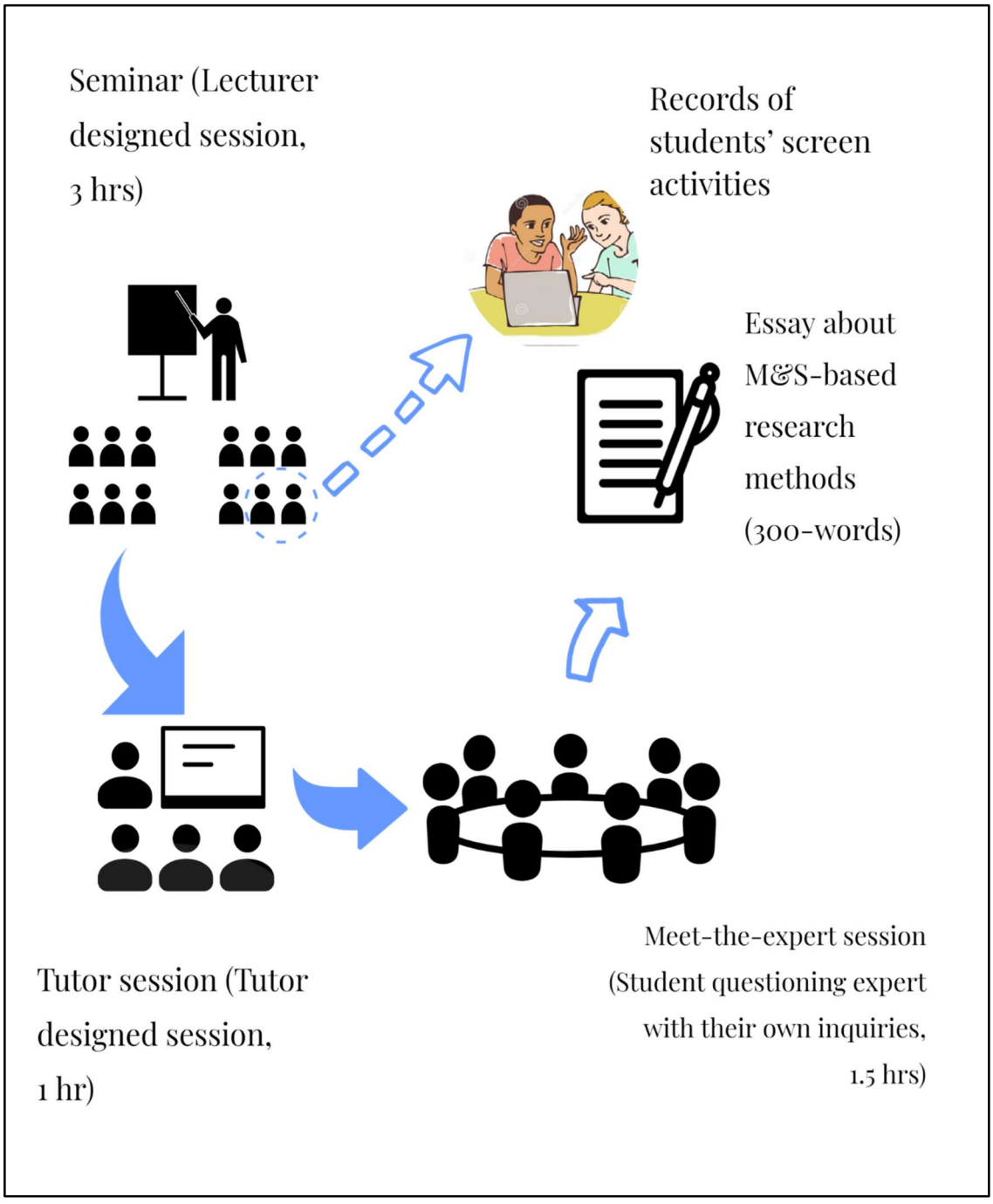


Figure 4.3: Data collection procedures in the Third Intervention

The M&S-based research methods module was a combination of seminar, tutor sessions, and meet-the-expert session. In intervention study III, the seminar entitled 'Research approaches to study social phenomena-will simulations give insights?' was designed around the theme of in/exclusion (i.e., social segregation). Figure 4.3 provides an overview of the structure of data collection and the organisation of the seminar, tutor session, meet-the-expert session, and student-written essay. The data generated includes a video recording of students' interaction, audio and screen activity records during the seminar, audio records tutoring session, audio records of students' interaction during the meet-the-expert session, and students' written essay.

In this intervention study, my focus was twofold. First, it was to study how can an M&S-based research methods module enable students to utilise their opportunity to learn M&S-based research methods. Second, to study students' interaction with the simulation-based educational tools (i.e., Schelling Applet) by constructing a priori epistemological analysis to operationalise students' interaction with the applet.

4.7.4 My field notes after the meet-the-expert session

As I have noted, the meet-the-expert session expands students' opportunity to learn about the M&S-based research methods through interaction with M&S-based researcher in their field. The meeting with the expert was organised as a part of the concluding session of the M&S-based research methods module. Students approach the meeting by asking some basic questions about M&S-based research methods. Some example of their questions were: Do you design a model? How long does it take to develop a model? How does a researcher a day look like? Student's choice of questions they were posing to experts reflect their naivety. It took a few minutes to get familiar with the experts. Students began to ask exploratory questions such as who use M&S-based methods, what are experts learning by using M&S-based approaches etc.

Experts aimed to convey how social scientists have studied society and social behaviour for many years, and then they developed theories (i.e., principled explanations). As an example, a model of a society is an interpretation of the theory. Likewise, experts have utilised their opportunity to define models, simulations and visualisations to help beginners. For this, they used examples such as a map is a model of geographical landscapes that are helpful to get from

one place, which includes critical characteristics of landscapes dynamics. I find the experts were describing the essential steps required to conduct M&S-based research methods. Experts are well-educated researchers who can connect necessary steps that are usually followed by social sciences researchers. For instance, social science researchers' professional practice entails connecting whole processes of M&S-based research methods such as real-world data, interpreting data, developing a theory, developing a useful model, and creating simulation and visualisations.

In contrast, the students are beginners in learning about M&S-based methods. They got the chance to interact with the Schelling applet during the seminar. They started learning about M&S-based research methods by exploring simulations and visualisations depicted by the Schelling applet. Then, they inquired about the research methods such as users of the model, data collection, experts' motivation to utilise the methods, and how the methods can help solve real-world problems. I suspect they skipped some of the necessary research steps that are followed by M&S-based researchers. It showed that students and experts were approaching the same phenomena from the opposite direction.

4.8 Design improvement on the M&S-based research methods module based on the formative assessment of intervention study I and II

From the experiences of conducting the intervention study I and II, the following design changes are made in the intervention study III:

- In the intervention study I, I had only initial lesson plans and PowerPoint presentations about M&S-based research methods. I realised a lack of resources that can be an additional reading for students who wanted to study more about the M&S-based research methods, such as its historical development, scope, limitations, opportunities, and challenges. In intervention study II, I identified some relevant journal articles for students of development studies. However, academic journals are not easy to understand for novices. Later, I identified a news article about an M&S-based researcher's conversation about artificial intelligence, social modelling virtual communities published in a popular newspaper, Aftenposten. The online version of the article is available at https://www.fvn.no/aktuelt/i/QlbrJA/lager-styringsverktoey-for-politikere-eksperimenterer-med-virtuelle-me. The newspaper article provided

background reading resources for tutor sessions and meeting with experts (see Appendix 3 for tutor session plan)

- In the intervention studies I and II, I utilised M&S-based educational tools as didactical tools to engage students in learning about M&S-based research methods to study population dynamics such as ghettoisation. However, some fundamental questions remained unanswered such as "What type of knowledge do learners draw on or apply while interacting with simulation-based tools? How do the simulation-based educational tools enable learners to develop, for example, knowledge of mathematics (signs, symbols, concepts, relationships, simulations, and visualisations) and metaknowledge about social processes? Does the interaction with simulation-based educational tools require metaknowledge of mathematics?" (text reproduced from my paper 4, p. 3). In an attempt to address these, I decided to capture students' interaction with didactical tools, peers, and teachers by using screen capture software so that I could develop an a priori epistemological analytical tool to interpret students' interaction with the online didactical/simulation tool.
- In the intervention studies I and II, I organised a seminar to introduce M&S-based research methods as a new research approach to study social dynamics. However, a 3-hours seminar was insufficient for learning about new research methods for novices. I, therefore, decided to re-design the M&S-based module in the intervention study to include an hour tutor session as a small-group meeting to help students clarify the concepts associated with these methods. Further, the sessions were intended to help students who chose to write a short essay about M&S-based research methods (see Appendix 4 for a call for student essay).

Design improvement during the intervention study III

- Students asked some challenging questions that required expert answers from practitioners of M&S-based research during the tutor sessions. Sometimes students asked questions that were beyond my expertise. I realised that the learning processes required interaction with M&S-based researchers (experts) so that interested students could ask questions regarding the usefulness, opportunities, challenges, and limitations of M&S-based research methods. I decided to call a round table meeting on the 9th of November 2018 entitled "meet the expert". It is interesting to note that the session focused on the open

discussion without pre-selected questions. The students appreciated the meeting.

4.9 The unit of analysis

Drawing on Vygotsky's (1978) mediated human activity, Yamagata-Lynch & Haudenschild (2009) describe a unit of analysis (UoA) as "capturing individuals interacting with the environment while making meaning of the world" (Yamagata-Lynch & Haudenschild, 2009, p. 509).To unpick this further, Roth and Lee (2007) state, "…unit of analysis allows for an embodied mind, itself an aspect of the material world, stretching across social and material environments" (p. 189). Further, the unit of analysis in the CHAT theoretical framework is an object-oriented activity within and across the context of university students and their future workplaces (Roth & Lee, 2007).

I consider UoA that is consistent with Blunden's (2009) suggestion supported by Ernest (2016), "the collaborative project". In this sense, "[…] project collaboration' is not something different from activity, but simply a unit of activity, a unit of joint mediated activity" (Blunden, 2009; as cited in Ernest, 2016, p. 51). As Leont'ev (1978) explains, mediated activity is the molar unit of life which I interpret as being not reducible to smaller elements but rather enable me to refer to episodes inter into my consciousness from the activity of participants.

Hence, I consider students' interaction with "M&S-based tools, sign/symbols or M&S-based researcher" as the unit being analysed; however, students' opportunity to learn about M&S-based research approach as an event can be understood if the UoA captures the situation as a whole. Consequently, the unit of analysis could include various mediational means, e.g., M&S-based tool being used, the natural language is spoken etc. In so doing, my choice of the UoA will differ as I refer to several studies of this thesis. For example, when I consider students' participation in the meeting with experts (i.e., M&S-based researcher) through CHAT-based analysis, the UoA will be the *interacting activity system of university study and workplace practices*, and M&S-based tools being the mediational means in this study.

Similarly, studying students' interaction with simulation-based educational tools through the theory of objectification and semiotic representation, *"Mathematical and social science sense-making processes" are* taken as UoA. In

this case, simulation-based educational tools (i.e., Schelling Applet), signs and symbols serve as the mediational means. In this way, the unit of analysis was helpful to select a "conceptualisation of a phenomenon that corresponds to a theoretical perspective or framework" (Säljö, 2009, p. 206).

4.10 Documentation, observation of iterative cycle, and re-design of M&S-based research methods module

Documentation in design-based research entails crafting a detailed account of design, implementation, and evaluation processes. In this present study, designing an M&S-based research methods curriculum module is one aspect of designing a learning intervention (i.e., artefacts), a learning environment or implementing a learning module within the social science study program. For McKenney and Reeves (2012), "Documenting the evolution of ideas so that others can understand the process is central to the enterprise of educational design research" (p. 111). To take this further, I agree with Kelly et al. (2008, p. 12) "Documentation is the archiving and indexing of the design research process that serves as a way of gathering evidence of the effects of design changes, and serves to inform re-design if changes to a prototype prove ineffective". Hence, documentation of design processes is equally important to associating evidence of what was implemented in an iteration. My documentation entails records of each intervention module elements such as session plans, a reflection of an internal and external observer, self-reflection notes. The documented items are archived in the project folder on my personal computer, and a sample of these documents attached appendices. Also, I wanted to implement a similar model in the successive iteration incorporating learning from the previous iteration.

The design-based research paradigm manifests both scientific and educational values through the active involvement of students and researchers in teaching and learning procedures. According to Kelly (2003), the research approach follows "scientific processes of discovery, exploration, confirmation, and dissemination" (p. 3). In this sense, the DBR approach is both scientific (i.e., systematic, purposeful, and driven by a search for evidence-based knowledge) and educational (i.e., focused on the creation of meaningful and effective learning experiences). Thus, the development of M&S-based research methods follows the scientific processes of design, implementation, and evaluation. The outcome of systematic observation enables the design-based researcher to compile an

ethnographic account of participants during the intervention teaching and note down the critical issues for the further re-design of the module for subsequent intervention. Therefore, the design of an M&S-based research methods curriculum module entails understanding the mediating processes in terms of epistemic commitments that include, among others, practical improvements on the module and theoretical refinement. Moreover, the DBR also involves the iterative implementation of the module, observation, analysis and cycle of module design; and attempt to link processes of enactment to the outcome of interest (Sandoval, 2014).

In this thesis, the documented learning from the first and second intervention study helped me to re-design the implementation of the M&S-based research methods module in intervention study III. In this study, for example, I added design tutor sessions and meeting with an expert to extend learning opportunities for the students (cf. Sub-section 4.7.3). The outcome of this study is not only the development of an M&S-based research methods curriculum module but also understanding about how the module can be used in social science study programs (McKenney & Reeves, 2012; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). Hence, I agree with O'Neill (2016), who argues that documenting processes of design, challenges and failure of design-based research could be an essential lesson for those who want to adopt design-based research in future.

4.11 Data Collection Methods

In a qualitative research approach, researchers often "[…] study spoken and written representations, and records of human experiences, using multiple methods and multiple sources of data" (Punch, 2009, p. 144). In this current study, the main ways of collecting qualitative data are the interview, participant observations, photos, and documents (as described in Table 4).

4.11.1 Interviews

An interview was conducted in the intervention study I of the M&S-based research methods module, where the basic idea behind the interview was to get a more profound qualitative sense of students' views about the M&S-based research methods module in social science study programs. I chose to use interviews as a method for generating data because the process is a "flexible tool

Table 4.3: Data collection methods

Intervention/ iteration	**Data source**	**Description**
Study I	Participant observation in the seminar	Video record of students' interaction with M&S-based tools, peers, and teachers
	Interview	The interview (video record) Email interview (recorded in email)
	Photos	Student work
	Document	Lesson plans, PowerPoint presentations
Study II	Participant observation in the seminar	Video record of students' interaction with M&S-based tools, peers, and teachers An audio recording of the students' interaction with M&S-based tools, peers, and teachers Researcher notes
	Photos	Student work
	Document	Lesson plans, Student essay, PowerPoint, Relevant reading resources such as journal articles, Student written notes.
Study III	Participant observation in the seminar	Video record of students' interaction with M&S-based tools, peers, and teachers An audio recording of the students' interaction with M&S-based tools, peers, and teachers
	Participant observations	An audio recording of the students' interaction with M&S-based tools, peers, M&S-based researchers
	Recording screen activities	Kaltura's CaptureSpace Desktop App[9] to capture students' voices and screen actions
	Documents	Student written essay, Lesson plans, PowerPoint, Relevant reading resources such as journal articles, Local newspaper article that feature the use of simulation-based methods
	Photos	Student work

[9]The app is useful for recording computer screen activities, audio, and videos. It also provides online storage for educational resources.

for data collection, enabling multi-sensory channels to be used: verbal, non-verbal, seen, spoken, heard and, indeed with online interviews, written" (Cohen et al., 2018, p. 506). Crucially, the purpose of the interview was to hear from the students in the form of social conversation following the seminar they attended. I posed just one predetermined question to initiate a conversation, "What do you remember from the research approach to study social phenomenon seminar?"

Three students from the first intervention study, i.e., "Students of Religion 2017", voluntarily showed their interest in a follow-up interview, which were performed mainly to evaluate the seminar and describe what they recalled from it (Poudel, Vos, & Shults, 2020).

4.11.2 Participant observations

Cohen et al. (2018, p. 542) explain, "observation is more than just looking. It is looking (often systematically) and noting people, events, behaviour, settings, artefacts, routines systematically, and so on". The observation gives a first-hand account of participants' activities in the naturally occurring social situations rather than the second-hand accounts such as reported data. The ethnographic approach allows me to take both; a researcher (being outsider) and an educator (being insider) role as a participant-observer of the culture of the M&S-based learning environment (Moschkovich, 2019; Moschkovich & Brenner, 2000).

In this present study, I employed participant observation techniques in all three studies (i.e., intervention study: I, II and III) to observe the activities in seminar and participants. More specifically, I take up account of students' activities (i.e., project collaboration) in the form of reflection notes right after the seminar, tutor session or meeting with experts. Furthermore, participant observation allows me to inquire into students' behaviour as continuously changing processes in the cultural environment of the M&S-based research methods module. This connects Roth and Radford's (2011) conceptualisation of students acting as a dynamic 'flux'.

My observation was concentrated to capture instances of the collaborative project and its emergence in my consciousness. More so, I intend to look at/for to be able to describe or explain or understand the collaborative project. My observation was based on the following guiding questions:

i) How students' patterns of interaction change over time?

ii) How their use of the different ways of interacting with the applet developed and change?
iii) How students communicated with each other orally, utilising sign /symbols or pointing out to the screen?
iv) How they might control the mouse, and the other is looking?
v) How the applet mediated the engagement between two pair of students?
vi) How/when the teacher engages with the student and how applet mediated that engagement?
vii) What type of language teacher and students use?
viii) How did this applet emerge in students' consciousness through their interaction with each other and the applet?

4.11.3 Recordings of interaction between M&S-based tools, peers, teachers, and researchers

In addition to participant observation, I obtained a video recording of interactions between M&S-based tools, peers, teachers, and researchers throughout the three intervention studies. I mostly handled the video camera for recording in the seminar sessions. During the pilot study, I only used the video recording to capture student's activity (i.e., explaining, engaging, participating etc.) or capturing patterns or trends of teaching and learning of M&S-based research methods. I agree with Moschkovich (2019) that "Uses of video data as an ethnographic method are multiple and varied. Video can be used to record, examine, and analyse many different types of phenomena and for multiple purposes." During intervention study II, I used the video data to capture the overall scenarios of the seminar and audio recordings to capture the interaction between students and teachers. The advantage of video data was that it captures activities of both teacher and students; seeks to capture moments that may entail something surprising or emergent occurring. Further, the video records and artefacts play an essential role in DBR to invite colleagues to address and analyse emergent questions to identify different variables that affect the failure and success of the design-based intervention (Collins, 1992). Also, I wanted to implement a similar module in the successive iteration incorporating learning from the previous iteration (see more details in Section 4.8).

On the other hand, the choice of audio recording was to capture the interaction between students, teachers, and peers. In intervention study III, I utilised both audio and video recordings. Further, in intervention study III, I have used all the methods such as video recording, an audio recording of students' voices and screen actions, photos, and documents. Students produced documents such as an essay that was collected in intervention study II and III. In intervention study III, the records of screen actions and voices were useful to capture the interaction with M&S-based tools, peers, and teachers. A screen capture software tool was used to capture students' screen activities that entail interaction with tools, peers, and teachers (see Section 4.7.3).

4.12 Data analysis

Participant observations, interviews, records of interaction between M&S-based tools, peers, teachers, and M&S-based researchers were transcribed. These students used their first language (Norwegian) for interacting with the M&S-based tools. A first-language Norwegian speaker carried out the transcription and translation of the video file into English.

Analysis of qualitative data is recognised as understanding phenomena within their context, sense-making through connecting concepts and behaviour, generating and refining theory (Miles, Huberman, & Saldaña, 2014; Patton, 2015). In their book techniques and procedures for analysing qualitative data, Corbin and Strauss (2015) emphasised that analysis is the "interplay between researcher and data out of which concepts are identified, developed in terms of their properties and dimensions, and integrated around a core category through statements denoting the relationships between them all" (p. 81). This strategy was attempted and realised differently in two unique strands (see above in the research design section): students' opportunity to learn about M&S-based research methods and their utilisation of metaknowledge in learning about M&S-based research methods. Specifically, I employed a thematic analysis approach for strand one and Miles and Huberman's framework for qualitative data analysis for strand two. The results from both methods were interpreted through the lens of the CHAT framework (i.e., Roth & Radford, 2011; Williams & Wake, 2007) (cf. Chapter 2 Section 2.3-2.6).

4.12.1 Thematic analysis

Thematic analysis is a qualitative data analysis approach widely used by researchers in diverse fields (Attride-Stirling, 2001; Braun & Clarke, 2006; Braun, Clarke, Hayfield, & Terry, 2019; Lehtomäki, Moate, & Posti-Ahokas, 2016). I followed Braun and Clarke's framework (2006) to conduct a mixture of inductive (data-driven) and deductive (analyst-driven) approaches. The six-step processes recommended by thematic analysis approaches are (1) Familiarisation of data; (2) Identification and grouping of themes; (3) Developing themes, (4) Revising themes; (5) Defining and naming themes; (6) Reporting the content of themes.

The thematic analysis provides a highly flexible approach that can be contextualised according to the needs of a study by providing a detailed and rich account of data (Braun & Clarke, 2006; King, 2004). First, the transcribed and translated media data (i.e., audio and video) were collected and read several times by the researcher (myself). The familiarisation phase involved "becoming "immersed" in the data and connecting with them in different ways: engaged, but also relaxed; making casual notes, but being thoughtful and curious about what you are reading" (Braun et al., 2019, p. 852). Table 4.4(a) (below) illustrates an example for the first step. Second, I identified and grouped data that are around similar meanings to developed themes according to the research questions**.** Third**,** the themes were developed identifying the meaning-making processes that indicate how students follow up their topics; for example, students are concentrating their interaction to understand M&S-based researcher's motivation behind M&S-based research methods. More specifically, to gather M&S-based researcher's motivation, for this students' questions were around professional lives, researchers' motive behind the research etc. I refer to Table 4.4(b) is attached bellow an example for step 2 and 3.

In the fourth stage**,** the relationships between and within the themes were categorised to represent a description of the M&S-based researchers' activities. Fifth, names of the themes were generated and defined to capture activities of M&S-based researchers and convey the essence of each theme. For example, "What strategies do researchers' employ to make their models better?" is a theme that encompasses researchers' strategies to validate models as well as their approach that could improve those models. Also, the theme captures student's awareness about trustworthiness criteria while implementing such research

methods. Steps 4 and 5 of the thematic analysis are illustrated in Table 4.4(c). In the final stage, I fully established the themes, and I prepared myself to begin the final analysis and write the report. Table 4.4(d) is attached below an example for step 6. In order to maintain the trustworthiness of the analysis processes, I have involved independent analysts at each step. In doing so, two analysts worked independently first, then compared the results and defined the themes through iterative cycles of generating meaning and establishing a connection between the themes.

Table 4.4(a): Familiarisation of data

	Utterances
	40:53 288. S3: So, what's the coolest thing you learned things… from the models? 289. Expert 2 : It's a great question. 290. S3 : Ha ha ha! 291. Expert 2 : Coolest thing 292. Expert 1 : Oh, for me I mean it is very nice to just …because you put behaviour into individuals. 293.S3 : Yeah. 41:13 294. Expert 1 : "You can come up with some, … any kind of behaviour if you can, so you can manipulate, so to say, individuals and then just put some, some kind of behaviors and see what comes out. So that's, that's for me is nice, so I really like that, I really like these models". 295. S3: Haam 41:30 296. Expert 2: For me, my favourite model we haven't published yet but it's on there is on supernaturalism like the tendency of people believe in invisible spirits, and that's this is a system dynamics model, and for most of the human history everybody believed in ghosts or ancestors' spirits so whatever. Aah…but only the 200 years started to go down through science, enlightens, secularism and so forth. And this model is able to simulate the fewer people believing the supernatural agents and more and more people being a naturalist and, and given the different call, the called mechanism behind it. Within about 40 or 50

	years, the crux will be more people who are naturalists the supernaturalists. 42:17 297.S3: "How many years did you say? 298. Expert 2: Around forty to fifty, [Student: Oh wow!] but that is only if the mechanisms Student: continue?] continue, and those mechanisms are four, er education, er, freedom of expression, er value of pluralism, and er, hang on, existential security. Around 40-50. 299. S5: I am sorry I do not understand all the words ...aah… you are saying.

Table 4.4(b): Examples of Identification, grouping and developing themes (Step 2 &3)

Sub-themes (# indicates the frequency of such sub-themes appeared)	**Supporting data sample (student questions, comments, notes) [] indicates the respondent's pseudonyms**
Special features about M&S-based research methods # 21	"So, what's the coolest thing you learned things… from the models?"[S3] "You can come up with some, … any kind of behaviour if you can, so you can manipulate, so to say, individuals and then just put some, some kind of behaviour and see what comes out. So that's, that's for me is nice, so I really like that, I really like these models." [Expert 1] "So, what's the coolest thing you learned…from the models?" [S3]
What makes a model better? (Trustworthiness of simulation model) # 13	"So how well your or. Is it, will it be like, how well your model to work depends on how much empirical data the country has?" [S3] "Yeah, so if we just do tons of empirical research your service will be, no, your models will be …." [S3]
	"Yeah. What makes your model better than other models?"[S3] "But they are not for us to use. Because we do not understand them. I don't get it." [S5]

	"I wanna see when it's done; you know not the programming that does not interest me. Aah, it's what can do with the model after that interests me." [S5] "Can I ask what approach you would take for making the model closer to the reality?" [S6]
Usefulness of M&S-based Tools #24	"I wonder, er, is it possible to make a model er that's, where it takes a specific person's, er, I don't know, data to put into a simulation, see how, figure out the way, for example, to rehab… rehabil …. rehabilitate the person from, for example, drug addiction, and then you know exactly how the best way to, to help this person, this specific person?" [S16] "Picking up, specifically about, for example, criminals, that instead of punishment we can have like everyone to do go through a system and when they come out, they will be good civilians (citizens?) instead of wasting time just locking, locking them up." [S16] "Teaching abstract concepts such as religious violence, extremism. and radicalisation are difficult." [S9] "This could be like an excellent example because modelling is like a computer; they could learn it while learning about important issues in our society would be interesting." [S9]

Table 4.4(c): Examples of revising themes, defining, and naming themes (step 4 &5)

Themes (final)	**Supporting data sample (student questions, comments) [] indicates the respondent's pseudonyms**
The motivation behind M&S-based methods	"You can come up with some, … any kind of behaviour if you can, so you can manipulate, so to say, individuals and then just put some, some kind of behaviour and see what comes out. So that's, that's for me is nice, so I really like that, I really like these models." [Expert 1] "So, what's the coolest thing you learned…from the models?" [S3]
What strategies do researchers' employ to make their models better?	"So how well your or. Is it, will it be like, how well your []model to work depends on how much empirical data the country has?"[S3] "Yeah, so if we just do tons of empirical research your service will be, no, your models will be." [S3]

How are M&S-based research methods useful in understanding religious social behaviour?	"There are also, erm, er did the model show that erm, if that happens, er, we'll erm, will it in decrease quicker? Or like, more naturalism [Expert: Right,] leads to less relatedness, ah, I don't know … (so the model …)." [S3] "(Talks over student) No, no, I think I understand what you mean, yep, yeah. Then it goes like this and hits a threshold and then it goes like this." [Expert 2] "How many years did you say? [S3] Around forty to fifty, [Student: Oh wow!] but that's only if the mechanisms [Student: continue?] continue and those mechanisms are four, er education, er, freedom of expression, er value of pluralism, and er, hang on, existential security." [Expert 2]
Opportunities by utilising M&S-based tools	"I wonder, er, is it possible to make a model er that's, where it takes a specific person's, er, I don't know, data to put into a simulation, see how, figure out the way, for example, to rehab… rehabil …. rehabilitate the person from, for example, drug addiction, and then you know exactly how the best way to, to help this person, this specific person? [S16] Picking up, specifically about for example, criminals, that instead of punishment, we can have like everyone to do go through a system and when they come out, they will be good civilians (citizens?) instead of wasting time just locking, locking them up." [S16]
Lack of coding and programming knowledge limits students understanding	"But they are not for us to use. Because we do not understand them. I don't get it." [S5]. "I wanna see when it's done you know not the programming that does not interest me. Aah, it's what can do with the model after that interests me."[S5]
Specific language or jargon used by experts is difficult for novices	"Yeah, ok so but have you found any indications whether your models are accurate or how accurate they are?" [S3] "It's just like a just like a map if you wanted a map to get to Oslo. Yea…you do not have every mode there , every balde of grass you know everything its sort of perfect replica of everything from here to Oslo. For instance, all of the mountains are there and the rivers and the everything you need just to figure out the best way to get from here to there. So, similarly with the certain kind of computer model the computer not gonna to include every blade of grass everything. But they include the big things that you need to figure out how to get from say, certain social situation where there is not much integration to more integration. Then you

	can explore the pathway and all the big things that you need to avoid or do in order to get there." [Expert 2]
Introduction of boundary-crossing objects.	"Yes. Ok, I understand. You do the coding (laugh) the models because it is like now if you make a webpage, you do not need to code it. But 10-15 years ago, you cannot make your own webpage if you did not know how to code it." [S5]

Table 4.4(d): Reporting the content of themes (Step 6)

Opportunities by utilising M&S-based tools
Student S16 was wondering if M&S-based research methods could create opportunities to develop an individualised treatment to rehabilitate a person with drug addiction. Expert 2 appreciated his ideas and described "lots of statistical and empirical studies on what it is describing: the different types of people, acceptability to criminality or drug addiction and lots of factor analysis correlational what connects to those things". The student showed his agency in imagining M&S-based tools that could enable him to develop an individualised treatment plan determined by a range of personal characteristics of the individual in need. Also, student S10 mentioned that governments could utilise M&S-based methods in the management of immigrants' integration. However, the student was worried that government officials lacked knowledge about these research methods, as the student felt that M&S-based methods could maximise governmental efficiency and be used to develop better policies. The students showed their awareness of the opportunities created by the use of M&S-based methods; for example, M&S-based methods can be helpful to maximise the services of government agencies as well as enable these organisations to develop better policies. Student S9 recognised the value of simulation of social dynamics, that it could help in teaching school students about abstract social theories. She mentioned that abstract teaching concepts such as religious violence, extremism and radicalisation are difficult. She said, "this could be like an excellent example because modelling is like a computer; they could learn it while learning about important issues in our society would be interesting". In this statement, she mentioned that modelling is like computing that motivates students to learn crucial societal context issues. Utilising such tools learning abstract social concepts would be more attractive to students, and learning would be relevant to a student's life. In this way, students understood the simulation and visualisations could be a useful tool to make learning about important issues in society (text reproduced from my Paper 3, p. 11).

4.12.2 Miles and Huberman's framework for qualitative data analysis

As described above in the research design section (see 4.5 research design), I used Miles and Huberman's framework for qualitative data analysis in strand

two. In analysing data, the interactive model of qualitative research suggested by Miles et al. (2014) was used to understand phenomena such as the interaction between M&S-based educational tools, peers and teachers. According to Miles et al., the interactive model entails three main concurrent flows of activity: data condensation data display and drawing and verifying conclusions. Data condensation refers to the first stage of analysis that sharpens, refines, focuses or organisation of data for further inquiry. The first stage entailed dividing the transcripts into chunks of data that illustrate each students' engagement with some (sense of completed) communication or meaning. Those pieces (i.e., units) were utilised to elaborate participants meaning by inserting commentary for each section. Table 4.5(a) illustrates the first stage of data analysis.

In the second stage, I developed analytical coding based on the epistemological analysis and various theoretical constructs such as metaknowledge, metaknowledge of mathematics, process, and product mathematics (the following text reproduced from my Paper 4, pp. 4-5).

"Metaknowledge

The notion of metaknowledge has emerged in several research contexts. For example, in the field of scientific research, Evans and Foster (2011) state, "metaknowledge research further explores the interaction of knowledge content with knowledge context, from features of the scientific system … to global trends" (p. 721). In the field of teaching mathematical modelling, Brown and Stillman (2017) defined metaknowledge as "the background knowledge that develops about the nature of modelling, how it is conducted and why mathematics can be applied in real situations" (p. 357). For this study, the author chooses to use Trouche's (2005) definition of metaknowledge.

According to Trouche (2005), metaknowledge is an evolution of "knowledge which students have built about their own knowledge (p. 202)" whenever they encounter a new activity context in which they discover new artefacts or tools. In this regard, Trouche distinguishes two dimensions or layers of metaknowledge. First, metaknowledge prompts students to seek to gather information (i.e., knowing what) about the semiotic resources about tools. For example, start and stop buttons, slider bars, outputs screen of Schelling applet, and manipulation parameters in the slider bars. In the second layer, students further process the information (i.e., knowing how) employing

several strategies, such as interpretation, verifying from more than one source, implementing explicit and tacit knowledge, and negotiating understanding that emerged from working together. Thus, metaknowledge plays a crucial role in the evolution of mathematical and social science sense-making by bridging tool-based knowledge (i.e., concrete knowledge) and conceptual (mathematical and social science) knowledge to be learned.

Metaknowledge of mathematics

Trouche (2005, p. 206) argues that individuals never act in an entirely "new situation when discovering new artefacts." In the context of didactics of mathematics, Trouche explains that metaknowledge is "knowledge linked to gaining access to mathematical knowledge, and knowledge about own mathematical functioning" (p. 206). Thus, metaknowledge of mathematics prompts a learner to engage in further investigation of a phenomenon, analyse and compare mathematical knowledge utilising language, value, position, and visualisation. The study reported here seeks to elaborate on the role of artefacts such as the Schelling applet in the evolution process of mathematical and social science sense-making.

Process mathematics

I use the expression "process mathematics" to refer to the interplay between known mathematical symbols, signs, and objects and the participation of a learner in the processes of generating new and using established knowledge. While developing knowledge, mathematical representations are perceived as cultural tools that are used during communication with others (Radford, 2001; Vygotsky, 1987). For example, learners develop metaknowledge about an object relevant to visualisation by calling on mathematical symbols or signs, such as fractions, percentages, approximations, rounding up and down, diagrammatic representations, the slider bars, for example, represent a measurement scale. This mathematical knowledge counts as "process mathematics" because students need to use this in the process of making sense and engaging with the visualisations. From the precisely "process mathematics" point of view, I include what a student is "doing," such as thinking, reasoning, arguing, sense-making, and predicting to see the future outcomes in the form of visualisation.

Product mathematics

By "product mathematics," I refer to what learners have internalised as a result of activity while interpreting mathematical signs and symbols in relation to a phenomenon or reference context through their experiences and implicit knowledge (Steinbring, 2006). The interpretive process provides an opportunity to develop reasons for manipulating mathematical symbols or signs, conceptualising the visual outcome of what students have gained in terms of metaknowledge, such as hunch, intuition, insights, representations, meaning, knowing, appropriations that are the result of their activity. Learners reflect on the relationship between the visualisations and the real world in a way that contributes to their development of understanding the above mathematical knowledge. The learned outcome is "product mathematics." "

This stage is more than just technical or preparatory work. Therefore, Miles et al. (2014) argue: "coding is a deep reflection about and, thus, deep analysis and interpretation of the data's meanings" (p. 79). At this stage, I utilised codes to connect and consolidate codes into themes, patterns, and more significant units. Table 4.5b(i) and Table 4.5b(ii) exemplify the analytic activities to expose the deeper meaning of the data. In the third stage, storylines were developed in order to draft findings. At each stage, two analysts (researcher and his supervisor) worked independently first, then compared and refined the practical use of categories involved in that stage. Table 4.5(c) offers an example of developing a draft in the processes of drawing and verifying conclusions.

Table 4.5(a): Data condensation

The following table illustrates the division of transcripts into chunks that illustrates each student's engagement with some communication or meaning. Ah-Ap refer to brief exchanges between A and K. I have marked the beginning of each of these on the transcript "REL206 20180907_IntroductorySeminar."

Student	Utterance	Code
29. Student K	: Okey, so there is just *as many of the red as* the blue ones, but then they choose to…	**Ad**
30. Student A	: Hm … if we take it up to 50 then	
31. Student K	: Yes	
32. Student A	: Just for fun, to see what happens then	Ae

33. Student K	: You have to hit it… it will probably start moving when you … I think	
34. Student A	: Hehe	Af
35. Student K	: There!	
36. Student A	: There!	
37. Student K	: Yes! Hehehe	
38. Student K	:Start. Now they did not move anything	Ag
39. Student A	: No, they did not…	
40. Student K	: Or did they?	
41. Student A	: Did they?	
42. Student K	: I don't know, but if we try. If we go down to … low	Ah
43. Student A	: Really low, 11%	
44. Student K	: 11, and then we see	
45. Student A	: Yes	Ai
46. Student K	: Are you sure, it is this one?	
47. Student A	: No!	
48. Student K	: Okey ha ha ha	
49. Student A	: Reset maybe	Aj
50. Student K	: Yes, maybe it is that one.	
51. Student A	: Maybe it is that one	
52. Student K	: And then let's go, we press start	Ak
53. Student A	: Yes, it happened …	
54. Student K	: That wasn't a lot	Ak
55. Student A	: That wasn't much	
56. Student K	: Okey, let's press reset again, and then we can try 50	Al
57. Student A	: Okey	
58. Student K	: Start, okey	
59. Student A	: Okey, yes. But "empty" is on 10%. We were supposed to have 50 one each, on each…	Am
60. Student K	: On all of them?	
61. Student A	: No, only 50 on each, the red and the blue is 50% and we understand that.	
62. Student K	: Yes, 50	
63. Student A	: So, then it is, it is very … clustered	An
64. Student K	: Yes	
65. Student A	: It is very	
66. Student K	: But it is like, I think it is … yeah	

67. Student A	: They are supposed to be the same now … they are… did you understand anything?	Ao
68. Student K	: Eah, I saw they moved, but	
69. Student A	: It wasn't a lot	
70. Student K	: Eah, so it is, but the thing is that they choose to go together with red neighbours then, instead of blue.	Ap

Table 4.5b(i): Data display

Aa	Not clear what "those" refers to. Student A & Student K decide what to do first. Start the applet running or drag the sliders?	Section A: This section appears to be about the two students gaining control of the applet. There is very little that appears systematic in their trial-and-error engagement with the applet. They engage with the slider bars to create new numbers (inputs) to the applet. They also seem to want to try some extreme inputs. By the end of this section A, it seems they have arrived at a sense of connection between the slider bars and the visualisation. Mathematical (meta) knowledge appears to be related to number (ordinal), and Student A uses the word "percent", but it is not clear whether this is only being read from the applet, or whether it is meaningful – as a fraction/proportion. I wonder how can that fraction/proportion relates to the visualisation – other than a form of a parameter that can be varied-has an effect, but the direct connection between the value and the visualisation is not evident.
Ab	They have tried one test. The teacher prompts the second attempt. Then agree on a second with a new value. They choose 49, is this a small change from earlier or a large change? There is no evidence that "49" carries any meaning.	
Ac	Teacher asks the question. It seems then they run the applet and the result on the screen – the visualisation indicates the answer. The students appear excited by the result.	
Ad	Student K comments on proportions of "red" and "blue", - "just as many" it seems that this is an interpretation of the visualisation rather than the value on the slider. When Student A says, "take it up to 50" what is Student A referring to? Is this a big change or a small change?	
Ae	This seems experimental, testing the applet to see what the result will be, but what was the input?	
Af	Student A & Student K appear satisfied with the result – in terms of the visual effect	
Ag	They start the applet again, but did they change any values before doing this?	
Ah	This seems to be more of a purposeful experiment. Student A refers to 11 "percent", Student K to just 11. – 11 is a low number, but what does it mean?	
Ai	It is not clear what "this one" refers to.	
Aj	Reset to start again, but what does "that one" refer to? Is it one of the slider bars?	
Ak	They restart but seem disappointed with the result.	

Al	They have reset and try "50" again. This must be a value on one of the slider bars, but which?	
Am	Student A & Student K discuss what is "allowed", but it does not seem to be related to the visualisation (what they are seeing) or what might happen.	
An	It is not clear what they mean by "clustered."	
Ao	Student A seems to have formed an expectation and asks Student K if Student K understood. It seems that may be Student A's expectation is not met. But what was Student A looking at … or expecting.	
Ap	They seem to have the idea about how the red and the blue move to be close to like colours. This seems to be an interpretation of the rule determining the behaviour of the applet.	

Table 4.5b (ii): Data display and analytic activity

The following codes (TP, TB, MS, ME, ME, SS and SE) are connected to the Schelling applet's epistemological analysis (cf. Section 3.4.2).

TP - It represents procedural knowledge at the starting position. Sometimes they propose new specification to interact with the tool with some expectation, and they only care about procedural knowledge.

TB - It represents the meaning between control and what happens in the tool.

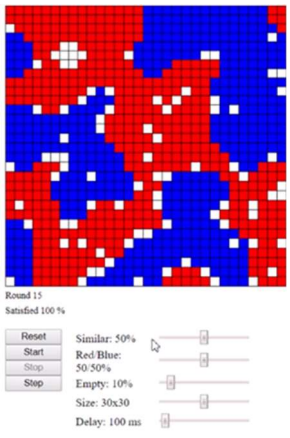
MS - It represents mathematics semiotic function (stands for).

ME - It represents mathematics epistemological (meaning and concept).

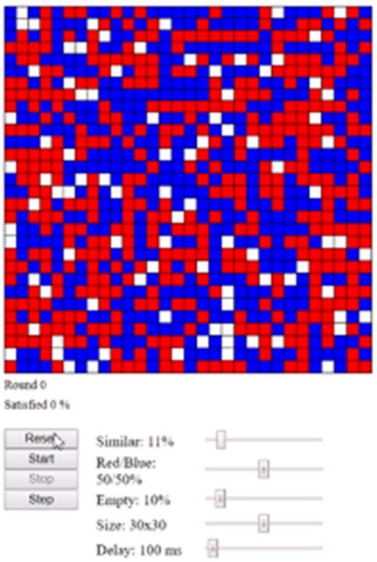
SS - It represents social science semiotic function (stands for).

SE - It represents social science epistemological function (meaning and concept).

Student	**Code**	**Utterance**	**Code analysis**
29. Student K	Ad	: Okey, so there is *just as many* of the red as the blue ones, but then they choose to…	Analyst 1: ME, Student K comments on proportions of "red" and "blue", - "just as many" it seems that this is an interpretation of the visualisation rather than the value on the slider.

			Analyst 2: Yes, this time, it is a ME interpretation of the visualisation. (a tool is meaningful to them that helped them to interpret the visualisation)
30. Student A		: Hm … if we take it up to 50 then	Analyst 1: MS: Student A proposed to increase the "Similar" slider bar up to 50. Analyst 2: I agree, but it is also connected to trying to achieve some effect on the visualisation
31. Student K		: Yes	
32. Student A	Ae	: Just for fun, to see what happens, then	Analyst 1: MS, they chose Similar bar 50%, empty 10%, size 30x30, delay 100ms. These are their inputs, and they expect to see outputs as a form of visualisation. These inputs are the mathematical metaknowledge that involved in the processes (i.e., process mathematics) Analyst 2 : They are controlling the values of variables by interacting with the slider bars. There is a connection between the values and the visual result. I agree with MS, but I think there is an implicit meaning underlying the actions because the students seem to accept that the values affect the visualisation. 
33. Student K		: You have to hit it… it will probably start	

		moving when you … I think	
34. Student A	Af	: Hehe	
35. Student K		: There!	
36. Student A		: There!	
37. Student K		: Yes! Hehehe	
38. Student K	Ag	:Start. Now they did not move anything	
39. Student A		: No, they did not…	
40. Student K		: Or did they?	
41. Student A		: Did they?	Analyst 1: ME, they follow the movement of the colour tiles but not make key comment. Analyst 2: I think you have to do more to justify the coding "ME". It seems to me that they are exploring the relationship between the controls (slider bars) and what is seen on the screen.
42. Student K	Ah	: I don't know, but if we try. If we go down to … low	
43. Student A		: Really low, 11%	
44. Student K		: 11, and then we see	Analyst 1: ME, Student K referred, putting down the slider bar low is decreasing the values in the slider bar. Analyst 2 : Here I agree with ME. Saying , set it really low is connecting several representations – language ("low"), value (11), and position (of the slider). This makes me wonder whether this can be taken as a form of evidence for ME (or SE) when the students connect several representation forms in action. Something to think about.

			They compare the earlier visualisation (turn 32) and the visual effect given by 11%  When they lower down the slider bar, the pointer dragged the slider to 11%. They reacted this value using 'really low', they inferred the position of the slider and value of illustration.
45. Student A	Ai	: Yes	
46. Student K		: Are you sure, it is this one?	
47. Student A		: No!	
48. Student K		: Okey ha ha ha !	Analyst 1: It seems they are expecting some connections it showed that they are working on meanings. They are working on meaning-making through language, the position of the slider and value displayed by the slider bar (Duval, 2006). They pressed the run button, but they didn't find major changes in the visualisation which they found that is because of low value in the slider (or position). It showed that they already mentioned that there would be a minimum effect on the visualisation. They are making the connection about what will happen

			next on the screen. They were only waiting for confirmation. They are trying to predict what's going to happened? TB- it seemed that they only spend a few seconds to look at the visualisation, and then they decide to reset the button.
49. Student A	Aj	: Reset maybe	
50. Student K		: Yes, maybe it is that one.	
51. Student A		: Maybe it is that one	
52. Student K	Ak	: And then let's go, we press start	
53. Student A		: Yes, it happened	
54. Student K		: That wasn't a lot	
55. Student A		: That wasn't much	Analyst 1: MS they compare the results with their expectation, but their expectation was not clear. Analyst 2: Here the students' attention is only on the behavior of the visualisation, and the controls. I do not see, in this brief episode that the students reflect on the inputs in any meaningful and systematic way. So, I do not think it is ME.
56. Student K	Al	: Okey, let's press reset again, and then we can try 50	Analyst 1: MS, they wanted to repeat the experiment with value 50% in Similar slider bar. ME It seems that they are repeating the experiment with the fact that they interpreted the previous results. Analyst 2: At this point the suggestion 50 indicates the students' reflection on the outcome and the values. Now, I might code ME
57. Student A		: Okey	
58. Student K		: Start, okey	

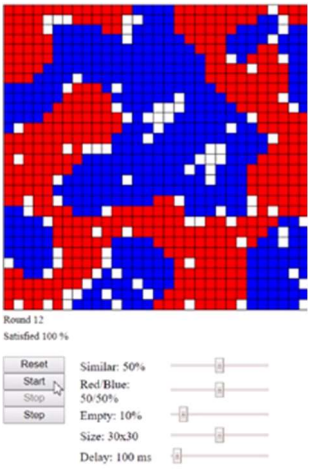
59. Student A	Am	: Okey, yes. But "empty" is on 10%. We were supposed to have 50 one each, on each…	
60. Student K		: On all of them?	
61. Student A		: No, only 50 on each, the red and the blue is 50% and we understand that.	
62. Student K		: Yes, 50	Analyst 1: ME, it seems that they analyse their inputs, carefully readings the scale of parameters. They expect 50 on each side, but their expectation was not clear.
63. Student A	An	: So, then it is, it is very … clustered	
64. Student K		: Yes	
65. Student A		: It is very	
66. Student K		: But it is like, I think it is … yeah	
67. Student A	Ao	: They are supposed to be the same now … they are… did you understand anything?	Analyst 1: ME, they interpreted the visualisation. It seems that the visual result was not as they expected. They got frustrated not meeting their expectation. There is gap between what they want to see and what they got in the output. 

Table 4.5(c): Drawing and verifying conclusions

Episode 1:Connection between inputs and effect in visualisation
Kevin (Student K) comments on proportions of "red" and "blue," stating "just as many" (turn 29). His interpretation was based on the characteristics of the visualisation that appeared on their screen. Anita (Student A) interpreted their outcome as "So, then it is, it is very … clustered" (turn 63), which represents product mathematics. She described the networked phenomena of coloured blocks that share the same critical social characteristics. It showed that Anita identified the movement of the colour blocks, and the pattern created by the blocks in the form of visualisation. The underlying behaviour of the applet caught Kevin's attention. He mentioned, "Yeah, so it is, but the thing is that they choose to go together with red neighbours then, instead of blue" (turn 70). It also showed that Kevin interpreted the rule determining the behaviour of the blocks. It revealed that the students' attention is on the behaviour of colour blocks and the controls of the slider bars. They understood the implicit meaning of mathematics in their underlying actions because they accept the effect on the visualisation. They demonstrated a connection between the values and the visual effect. In this regards, Kevin and Anita explicitly connected several representation forms in their semiotic representations (turn 42, 43, 44, 63). In this process, students utilise mathematical understanding through the interplay of multiple representations, language ("low"), value ("11%"), the position of slider ("lower down"), and visualisation ("clustered") in terms of students' utterances. It reveals that they controlled the values of the variables by utilising the semiotic system of resources (Duval, 2006, 2017) (text reproduced from my paper 4, p.13).

4.13 Quality criteria in design-based research

"Quality of a research project is not a singular characteristic" (Bakker, 2018, p. 87). The quality criteria for design-based research are linked to the planning, implementation, and formative assessment of the designed intervention and results analysis. In this connection, successful intervention and the generation of useful theory could be an outcome of the current DBR study (Van den Akker et al., 2006). To improve the quality criteria for design-based research, McKenney and Reeves (2012) highlighted that the "careful, detailed accounts of design study propositions, interventions, and findings allow others to understand, question and possibly even build on the theoretical understanding produced" (p. 205). Moreover, the quality standards of qualitative research are fundamentally different from those of the positivist approach because the notions of validity and reliability cannot be addressed in the same way that interpretive research operationalises.

Guba and Lincoln (1994) propose trustworthiness as a criterion to assess the quality standards of qualitative research, which involves establishing credibility, transferability, dependability, and confirmability. First, to increase credibility relating to the trustworthiness of the current study's findings, my engagement with undergraduate students of religion was helpful to build trust with the participants and minimises possible distortions. In this regard, I attended several lectures of the course, which allowed me to interact with the students. Further, to increase consistency, I engaged in the design, implementation, and evaluation of the M&S-based research methods module. For instance, I was involved in planning and implementing the intervention activities (i.e., seminar, tutor session and meet-the-expert session) and the assessment process. Furthermore, in the intervention I and III, I have involved independent observers for their observation on seminar and meeting with experts that provide an idea for further developments (see Appendix 5 for independent observers' comment on the meet-the-expert event).

The second criterion, transferability, which relates to how the findings can inform other contexts, can be improved by providing a full description of the procedures and explaining the key processes (Schoenfeld, 1992). In contrast to experimental research, DBR researchers often present their findings so that others can use them for their benefit because "context is perceived as a core part of the story and not an extraneous variable to be trivialised" (Barab & Squire, 2004, p. 3). In the context of design-based research, Bakker and Eerde (2015) prefer the generalisability of research results that the insights of the findings transposable to another educational context. Records of seminar planning scripts, post-seminar refection, and student reading resources were crucial for successive intervention cycles.

I also document the procedures for analysing the context-specific supporting documents of this research projects described extensively in this chapter, Section 4.10.

The third criterion, dependability, which indicates how consistent the findings are and can be repeated, can be illustrated by the same set of design propositions by using the same set of designs. I employed a variety of methods and tactics: the use of critical friends, multiple observers/analysts, and the accounts of inter-observer/rater reliability, etc.

The fourth criterion, confirmability, refers to the extent to which the findings are free from the researcher's bias, motivation, and interest. It can be ensured through the triangulation strategy (Denzin, 1978), which involves enhancing the quality of the data and analysis by avoiding the influence of any specific researcher (Denscombe, 2007). In this case, I performed the following strategies: (i) cross-checking through the different data sources, such as observation, group discussion, and document analysis; (ii) conducting a literature review of studies in which the researchers used similar theories, methods, and techniques to collect data; (iii) collaborating with a critical colleague to clarify and elaborate contradictions; and (iv) maintaining systematic documentation of, analysis of, and reflection on the design (including re-design), development, evaluation, and implementation processes and their results.

Although I am the primary investigator, I collaborate with my supervisor and other colleagues in different stages of this study and analysis of results. For example, while conducting three-step data analysis (data condensation, data display, and drawing and verifying conclusions), at each stage, two analysts were involved in comparing and refining the utilisation of the epistemological analysis table (see Table 4.5b (ii)). To enhance the issue of confirmability, I cross-checked through the data sources such as video records in the seminar, interview (oral and email correspondence), student's reflection about the seminar (see Appendix 6), collecting students work, photos, student's interaction with M&S-based tools, audio records of meeting with experts, student-written essay.

4.14 Ethical Considerations

Ethical approval for this PhD study was gained as research was registered with NSD— Norwegian Centre for Research Data (http://www.nsd.uib.no/) and received their approval. All participants are informed beforehand of the aim of the seminar and the process in which they involved. By giving their voluntary informed consent, the participants understood and agreed that their participation is without any compulsion. Following the Norwegian Research Ethics

Committee[10] and Bryman (2012), I also distinguished between the notions of anonymity and confidentiality, the former ensuring that no uniquely identifying information is attached to the data materials. Thus no one, not even the researcher, will be able to trace the data back to the individual who provided it.

4.15 Chapter Summary

In this chapter, I have discussed the research paradigm, the ontological and epistemological position, research design, development of intervention cycle and unit of analysis. The chapter also describes the sequence of the design cycle and their connection to research questions; it details an account of data generation methods, strategies for data analysis, and quality criteria in this study. The data collection of iterative cycles is illustrated in Figure 4.4 (McKenney & Akker, 2005). From the pilot study (Study I), my focus was on the available and practical design of the M&S-based research methods module and to develop a better understanding of learning processes. The results from the intervention study I is reported in paper 1, which has the title 'Students of Religion Studying Social Conflict Through Simulation and Modelling - An Exploration'. The results of the second intervention study are reported in paper 2, which has the title "Students of Development Studies learning about modelling and simulations as a research approach in their discipline." Likewise, the results of intervention study III are reported in the form of journal articles which I refer to as papers 3 and 4. Paper 3 is entitled 'So, what is the coolest thing learned… so far: Undergraduate students utilise an opportunity to learn about modelling and simulation-based research methods.' Paper 4 is entitled 'Exploring, experimenting, and sense-making: An epistemological analysis of students' interaction with social simulation applet.

The next chapter (Chapter 5) sets out a summary of each of the research papers arising from the study.

[10] De nasjonale forskningsetiske komiteer: Etiske retningslinjer for samfunnsvitenskap, humaniora, jus ogteologi. Available at: http://www.etikkom.no/no/Forskningsetikk/Etiske-retningslinjer/Samfunnsvitenskap-jusog-humaniora/

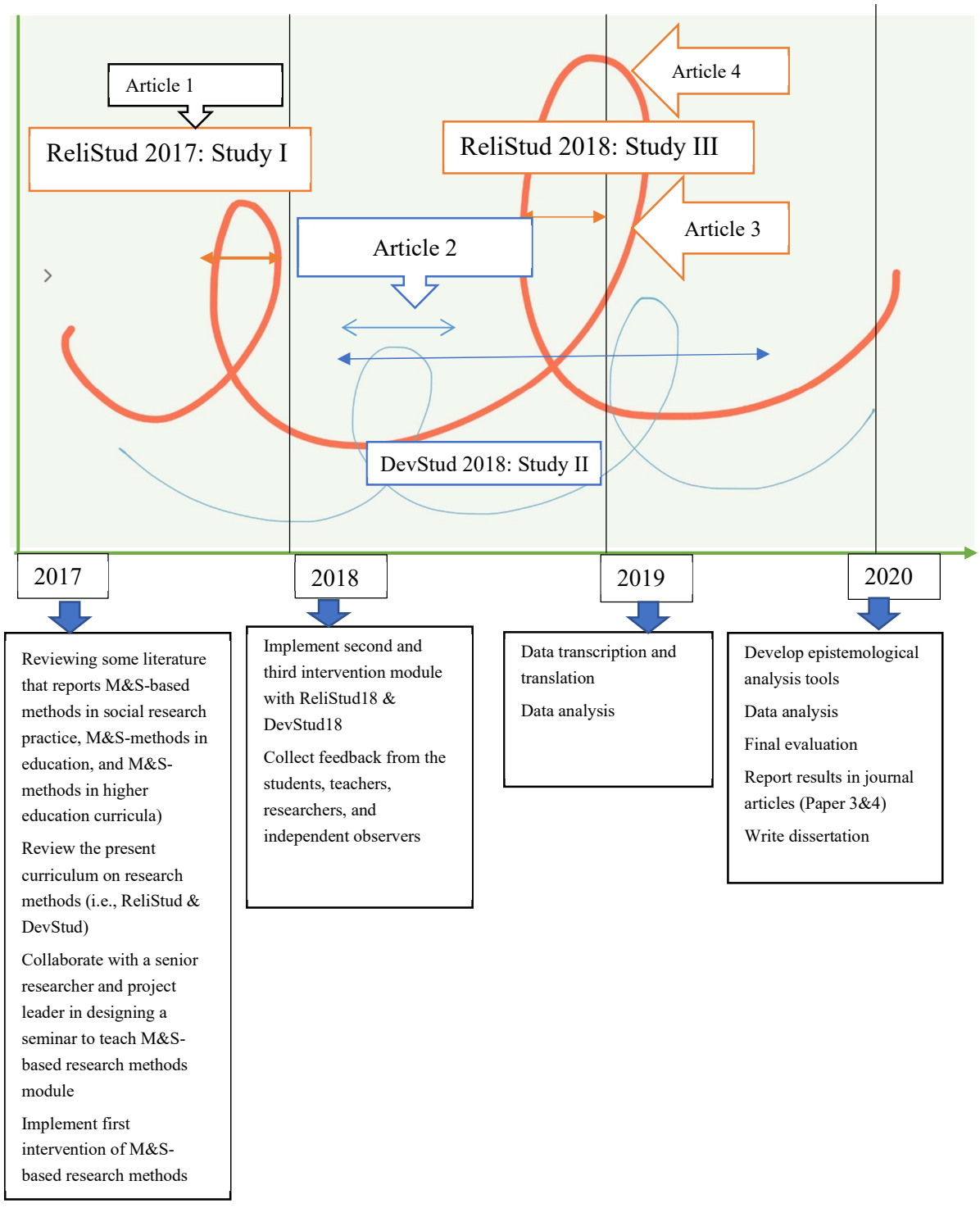


Figure 4.4.: The iterations of cyclic interventions. The thick line (red) denotes the cyclic process of data collection with the religious studies (ReliStud) students, and the thin line (blue) denotes the cyclic process of the Development Studies (DevStud) students.

5 Summary of research papers originating from the study

In this chapter, I introduce four papers that constitute the published (and to be published) component of this dissertation. The papers are presented in the order in which the data reported were generated, and the articles subsequently are written. The first paper reports on the first iteration of the M&S-based research methods module and focuses on the effectiveness of the design of lessons as well as an understanding of the learning processes. The second paper reports on the second iteration of the M&S-based research methods module with the students of Development Studies and focuses on how students can gain metaknowledge of M&S-based research. The third paper reports on the formative evaluation of a 'meet-the-expert' event which was an element of the third iteration of the M&S-based research methods curriculum module. The final paper explores and exposes how simulation-based educational tools can facilitate students in the evolutionary process of mathematical and social science sense-making during their interaction with the social simulation applet. These four papers altogether establish the foundation for the findings of this dissertation.

5.1 Paper 1

> Poudel, A. B., Vos, P., & Shults, F. L. (2020). Students of Religion Studying Social Conflict Through Simulation and Modelling: An Exploration. In H. Verhagen et al. (eds.), *Advances in Social Simulation*, Springer Proceedings in Complexity, (pp. 379-383) New York: Springer. https://doi.org/10.1007/978-3-030-34127-5_37[11]

Background

This paper reports the first iteration of the M&S-based research method module. The reported inquiry set out to gain a sense of feasibility and effectiveness of the design of lessons and a better understanding of learning processes. The study utilises design-based research methods for designing the learning environment; in

[11] Declaration signed by co-authors: I hereby declare that PhD candidate Amrit Bahadur Poudel has coauthored the paper: "Poudel, Amrit Bahadur; Vos, Pauline; Shults, F. LeRon (2020). Students of Religion Studying Social Conflict through Simulation and Modelling - An Exploration. Advances in Social Simulation. Looking in the Mirror. ISBN: 978-3-030-34126-8. *Springer Nature*. 37. s 379 – 383." made a minor contribution to the work in the research phase and made an average contribution to the work in the writing phase.

this case, new teaching methods were needed to deal with the new content of the M&S-based research methods module (Barab & Squire, 2004; McKenney & Reeves, 2014). The study hypothesised that the students learning is not merely an interplay between minds and simulations. Instead, their learning can be framed in light of three socio-cultural contexts: (i) the course, (ii) the world of academic researchers using M&S in social research and (iii) broader society in which there is a need to understand and limit conflicts. Cultural-Historical Activity Theory (Engeström, 2016) was employed to analyse students interaction with their peers, tools and environment.

Research questions

1. What are the strong and weak points in our educational design?
2. To what extent can the students understand how others (social researchers at their university) use M&S in their research?
3. Would they use this approach in their future research?

Methodology

In this study, a three-hour seminar was conducted for the bachelor's degree students of religion. The main features of the seminar were an introduction to different research methods in social sciences, hands-on experience with a social simulation applet (i.e., the Schelling applet) and guided discussion facilitated by probing questions. The social simulation applet was the digitalisation of a model of segregation developed by American economist Thomas Schelling (http://nifty.stanford.edu/2014/mccownschelling-model-segregation/). The applet engages students in actions aimed at developing their understanding of the processes of segregation of two distinct social groups. The video recording of the students' interaction in the seminar and video recording of the follow-up interview were analysed through the lens of the CHAT framework to answer research questions.

Results, discussion, and conclusion

The study results revealed students fully engaged in interacting with Schelling applet as they operated using the applet's sliders, run and stop buttons. They manipulated the imaginary people's behaviour to explore future scenarios such as positive, unsegregated, inclusive outcomes. In response to the teacher's

questions, ‘what could be studied using M&S-based methods?’, students shared several examples in which an M&S-based application could be utilised. They mentioned that M&S-based methods could be applied to predict unemployment rates, to discover what would happen if radical religious groups came into power, to understand criminality by understanding people’s behaviour. They identified that the use of computer simulation-based experiments is less harmful, ethically possible and cost-practical. It showed that students created a connection between their university context, their future professional goals, and their social lives as citizens. The study concludes that the M&S-based research methods module was useful for studying social dynamics and demonstrated the possibility of adapting the module in a future iteration. Thus, paper 1 (Poudel et al., 2020) lays the groundwork of the exploratory study to understand the effectiveness of the M&S-based module and to understand the learning processes. The overall result of the study led me to conduct the second iteration of the M&S-based research methods module with the students of Development Studies.

5.2 Paper 2

> Poudel, A. B., Vos, P., & Shults, F. L. (2019). Students of Development Studies learning about modelling and simulations as a research approach in their discipline. Paper presented at *Eleventh Congress of the European Society for Research in Mathematics Education*, Utrecht University, Feb 2019, Utrecht, Netherlands. https://hal.archives-ouvertes.fr/hal-02408983[12]

Background

This study focuses on the second iteration of the M&S-based research methods curriculum module with the students of Development Studies. The study hypothesised that the students could understand the ways social simulation can assist researchers in the field by gaining a metaknowledge of M&S-based

[12] Declaration signed by co-authors: I hereby declare that PhD candidate Amrit Bahadur Poudel has coauthored the paper: “Poudel, Amrit Bahadur; Vos, Pauline; Shults, F. LeRon (2019). Students of Development Studies learning about modelling and simulations as a research approach in their discipline. Proceedings of the Eleventh Congress of the European Society for Research in Mathematics Education. ISBN: 978-90-73346-75-8. *European Society for Research in Mathematics Education*. KAPITTEL. s 1256 - 1263.” and made a major contribution to the work in the research phase and made a minor contribution to the work in the writing phase.

research, that is background knowledge about the research methods, its rationale, the way it is conducted, and the extent to which it can provide policy-relevant information. The study utilises the definition from Brown and Stillman (2017), who used metaknowledge concerning the teaching of mathematical modelling. The study used the Cultural-Historical Activity Theory (CHAT) (Engeström, 1987, 2016) to analyse students' participation in several socio-cultural worlds in which they negotiate their meaning. Based on the CHAT framework, the students participating in the seminar on 'M&S-based research methods' are understood as actors participating in different worlds such as students in the university context, future professionals, future researchers, and citizens in the real-world.

Research questions

To what extent can students in a Development Studies program gain meta-knowledge about the relevance of M&S for their discipline during a short intervention seminar? The main question was breakdown into four sub-questions: To what extent do students:

i. Understand the way in which these research approaches describe and explain social dynamics
ii. Grasp the basic benefits and limitations of M&S-based research?
iii. Gain a sense of how researchers in Development Studies use such research approaches? and
iv. Imagine themselves as future researchers using M&S-based approaches?

Methodology

Based on design-based research methods, the second iteration of the M&S-based module was implemented through a seminar aiming to improve research methods curriculum practices in the Development Studies program (Van den Akker et al., 2013). A 3-hour seminar was composed of three sections. In the first section, some social problems such as an earthquake and its social consequences, social in/exclusion, and segregation were introduced. The second section was allotted for hands-on simulation experience regarding the issues relevant for Development Studies: social in/exclusion, migration, segregation of city's neighbourhoods. In the third, students shared their reflection based on the teacher's probing questions. The data generation comprises students' interaction

with their peers, tools, and teachers were video recorded and transcribed. The data analysis was performed using the constructs from a CHAT theoretical framework by coding student's engagement in four socio-cultural contexts: (i) as participants in a learning environment, (ii) as future development professionals, (iii) as potential M&S-researchers in Development Studies, or (iv) as citizens in a dynamic society.

Results, discussion, and conclusion

The study reported that students interactively ran a computer simulation to see the effects of the varieties of their inputs in slider-bars. By changing the parameters of the Schelling applet, they tried many scenarios such as removing empty spaces and people's behaviour in the time of crisis. The study reported that students were not only participating in the learning environment (discovering the effects of changing sliders in the applet) but also related their meaning as citizens in the real-world. To the question of what issues from development Studies could be answered by studying virtual worlds, students came up with several examples. It could be applied 'to provides a dynamic visualisation of phenomena and enable a researcher to observe long-term changes visually' or 'simulation could be medium for communication for those who dislike large data sets and do not have a strong background in mathematics.'

Further, students also reflected on their role imagining themselves as urban planners and how might they utilise M&S-methods to promote a tolerant community. They agreed that Schelling Applet, an example of a social simulation, represented a certain underlying structure in a society. However, agents' movement in the real-world is related not only to the colour of the neighbours but also to other factors, such as economic concerns or a desire to live close to relatives.

Students agreed that the M&S-based tool could serve as a tool for development professionals and policymakers who assist their societies in preparing for fighting criminal behaviour, setting up health posts, or training for natural disaster preparedness. The study reported that students alter their roles from university students to citizens and future professionals but not to that of researchers using M&S-based methods in their research activities. The CHAT framework was also useful in analysing students' engagement in the seminar as participants in different worlds. It showed that the M&S-based research methods

module was helpful to develop metaknowledge and relevance of M&S-based research methods in Development Studies. As the following excerpts illustrate that students imagined situations in which M&S-based research methods could be applied in their field.

> "Student B: Here is a different thought …If I have a virtual Nepal, I think we can find vulnerable places for a natural disaster. We can find out how likely it is.
>
> Student K: If we talk about health facilities, there is one health post in a VDC [Village Development Committee; Nepalese term for a rural organization unit]. Isn't that right? Any VDC has nine wards, and the health post will be in one ward. For [people in] other wards, it is far. So, if we can see distance virtually, then it will help us to decide whether there is a need for an additional health post.
>
> Student B: For example, in the Artificial Intelligence Systems course, we studied the PredPol model [an Artificial Intelligence system used by the police in Los Angeles]. If we borrowed the PredPol model, which will be helpful to identify key places where crime is increasing. It will be helpful to estimate sufficient armed forces for those identified places. Find out the crime spots observing past situations. This PredPol model is helpful to predict future crime using previous data.
>
> Student K : A predictive tool
>
> Leader : […] Is that model a simulation?
>
> Student B : I think it is a simulation model because it helps us to predict."
>
> (Poudel, Vos, & Shults, 2019, p. 6).

In the above extract, Student B was imagining ways in which M&S-based tools could assist their societies set up health facilities, prepare for natural disasters, or fight criminality[13]. This study gathered evidence that the students of Development Studies have developed metaknowledge about the nature and

[13] It should be noted that the software "PredPol", referred to by a student in the above transcript has is based on an algorithm developed from "large data", and has been heavily criticised by mathematicians because of the way the algorithms feed into social and racial stereotypes. See https://www.nature.com/articles/d41586-020-01874-9. I am grateful to Prof. Vos for drawing my attention to this critique.

relevance of M&S-based research in their field. The study's overall results led me to conduct the third iteration of the M&S-based research methods module with another cohort of religion students.

5.3 Paper 3

> "So, what is the coolest thing learned… so far": Undergraduate students utilise an opportunity to learn about modelling and simulation-based research methods[14].

Background

This study explores how undergraduate students of religion utilise an opportunity to learn about M&S-based research methods. Further, the study aims to report on a formative evaluation of a 'meet-the-expert' event, an element of the M&S-based research methods curriculum module implemented through seminars and workshops. This study adopts a socio-cultural account of learning/knowing to manifest boundary-crossing activities between novices (i.e., university students) and experts (i.e., professional researchers) (Akkerman & Bakker, 2011). In this framework, students' opportunity to utilise the M&S-based research methods module can be presented in terms of participation in four socio-cultural contexts: university studies, the world of future professionals, the world of an academic researcher and their role as a citizen in everyday life. Moreover, students are legitimate peripheral participants of the community M&S-based professionals and academic researchers who utilise M&S-based tools in their professional environment (Lave & Wenger, 1991). The unit of analysis was taken as the interacting activity systems of university study and workplace practices and M&S-based tools, which were mediational means in this study.

Research questions

How can students of religion utilise their opportunity to learn about M&S-based research methods?
The following two questions were articulated to answer the primary question.

---

[14]. This paper is submitted to a peer reviewed journal.

(i) To what extent and how do students develop a sense of social science researchers' motivation for using M&S-based research methods?

(ii) To what extent and how do students develop an understanding of the opportunities, limitations, and challenges by utilising M&S-based research methods?

Methodology

The third iteration of the M&S-based research methods module was implemented in the fall semester of 2018 through the seminar, tutoring session, and meet-the-expert session to provide an experience of M&S-based research methods. The participants in this study were in their second year in the undergraduate religious studies program. The introduction seminar entitled 'Research approaches to study social phenomena–will simulations give insights?' with the theme of social in/exclusion was organised. The seminar was composed of three sections: introduction to research methods, hands-on experience with social simulation (i.e., Schelling applet) and discussion with the help of probing questions. In the tutor session, students were given the opportunity to clarify the concepts related to the M&S-based research methods. They also had a chance to discuss the opportunities and challenges related to M&S-based research methods. Further, the tutor session was intended to help students who chose to write a short essay on M&S-based research methods.

The meet-the-expert event was a round table discussion in which students posed questions to experts (M&S-based researchers) regarding the usefulness, opportunities, challenges, and limitations of M&S-based research methods. They were also asked to write a short essay based on the knowledge they developed at the seminar, tutoring session, and meet-the-expert session. In this study, the data generated includes an audio recording of the students' interaction with experts. The transcription of the audio records was analysed using a thematic approach (Braun & Clarke, 2006; Braun et al., 2019).

Results, discussion, and conclusion

This study seeks to uncover evidence of the extent to which students engage meaningfully and develop an understanding of M&S-based research methods in the context of M&S-based professionals in their field. The students showed their interest in understanding the experts' motivation in adopting M&S-based

research methods and sought an insider's perspective of practitioners of the methods in their field. Students inquired about the validity of the methods and researchers' strategies to tackle the issues of validity. It appears that students showed their awareness regarding empirical sources of data and the accuracy and efficiency of the models developed by experts. They showed their concern about the trustworthiness of models as well as strategies employed by the experts.

Students posed several questions about the usefulness of expert-designed models in understanding religious, social behaviour. The following excerpts illustrate the interaction between Student S9 and M&S-based expert :

"S9 : OK. So, the model doesn't show like, new religious tendancies, and stuff like that?

Expert 2 : Or, or, or less attendance in churches and anything to do with that, it only has to do with whether people believe in say spirits or the Holy Spirit or angels or stuff like that. That's going down in the population and it should continue to go down if those conditions hold.

S9 : So, you will get more new age people? Correct?

Expert 2 : Well, no, new age, new age is included in that.

S9 : I was just thinking that naturalism is growing in Norway and so is the sort of new spirituality in (indistinct) with traditional religions going down" (text reproduced from my Paper 3, p. 10).

In the above excerpt, Student S9 was inquiring if expert-designed models could explain religious, social dynamics. In this sense, students imagined a situation, concerning new trends on religion and spirituality in their local context, in which M&S-based methods could apply in their field. It showed that students hypothetical questioning led them to understand causal reasoning.

Further, the student's interaction with M&S-based researchers gave them opportunities to identify several areas in which M&S-based tools can be utilised. As the following excerpts illustrate the exchange of ideas between students and experts:

"S16 : I wonder, er, is it possible to make a model er that's, where it takes a specific person's, er, I don't know, data to put into a simulation, see how, figure out the way, for example, to

rehab… rehabil …. rehabilitate the person from, for example, drug addiction, and then you know exactly how the best way to, to help this person, this specific person?

Expert 2 : Great idea!

S16 : Picking up, specifically about for example, criminals, that instead of punishment we can have like everyone to do go through a system and when they come out, they will be good civilians (citizens?) instead of wasting time just locking, locking them up" (text reproduced from Paper 3, pp. 10-11).

In the above extracts, student S16 imagined a situation in which M&S-based methods could apply in developing an individualised treatment plan to rehabilitate a person with drug addiction. Likewise, Student S9 recognised that the social simulation applet could apply as an educational tool that motivates students to learn critical societal issues. She said: "this could be like an excellent example because modelling is like a computer; they could learn it while learning about important issues in our society would be interesting". In this excerpt, she mentioned that the simulation and visualisation features of the social simulation applet could be useful tools to motivate students to learn about abstract social concepts. It showed that students imagined situations in which M&S-based tools could be applied in their professional context.

Students experience themselves as outsiders of M&S-based researchers practice due to their lack of knowledge about coding and programming languages. Consequently, the students could not experience the expert-designed models that may lead to obstructing their opportunity to learn about these methods. For instance, students find obstructions in developing a sense of researchers' practices studying religious and social behaviour through the utilising of M&S-based tools to understand the hidden causal mechanisms, develop theories, and explore possible consequences. To overcome these challenges, students identified 'boundary-crossing objects' (see Table 5.1) that bridged the understanding gap between layperson and expert about M&S-based practices.

In this study, students' lack of coding and programming knowledge delay or obstruct their participation in future practices such as becoming M&S-based

professionals in their field. Additionally, student's involvement in the 'meet-the-expert' event is hindered by experts' use of specific language or jargon.

Table 5.1: Two activity systems (students and experts) tensions and boundary-crossing objects

Student (issue)	**Tension or Boundary-crossing object**	**Expert (issue)**
Non-expert language register	Tension: students do not understand experts' use of jargon Boundary-crossing object: Imagine a map from Kristiansand to Oslo/introduced by the expert	Jargon, expert language
Does not know the programming language	Tension: student frustrated because she/he cannot engage with the programming code Boundary-crossing object: expert software for web page design/introduced by student	Simulations only exist in code.
Does not understand the model published in a journal article	Tension: students do not see the use-value of the models Boundary-crossing object: Scholarly journal articles/introduced by expert	Codes for models published in journal article require expertise to use
M&S-research methods can provide policy-relevant information. Students believe that policymakers may not be aware of the limitations of researchers' models.	Tension: student worried that knowing policymakers are less aware of M&S-based methods and policymakers have to learn before they can use a model for policymaking	Researchers are conscious of a gap between model and reality

(table reproduced from Paper 3, p. 13)

This study provides evidence that there exists a possible role for M&S-based research methods modules in the social science study programs. Further, the study recommends two potential studies that could contribute to developing the M&S-based research methods module. The recommendation for further studies are an inquiry into the affordances of M&S-based tools within the research

methods curriculum module and an investigation of an 'a-priori epistemological analysis of Schelling Applet' (i.e., didactical tool) to understand the implicit and explicit use of mathematical knowledge while learning about M&S-based research methods. The overall findings of Paper 3 helped me to write Paper 4.

5.3 Paper 4

> Exploring, experimenting, and sense-making: An epistemological analysis of students' interaction with social simulation applet [15]

Background

This study explores and exposes how simulation-based educational tools can facilitate students in the evolution processes of mathematical and social science sense-making during their interaction with a social simulation applet. The study aims were: (i) to develop a priori epistemological analysis of Schelling applet, and (ii) apply the epistemological analysis tool to interpret the students' interactions with the Schelling applet. In doing so, the study leans on several theoretical backgrounds to develop an analytical framework to analyse students' interaction with simulation-based tools. The paper begins with defining the Schelling applet as a didactical tool. This is followed by a working definition of metaknowledge (general), metaknowledge of mathematics, process, and product mathematics and 'a priori mathematical/epistemological analysis of the Schelling applet are portrayed. The epistemological analysis tool was applied to analyse students' engagement with the Schelling applet. This study also developed an analytical framework comprising the theory of objectification and semiotic representation theory to investigate students' interaction with the Schelling applet.

Research questions

The research questions (RQ) addressed by this study are:

RQ1. What possibilities are there to expose the evolution of students' mathematical and social science sense-making?

[15] This study is submitted to a peer-review journal.

RQ2. What can be deduced about the evolution of students' mathematical and social science sense-making during interaction with the social simulation applet?

Methodology

This study utilised the data generated from the third iteration of the M&S-based research methods module. Specifically, this study sought to investigate how students' mathematical and social science sense-making evolved during the interaction with the social simulation applet. The data utilised in this study were the student's interaction with the Schelling applet during the second section of the seminar, "Research approaches to study social phenomena—will simulations give insights?" The first and third section of that seminar was background knowledge about research methods and students' reflection about the research methods. The students' interactions with the Schelling applet (recorded by Kaltura's CaptureSpace Desktop App[16]) were transcribed. The analysis was performed by applying Miles, Huberman, and Saldaña's (2014) qualitative data analysis approach. The data analysis was completed in three sequential steps: data condensation, data display, and drawing and verifying conclusions. The analysis of the evolution of students' mathematical and social science sense-making processes was analysed in the light of theoretical constructs and epistemological analysis of the Schelling applet. The 'unit of analysis' was mathematical and social science sense-making processes, and the simulation-based tools, signs and symbols served as the mediational means.

Results, discussion, and conclusion

In this study, the analysis of students' interaction with the Schelling applet was presented in three episodes. The first episode illuminates how students identified a connection between inputs and effect in visualisation and sense-making processes. The study reported that students utilise mathematical understanding through the interplay of multiple representations (i.e., language, position, and visualisation) (Duval, 2006). In the second episode, the study reported the students' observation of patterns through experimentation and how they

[16]The app is useful for recording computer screen activities, audio, and videos. It also provides online storage for educational resources.

generalise the rule determining the blocks' behaviour in the Schelling applet. In this episode, the student's interaction with the applet was reported in three modes of generalisation: mathematical symbol, students' action, and language (Radford, 2002). The third episode emphasises how students utilise deictic natural language and linguistic expressions to understand the role of semiotic means of objectification for reasoning and argue for an explanation (Radford, 2003).

The study concludes that the evolution of students' sense-making activity takes place in three phases: exploring and gaining control, experimenting and observing, and interpreting and applying. The study provides evidence that the possibilities of using educational technology (i.e., simulation-based educational tools) to enrich research methodology curricula in social science study programs. The Schelling applet's epistemological analysis is a tool that can be an exemplar to analyse learners' engagement with simulation-based tools in educational practices.

5.4 Chapter Summary

Whilst this dissertation involved four independent papers, and it should be noted that the design-based research processes were cyclic and iterative, with each separate components of intervention affecting each other (see Figure 5.1). The design studies reported in these papers resulted in the development of an M&S-based research methods module that was informed by and involved throughout each paper. Paper 1, the outcome of intervention study I, aimed to explore the feasible and practical design of the M&S-based research methods module with the students of religion. This paper contributes to addressing research questions 1 and 2 (see detail in Table 4.2 for the sequence of intervention studies and their connection to research questions). Precisely, Paper 1 prepared foreground empirical foundation of this study that allowed me to increase the intensity of the M&S-based research module with the students of Development Studies.

Paper 2 reports intervention study II results, which investigates how Development Studies students can gain metaknowledge about M&S-based research methods, its rationale, background knowledge, and opportunities and limitations of the research methods. Built on the results of intervention studies I and II, intervention study III aimed to explore how undergraduate students of religion utilise an opportunity to learn about the M&S-based research method. On the other hand, paper four deals with the pedagogical aspects of M&S-based

tools, which reveals how such tools can facilitate students' evolutionary process of mathematical and social science sense-making during their interaction with the social simulation applet. Papers 2 and 3 also contribute to study research question 1 and 2, while paper four deals with research question 3 and 4.

The next chapter presents how these papers address the research questions, first individually and then the overall contribution of this dissertation.

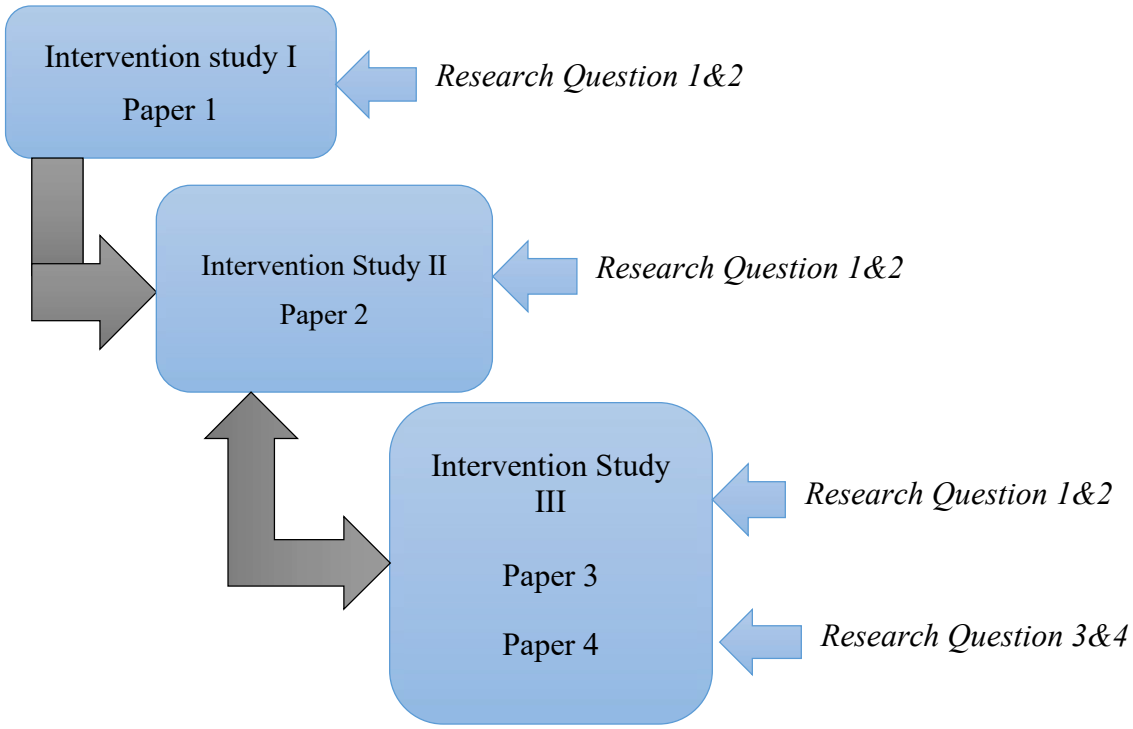


Figure 5.1: Intervention study development process

6 Addressing the research questions of this study: "So, what is the coolest thing learned… so far" [a student]

This chapter addresses the answer to the research questions. I begin section 6.1 by recalling the purpose of this study and the research questions that were formulated to guide the inquiry. Sections 6.2,6.3,6.5, and 6.6 elucidate answers to the individual research sub-questions. Section 6.4 elaborates the rationale for adjusting the theoretical construct-metaknowledge in this study. Finally, Section 6.7 presents an answer to the main research question.

6.1 Revisiting the research purpose and research questions

The purpose of this study is to understand better how students of social science utilise opportunities to learn about simulation-based research methods for the study of social dynamics. Further, to achieve the goal, as mentioned earlier the research has two main objectives, (i) to study how students utilise the opportunity to learn about M&S-based research methods to understand social dynamics, and (ii) to study how students use metaknowledge while learning about M&S-based research methods. Based on these objectives, the following main research question was formulated to guide this study:

How do students in the social sciences (i.e., Religious and Development Studies) utilise the opportunity to learn about M&S-based research methods?

To answer this main research question; the following sub-questions were formulated:

1. To what extent and how do students develop a sense of social science researchers' motivation for using M&S-based research methods?
2. To what extent and how do students develop an understanding of the opportunities, limitations, and challenges of utilising M&S-based research methods?
3. What possibilities are there to expose the evolution of mathematical and social science sense-making?
4. What can be deduced about the evolution of students' mathematical and social science sense-making during their interaction with social simulation applet?

In the following sections, I will discuss the study results by integrating the findings from the papers attached to this thesis. Further, I will outline answers to

the research questions, first individually and then present the overall outcomes of this dissertation.

6.2 Sub-question 1: To what extent and how do students develop a sense of social science researchers' motivation for using M&S-based research methods?

In this study, I perceive students as actors who utilise the opportunity to learn about M&S-based research methods. Additionally, the students are also legitimate peripheral participants of the community of professional and academic researchers who use M&S-based tools in their professional environment (Lave & Wenger, 1991). Also, I use the CHAT framework (Roth & Lee, 2007; Roth & Radford, 2011; Williams & Wake, 2007) to structure the analysis of students' activities, in particular, their actions that evoke learning and knowing through participation in mediating the students' sense-making as they engage with their object of activity. In this approach, students' opportunity to participate in the M&S-based research methods module in terms of (peripheral) participation can be framed in four socio-cultural contexts: university studies, the world of future professionals, the world of an academic researcher and the students' roles as citizens in the real-world.

In the seminar as well as the meet-the-expert session, I focused on the instances in which the students' interaction with the social simulation applet (i.e., the Schelling applet), peers and teachers manifested how the students were developing a sense of social science researchers' motivation for using M&S-based research methods. The students interacted with the Schelling applet by using slider-bars, run and stop buttons. Poudel et al. (2020) reported:

> "Students fully engaged in a hands-on activity and discovered how small individual bias could lead to large collective segregation. They interacted with the simulation by using the sliders and click buttons. We observed wonder, excitement and sorrow on their faces. They played with the parameters to explore future scenarios, and without exception, they tried to create positive, unsegregated outcomes" (p. 382).

The quoted text reveals that the students manipulated the behaviour of imaginary people to explore future scenarios such as positive, unsegregated, inclusive outcomes. Poudel et al. (2019) also reported that students interactively ran a

computer simulation to see the effect of varying the inputs in slider-bars. Students:

> "Tried many scenarios and consistently found that raising agents' bias quickly leads to segregation, and even relatively low levels achieved the same result, albeit more slowly. They also tried removing the empty spaces and discovered that no segregation could occur since *"no options are available anymore"* (Student S). They had experienced that in times of crises, people need to be tolerant: in the case of the Nepalese earthquake, people moved in with each other or lived peacefully in overcrowded tents" (p. 6).

As reported in the above quote, students tried removing the empty spaces and discovered that no segregation could occur when "no options are available". They connected these scenarios to people's behaviour in the time of crises. For example, in the Nepalese earthquake case, people moved in with each other or lived peacefully in an overcrowded tent; as a consequence of the emergency, their behaviour needs to be more tolerant. In this regard, students were primary participants in a learning environment (discovering the effects of changing sliders in the applet), but they also expressed their real-world experiences as citizens. The analysis reported above revealed that students played with an M&S-based tool to reach a particular goal. Students imagined a situation being an M&S-based researcher in their field in which the M&S-based tools could be applied in studying social dynamics. In this, there is evidence that "the simulation created a connection between the students, their goals and social life beyond the university" (Poudel et al., 2020, p. 382).

In response to the teacher's question 'what could be studied using M&S-based methods, students shared some instances reported in (Poudel et al., 2020). Here is one:

> "It could be applied to forecasting elections, to predicting unemployment rates, 'to understand criminality by understanding people's behaviour' or to discover 'what would happen if radical religious groups came into power'. These varied answers indicate that the students were able to connect M&S to doing social research" (Poudel et al., 2020, p. 382)

Students stated that M&S-based methods could predict unemployment rates, discover what would happen if radical religious groups came into power, or understand criminality by understanding people's behaviour.

On the other hand, in Poudel et al. (2019), it is reported, the teacher asked what issues from development Studies could be answered by studying virtual worlds? Students came up with several examples in which M&S-based methods could be applied:

> "Student S suggested that the different clusters of people could be studied with respect to their socio-economic status. The seminar leader realised that such a study would likely require a survey rather than a simulation but did not comment so the others could respond. Student B then said that simulations provide a dynamic visualisation of phenomena and enable researchers to observe long-term changes visually. She suggested that simulations could be a medium for communication *"for those who hate large data sets"* and do not have a strong background in mathematics. At this stage, the students were participating as potential future Development Studies researchers, in a world in which they anticipated executing and publishing quantitative research" (Poudel et al., 2019, p. 6).

Here students mentioned that M&S-based methods could be used to provide a dynamic visualisation of phenomena. Besides, they appreciated that the M&S-based tool could enable a researcher to observe long-term changes visually, or simulation could be a medium for communication for those who dislike large data sets and do not have a strong background in mathematics. At this stage, students' arguments were general and abstract without providing further clarification. It is worth noting that they were novice learners of M&S methodology. They were just being introduced to the M&S-based research methods through limited exposure to a seminar, tutor session and meeting with the expert session.

In Poudel et al. (2019), it is reported, the teacher asked students to imagine themselves in an urban planner's role in which they could utilise M&S-based methods to promote tolerance in a community. The students:

> "Agreed that the Schelling Applet represented a certain underlying structure in society, although agents' movement in the real world is related not only to the colour of their neighbours but also to other factors, such as

economic concerns, or a desire to live close to relatives" (Poudel et al., 2019, p. 7).

These examples revealed that students imagined a problem situation in which the M&S-based methods could be relevant in their field. The above analysis revealed that students "shifted their roles from learner to citizens, and future professionals in their field" (Poudel et al., 2019, p. 8).

Paper 3 provided evidence of how students engage in understanding M&S-based research methods in the context of M&S-based professionals in their field. Students asked in what way experts use M&S-based methods in their professional lives. For example, Student S3 asked, "So, what's the coolest thing you learned…from the models?" It showed that they were exploring the experts' motivation in adopting M&S-based research methods that helped them understand the insider's perspectives of the methods. It indicates that students demonstrated mild interest, engagement and lacked a sophisticated understanding about M&S-based research methods. We must acknowledge that they were recently introduced to the M&S-based research methodology through an introductory seminar, tutor session, and meet-the-expert session. Thus the level of critical engagement with the potentialities of the methodology is inevitably limited.

Likewise, students interrogate the experts to find out how they tackle the issue of validity, efficiency, and accuracy of the model they develop. For instance, Student S10 asked what approaches the researchers used to reduce the gap between reality and their model. In this, there is evidence that the students advanced their knowledge of M&S-based methods by developing insights about the accuracy of models and experts' strategies to ensure the validity of the model they developed.

With reference to the findings reported in Paper 3, students' questions were consistent towards understanding how experts utilise M&S-based research methods to study religious, social behaviour. For instance, Student S3 asked if experts have developed a model that could explore many different scenarios related to religious, social behaviour, such as what happened if people behave less religiously or more naturalistically. The analysis reported (cf. Paper 3) indicates that students use of phrases such as '…if that happens…' 'if religion….increases or decreases' provide evidence of their engagement in 'what

if thinking' that characterises their developing awareness about M&S-based research methods in their field.

It can be argued that the students' engagement was explorative, informed, and persistent. The students' engagement with the teachers' questions, providing a realistic and relevant example for the application of M&S-based methods, offers further evidence of the extent of their development of a sense of researchers' motivation of using such methods in their field. In their interaction with the researchers, students move beyond the curricular context of the M&S based research module; they imagined a sense of the problem in their field in which M&S-based methods could be applied. The above synthesis suggests the students engaged truly in explorative, informed, and persistent learning activity. They were able to move beyond the abstract learning context by imagining a situation in which they could apply their knowledge to the real world.

Also, the students' engagement was meaningful and rational. The students systematically approached the task by testing the specific case (no vacant/empty squares and related this to their own experience - the aftermath of the earthquake in Nepal) is evidence of "how do" students develop a sense of researchers' motivation for utilising M&S-based research methods. As the students are given the agency to question researchers, with their inquiries, they expose evidence of the process of their development of a sense of M&S-based research steps often followed by researchers in their field. In this regard, Paper 3 offers several instances that illustrate their active participation. Here is one:

> "Students' active participation in asking questions about the use of M&S-based research methods practice understanding issues such as religious, social behaviour, the trustworthiness of models, the usefulness of M&S-based tools showed their interest in M&S-based research methods. The students' questions and comments display most research steps, often followed by M&S-based researchers. Do you design the model? How do you collect data? How do you validate your model? How can you claim that your model is better than others? Who are the users of the model? What does your model say about religious, social peace? How can these methods be used to develop a model that can help to create an individualised rehabilitation syllabus?" (text reproduced from Paper 3, p. 14).

The quoted text reveals that students showed their curiosity about background knowledge about designing a model and the trustworthiness of models designed by experts. Also, students inquired about the users of the model they developed. Here is evidence that the students develop their sense of what researchers do in their field using M&S based research methods through meaningful, rational, and systematic inquiry. Also, they showed their understanding by imagining a situation the M&S-based research methods could be relevant in their field.

6.3 Sub-question 2:To what extent and how do students develop an understanding of the opportunities, limitations, and challenges by utilising M&S-based research methods?

The second research sub-question deals with the way students developed an understanding of the opportunities, limitations, and challenges by utilising M&S-based research methods in their field. Poudel et al. (2020) reported that students recognised that the use of computer simulation-based experiments is less harmful, ethically possible and cost practical comparted with using live communities in the real world. For this reason, students realised that the M&S-based research method is an alternative approach to study social behaviour. For example, in the follow-up interview, one student said, “It is easy to find answers to hypothetical questions in social research using social simulation… we may not afford experiments like Zimbardo, which has a high-cost value as well as it affects peoples’ personal lives. Instead, if you run computer simulations, it is less harmful and more cost-effective” (Poudel et al., 2020, pp. 382-383).

With reference to findings reported in Poudel et al. (2019), students identified that M&S-based methods could help development professionals in their field, such as urban planners, to understand and predict dynamics of urban life, crime prediction, and preparation for potential disasters. For example, student B said M&S-based tools would help develop simulation and visualisation of road networks that could help inclusive urban planning and development. As the following excerpts illustrate the interaction between Student B and the seminar leader (teacher):

“Student B :We can find out the road conditions, specifically in Kathmandu.

Because they are constructing roads in different places. I want to know whether it [the road network] is effective or not, basically, already at the planning stage.

Leader : How effective is that planning? Any examples?

Student B : For example, roads in Kristiansand [Norway] are well planned. If you walk in this city, nobody gets lost. But in Kathmandu, we always get lost or run into a wall[dead-end]. With these [simulations], we can study the trend of urbanisations. We can compare the situations. Find out the areas where more housing is needed" (Poudel et al., 2019, p. 7).

In the above extract, Student B was imagining ways in which M&S-based tools could help her understand and predict the dynamics of urban life. The findings of Poudel et al. (2019) exposed that students appreciated the M&S-based tool could serve as a tool for development professionals and policymakers. In this, there is evidence that they grasped the opportunities by using M&S-based methods in their field.

Paper 3 also illuminates how students discovered the opportunities by utilising M&S-based research methods. In so doing, students explored the possibilities of using M&S-based research methods in developing individualised approaches to tackle social issues. For example, S16 wondered if M&S-based research methods could create opportunities to develop an individualised treatment to rehabilitate a person with drug addiction. The following excerpt captures the exchange of idea between expert and novice in co-constructing and advancing their meaning about M&S-based methods:

"S16 :I wonder, er, is it possible to make a model er that's, where it takes a specific person's, er, I don't know, data to put into a simulation, see how, figure out the way, for example, to rehab… rehabil …. rehabilitate the person from, for example, drug addiction, and then you know exactly how the best way to, to help this person, this specific person?

Expert 2 :Great idea!

S16 :Picking up, specifically about for example, criminals, that instead of punishment we can have like everyone to do go through a

> system and when they come out, they will be good civilians (citizens?) instead of wasting time just locking, locking them up" (text reproduced from Paper 3, p. 10-11).

In the above excerpt, Student S16 imagined a model that utilises an individual's data, put it into a simulation, and thus figures out rehabilitation plans for the specific person. Likewise, Student S10 said that M&S-based methods could be a useful tool to maximise governmental efficiencies and in developing better policies. However, she did not exemplify how M&S-based methods could be applied in the field. In this, she mentioned that these methods could be helpful for government officials in the management of immigrants' integration.

Moreover, students also realise the usefulness of simulation and visualisation in teaching school students about abstract social theories. Student S9 argued that teaching concepts such as radicalisation and religious, social conflicts are difficult to teach and hard to understand. Student S9 said:

> "This could be like an excellent example because modelling is like a computer; they could learn it while learning about important issues in our society would be interesting". In this statement, she mentioned that modelling is like computing that motivates students to learn important issues in the societal context by utilising such tools in learning of abstract social concepts would be more attractive to students as well as learning would be relevant to a student's life. In this way, student (S9) understood the simulation and visualisations could be a useful tool to make learning about important issues in society" (text reproduced from Paper 3, p.11)".

To make the school curriculum more appealing to students, Student S9 emphasised that use of M&S-based tools (e.g., computer simulation, simulation-based educational games) could be interesting ways to engage students to make learning about essential issues in society.

In Paper 2, I have documented students' understanding of the limitations of M&S-based research methods. For instance, Student S pointed out that M&S-based tools do not produce realistic pictures. Student K raised an issue about expenses and training required for creating models, and Student B wondered whether M&S-based methods were sufficiently scientific. These are evidence that students utilise their opportunity to learn about the limitations of M&S-based research methods. In contrast to previous studies, Paper 3 documented the

evidence of students' talk about the challenges of utilising M&S-based research methods through examples.

Table 6.1:Two activity systems (students and experts) tensions and boundary-crossing objects

Student (issue)	**Tension or Boundary-crossing object**	**Expert (issue)**
Non-expert language register	Tension: students do not understand experts' use of jargon Boundary-crossing object: Imagine a map from Kristiansand to Oslo/introduced by the expert	Jargon, expert language
Does not know the programming language	Tension: student frustrated because she/he cannot engage with the programming code Boundary-crossing object: expert software for web page design/introduced by student	Simulations only exist in code.
Does not understand the model published in a journal article	Tension: students do not see the use-value of the models Boundary-crossing object: Scholarly journal articles/introduced by expert	Codes for models published in journal article require expertise to use
M&S-research methods can provide policy-relevant information. Students believe that policymakers may not be aware of the limitations of researchers' models.	Tension: student worried that knowing policymakers are less aware of M&S-based methods and policymakers have to learn before they can use a model for policymaking	Researchers are conscious of a gap between model and reality

(Table reproduced from my Paper 3, p. 13)

During the interaction with an expert, students experience themselves as outsiders of the M&S-based researchers' community of practice due to lack of knowledge about coding and programming languages. In the meeting with the expert session, Student S5 worried that she could not use an expert's models due to lack of coding and programming knowledge. Students also felt outside of

practice when experts use abstract language, codes, and jargon which hinders students' opportunity to learn about M&S-based research methods.

In Paper 3, I have reported how students attempt to overcome the issue of boundary-crossing between the activity system of university studies and professional's workplace practices. It appears as tension (i.e., student frustrated because she/he cannot engage with the programming code) between university students' activity system and the activity systems of researchers' practices. For instance, students' lack of coding and programming knowledge could delay their participation in future practices such as becoming M&S-based professionals in their field, as the table above illustrates two activity systems, tensions and boundary-crossing objects.

The table above shows that students identified 'boundary-crossing objects' that bridge the understanding gap between layperson and expert about M&S-based practices. The boundary-objects are part of students' activities that bridge the understanding gap between the activity system of university studies and future professional context.

Likewise, students discovered M&S-based research methods as an alternative approach to study social dynamics exposing basic features of the methodology (i.e., less harmful, ethically possible, and cost-practical). Students demonstrated awareness of possible areas in which the M&S-based research method might be applied. Beside M&S-based methods being a useful tool for professionals to engage actively with social issues, students envisaged it could help broaden lecture-based teaching of social studies school instruction by adding hands-on learning activities. Also, students' attempt to talk about constraints of M&S-based research methods such as producing a realistic picture of phenomena or questioning how scientific are M&S-based methods indicates that they have been exposed, to some extent, to the limitation of M&S-based method. However, I lacked sufficient evidence to claim that students gained understanding about the limitations of the M&S-based research methods. The evidence showed that students appeared unable to position themselves as academic researchers; instead, they could imagine a problem situation in which M&S-based methods can be applied in their field. However, there is evidence of students' attempt to explore the limitations of M&S-based approaches by utilising their limited exposure to M&S-based research methods curriculum module. I will discuss this issue critically in Chapter 7. The above synthesis suggests the evidence of the extent of

the development of students' understanding of opportunities and limitations by their attempt to expose attributes of research methods in the context of M&S-researchers' practice.

It can be argued that students acknowledged M&S-based tools as a helpful device for professionals' practices (i.e., urban planning, crime prediction and disaster preparation). As the students were given a chance to explore opportunities by utilising an M&S-based research method, they concluded that the research methods could help tackle social issues, maximise governmental efficiencies, or develop better policies. In this, there is convincing and rational evidence exposed to "how do" students develop an understanding of opportunities and challenges by utilising M&S-based research methods. Also, students identified that the lack of exposure to coding and programming knowledge is a potential challenge that could delay their participation in future practices as becoming M&S-based professionals in their field. The above synthesis suggests the students develop their understanding about the opportunities and challenges of M&S-based research methods through logical and practical illustrative examples while reflecting M&S-based research methods as their future professional practice.

6.4 Justification for adjusting the theoretical construct-metaknowledge in my research journey

In the first intervention, I aimed to explore the effectiveness of the design of M&S-based research methods module lessons that provides an essential foundation for my research. The design-based research methodology allowed me to increase the intensity of the M&S-based research methods module based on the previous iterations' findings. For example, my report in described how Students of Religion developed their understanding of the way M&S-based researchers utilise such methods in their field. In this paper, I have used the CHAT theoretical framework to analyse the student's opportunity to learn about M&S-based research methods. Afterwards, in the second intervention, the improved version of the same module was implemented with Development Studies students. In this iteration, I aimed to study how this group of students can *gain metaknowledge* of M&S-based research methods. I utilised the notion of metaknowledge of M&S-based research methods, that is, general knowledge

about the nature of such research, its rationale, how it is conducted, and the extent to which it can provide policy-relevant information (Poudel et al., 2019).

Poudel et al. (2019) was an outcome of intervention II. I have also utilised the CHAT theoretical framework to analyse students' opportunity to learn about the M&S-based research method. One of the distinctive features of the CHAT framework is that it "explains not only how individuals learn from interaction with others, but also how collective understanding is created from interactions amongst individuals" (Mercer & Howe, 2012, p. 13). In this regard, mediating artefacts (e.g., spoken or written language, M&S-based tools) play a central role in the activities "connecting humans with the world of objects and other people" (Nilssen & Klemp, 2020, p. 77).

As my project developed, in the third intervention, I concentrated on how undergraduate students of religion utilise an opportunity to learn about M&S-based research methods. On the one hand, the first part of this intervention was reported in Paper 3. The analysis was performed by applying constructs from CHAT, boundary-crossing, and community of practice theory. On the other hand, while reporting the second part, I found the definition of metaknowledge offered by Trouche (2005) to be more relevant to my study. He defines metaknowledge as an evolution of "knowledge which students have built about their own knowledge" (p. 202). Further, these knowledge types are useful whenever students encounter new activity in which they discover new artefacts or tools. In Paper 4, I have utilised the notion of metaknowledge, metaknowledge of mathematics, process and product mathematics and a priori mathematical/epistemological analysis of the Schelling applet. Besides, the analysis was performed by using the theory of objectification and the theory of registers of semiotic representations.

6.5 Sub-question 3: What possibilities are there to expose the evolution of students' mathematical and social science sense-making?

The third research question addresses the manner in which students' (mathematical and social science) sense-making can be exposed. The students' utilisation of simulation and visualisation was discussed concerning the epistemic value of a social simulation applet that mediates students' activities. As described by Artigue (2002) the social simulation applet mediates instrumented activity in two ways: (i) it utilises their opportunity to operate the social simulation applet

(i.e., Schelling applet), and (ii) the social simulation applet adapts students' metaknowledge and influences their activity through the phenomena represented by the applet (for details see Section 3.4.1). The Schelling applet, as a pedagogical tool (i.e., a cultural artefact), enabled students' sense-making processes by connecting the physical world (i.e., interaction with the tools, sign, and symbols) and the conceptual world (i.e., mathematical and social science meaning). It can be argued that students' sense-making processes were possible to observe through their interaction with the Schelling applet (i.e., sliders) as well as their use of signs and language (i.e. psychological tools) in the socio-cultural context (cf. Vygotsky, 1978). In this sense, my Paper 4 offers several instances of students use of signs and symbols in the processes of sense-making. Here is one:

> "Anita and Kevin used the slider bars to create new values (i.e., inputs), and the results or effect of their inputs are visualised in the output screen. In the above extract from the transcript, Anita proposed, "if we take it up to 50 then" (turn 30). It illustrates that she represented the input value by utilising the increasing or decreasing position of the slider bar. Metaknowledge of mathematics appears to be related to number (ordinal) and percent (fraction). For example, Anita was proposing an experiment with 50% in the "Similar" slider bar" (text reproduced from my Paper 4, p. 13).

The above-quoted text illustrates an example that links students' use of sliders, keys or sign/symbols alongside their speech indication of sense-making. In this, Anita asked Kevin to drag the slider bar up to 50. It showed that they were interacting with the Schelling applet's variety of ways, such as changing the slider's position, pointing to the pattern of visualisations, oral communications.

As described by Steinbring (2006), the sign and symbol have two primary functions: (i) a semiotic function, "something that stands for something else," and (ii) an epistemological function, indicating "possibilities with which the signs are endowed as means of knowing the objects of knowledge" (p. 134). In Paper 4, the epistemological analysis of the Schelling applet is useful to expose students' mathematical and social science sense-making into four categories: procedural knowledge (i.e., pre-operational experience, getting ready to interact with the applet), operational knowledge (i.e., meaning that exists between control and what happens in the tool), mathematical knowledge (i.e., meaning that is

generated through signs and symbols), and knowledge about social dynamics (i.e., meaning connected to life) (cf. details in section 3.4.2).

Paper 4 exposes the evolution of students' utilisation of metaknowledge (including metaknowledge of mathematics), process and product mathematics during their interaction with the Schelling applet. The following paragraph provides instances of how students, Kevin and Anita utilised the notion of process and product mathematics:

> "Kevin comments on proportions of "red" and "blue," stating "just as many" (turn 29). His interpretation was based on the characteristics of the visualisation that appeared on their screen. Anita interpreted their outcome as "So, then it is, it is very … clustered"(turn 63), which represents product mathematics. She described the networked phenomena of coloured blocks that share the same critical social characteristics. It showed that Anita identified the movement of the colour blocks, and the pattern created by the blocks in the form of the visualisation. The underlying behaviour of the applet caught Kevin's attention. He mentioned "Yeah, so it is, but the thing is that they choose to go together with red neighbours then, instead of blue" (turn 70). It also showed that Kevin interpreted the rule determining the behaviour of the blocks" (text reproduced from my Paper 4, p. 13).

As illustrated in the above paragraph, Anita utilises the notion of *process mathematics* in the form of her choice of inputs in making sense and engaging with the visualisation. Students' utilisation of metaknowledge of mathematics appears to enable them to understand the reason for individual blocks' behaviour, and metaknowledge (general) allows them to build a connection between visualisation and their knowledge of ghettos in their real-life. As a result, they interpreted the rule determining the behaviour of blocks based on their choice of values and their effect in visualisation. In this way, Anita and Kevin's understanding evolves by interpreting the characteristics of the visualisation that appears in the output screen.

With reference to the findings reported in Paper 4, students find connections between mathematical representations, mathematics in tools, how mathematical knowledge influences students' critical awareness about their actions, metaknowledge about mathematics and metaknowledge about social dynamics. For instance, students used the Schelling applet to tackle the issue of in/exclusion

or segregation of imaginary social phenomena at hand or related purposes such as inclusive social phenomena. Therefore, I describe the Schelling applet as a type of specially designed artefact or tool that helps students see specific aspects of social phenomena (i.e., social in/exclusion, segregation) and facilitating their appropriation of understanding M&S-based research methods.

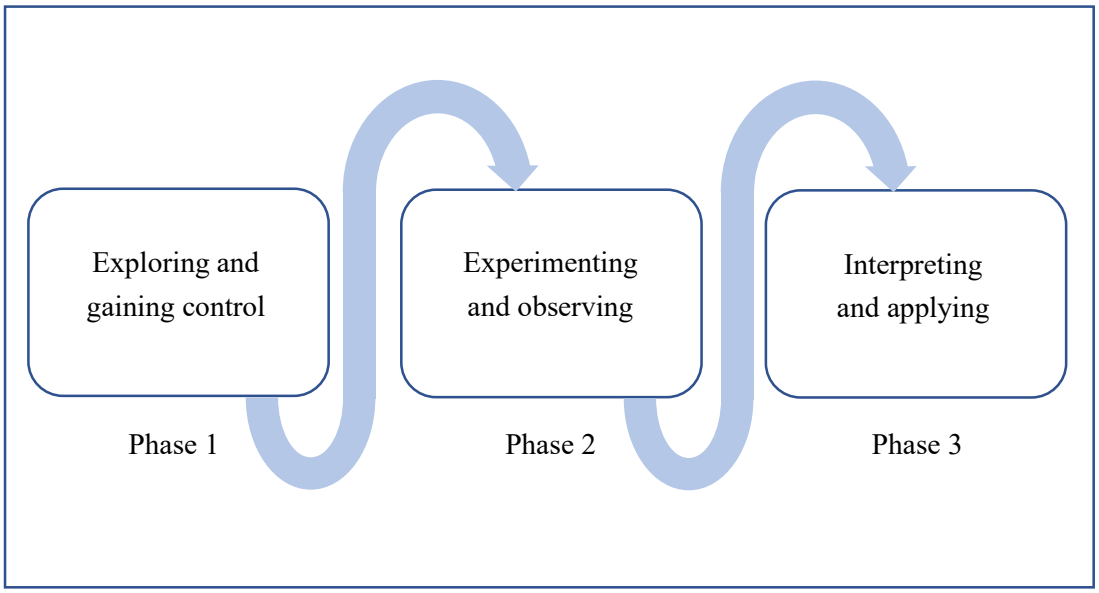


Figure 6.1: Evolution of students' sense-making during their interaction with the Schelling applet (reproduced from Paper 4, p. 18)

It can be argued that exposing the meaning-making processes of students' interaction with the social simulation-applet was made possible by viewing their interaction through the lens of the epistemological analysis of the Schelling applet. The epistemological analysis of the Schelling applet helped place students' mathematical and social science sense-making into four categories: procedural knowledge, operational knowledge, mathematical knowledge, and knowledge about social dynamics. As the students maintain their engagement with the social simulation applet such as interacting with Schelling applets, operating parameters, utilising the opportunity to reflect on sign and symbols were evidence of evolving mathematical and social science sense-making. It is observed that the students' engaged with the Schelling applet by utilising metaknowledge, metaknowledge of mathematics. Their engagement with these mediating tools were helpful for making sense and further engagement with the visualisations. As a result, students interpret the characteristics of the visualisation which provides further evidence of sense-making of 'how' students'

evolution of mathematical and social science sense-making became possible to observe. Figure 6.1, above, presents a model that illustrates the evolution of students' sense-making during their interaction with the Schelling applet.

Further, students' engagement with the social simulation-applet moves beyond the phenomena represented by the artefacts or tools to develop their awareness about their actions concerning social dynamics (i.e., social in/exclusion). The above synthesis suggests that students' evolution of mathematical and social science sense-making was exposed through meaningful, systematic analysis of their interaction with the Schelling applet.

6.6 Sub-question 4: What can be deduced about the evolution of students' mathematical and social science sense-making during interaction with the social simulation applet?

As stated earlier, this research aimed to study social science students' engagement with the Schelling applet as well as how they utilise metaknowledge while learning about M&S-based research methods. To answer the fourth research question, I use the theory of objectification (Radford, 2002, 2003) and the theory of semiotic representations (Duval, 2006) to characterise the processes of students' engagement with the Schelling applet.

Paper 4 illuminates how students interacted with the Schelling applet and the characteristics of their interaction with the applet. The findings reported in Paper 4 reveal that the evolutionary processes of students' mathematical and social science sense-making are illustrated in three consecutive phases: exploring and gaining control, experience and observing, and interpreting and applying. In the first phase, students' engagement appears in the form of changing the Schelling applet's parameters by adjusting the slider bars, the effect of their inputs in the form of visualisation, movement of colour blocks, and emerging patterns appear in the visual form. In so doing, students' utilise the notion of semiotic representations as described by Duval (2006). Kevin and Anita explicitly:

> "Connected several representation forms in their semiotic representations (turn 42, 43, 44, 63). In this process, students utilise mathematical understanding through the interplay of multiple representations, language ("low"), value ("11%"), the position of slider ("lower down"), and visualisation ("clustered") in terms of students' utterances. It reveals that they

> controlled the values of the variables by utilising the semiotic system of resources" (Duval, 2006, 2017) (text reproduced from my Paper 4, p. 13).

In the above-cited text, students use mathematical representations (i.e., %, fraction), position of slider bar (i.e., lower down, higher up), language (i.e., really low, what happens then), and visualisations (i.e., clustered). Here is evidence that students identified the connection between inputs and the effect of visualisation that enable them for the next phase of activities.

In the second phase, students' interaction with the Schelling applet focuses on activities such as varieties of experiments, observation of patterns, and a generalisation of rules determining the behaviour of the coloured blocks in the processes of mathematical and social science sense-making. Using the theory of objectification (Radford, 2002), I argued that students' interaction with the Schelling applet appears to embrace three modes of generalisation: mathematical symbol, students' action, and language. The following quoted paragraph presents an example in which students utilise semiotic means of objectification:

> "Kevin proposed lowering the slider bar down to the minimum of the scale that is opposite to the previous inputs. They ran the simulation, putting 4% (turn 85) in the "Similar" slider bar. They noticed that there were no significant changes in the visualisation. They became frustrated with the results. Anita says, "But has it something to do, has it something to do with…" (turn 89). She saw possibilities to develop a connection between their inputs and outputs in the visual form. It is worth noting Kevin's expression, "The higher it is, the more divided it gets. Then the red and the blue ones get…but if it is further down, then nobody cares" (turn 94). Kevin interpreted the phenomena by comparing previous inputs (i.e., higher, and lower value) in the slider bar and the visualisation at the output screen. According to Kevin, whenever the input values are higher, the behaviour of blocks leads them to be divided, which can be seen in the form of the visualisation" (text reproduced from Paper 4, p. 14-15).

In the exchange cited above, students utilise mathematical symbols (i.e., higher the value, too much for them), students' action (i.e., higher it is, or further lower down), and language to represent the social behaviour (i.e., nobody cares). The analysis shows that students utilise semiotic means of objectification that appear

in the form of goal-oriented students' actions that lead towards the evolution of mathematical and social science sense-making.

In the third phase, students' interaction with the Schelling applet focused on sense-making activities such as interpretations of inputs and visualisation, appreciating visual images as resources to interpret, exposing underlying reasons for blocks to behave in a particular way. The analysis reveals that students' assertion about their interpretations is based on the resources of visualisations, such as the pattern created by coloured blocks that emerged as a ghetto. The following quoted text presents an example in which students make the connection between the visualisations and their knowledge of ghetto in their real-life:

> "Students' attentions were caught by the visualisations given by the different inputs; that is, the way the blocks formed ghettos. Kevin noticed that the vacant blocks (white) were distributed between the red and blue blocks. He says, "Yeah, mhm. We still get the white ones in the middle" (turn 162). They were amazed to see the white blocks that separate the red and blue blocks. The image of separated blocks leads Anita to explore more about ghettos using metaknowledge: "Mm, but I just have to ask. Is this what we call ghettos? Like how they occur?" (turn 163) Anita utilises the resources of visualisations to interpret the pattern of colour blocks that emerged as a ghetto" (text reproduced from my Paper 4, p. 16).

In the exchanges cited above, students' activities utilise linguistic devices to conceptualise the visualisation that appeared on their screen. Here is the evidence that supports my argument that students transformed their observation from concrete objects (i.e., visual image) to conceptual worlds (i.e., ghetto) through the sign and artefacts (Radford, 2003). In this manner, students' exploit the epistemic value of the Schelling applet by transforming their observation of the concrete object to their conceived world.

6.7 The main research question: How do students in the social sciences (i.e., Religious and Development Studies) utilise the opportunity to learn about M&S-based research methods?

As mentioned earlier in Section 6.1, the research sub-questions 1-4 were formulated to address the main research question 'How do students in the social

sciences (i.e., Religious and Development Studies) utilise the opportunity to learn about M&S-based research methods?' This section addresses the previously stated design of this research (cf. Section 4.5.1). The first two sub-questions (RQ1, RQ2) address the research strand one and the last two sub-questions (RQ3, RQ4) address research strand two.

Section 6.2 offers an answer to sub-question 1. The evidence points to students' participation in the M&S-based research methods module being explorative, informed, and persistent. Furthermore, students' activities moved beyond the abstract learning context, such as they imagined several situations in which M&S-based methods might be applied in the real-world. It is worth noting that students demonstrated their agency to question researchers; with their own inquiries, they exposed evidence of the processes of their development of a sense of researchers in their field. This section also documents the manner in which students developed a sense of problems in their field by utilising M&S-based research methods. Besides, they advanced their understanding about M&S-based research methods through meaningful, rational and systematic inquiry and students reflected on the application of M&S-based research methods to their own experience.

Section 6.3 offers an answer to sub-question 2. The evidence showed that students demonstrated an expanded awareness of the value of M&S-based research methods as a resource for professionals and students, educators, and policymakers. However, there was insufficient evidence to illustrate that students explored the limitation of the M&S-based research methods since they could not position themselves as future academic researchers who can critically examine the methodology of the research methods. The section also documents evidence that students acknowledged a potential challenge, which could delay their participation in future practices as becoming M&S-based professional in their field. For instance, they could not use models developed by an expert due to lack of coding and programming knowledge.

Likewise, Section 6.4 offers answers to sub-question 3. The evidence documented in this section includes the epistemological analysis of the social simulation-based educational tool (i.e., Schelling applet) and shows how this helped expose students' evolution of mathematical and social science sense-making processes. The sense-making processes were possible to reveal through the systematic analysis of students' engagement with the Schelling applet (i.e.,

utilisation of metaknowledge of mathematics, making sense and engaging with visualisation, and interpreting the characteristics of the visualisation).

Lastly, Section 6.5 offers the answer to research sub-question 4. The evidence documented in this section illuminated the evolution of students' sense-making (mathematical and social science) during their interaction with the Schelling applet. These evolution processes can be manifested in three consecutive phases: exploring and gaining control, experience and observing, and interpreting and applying. Further, this section also documents evidence that students' demonstrated their utilisation of multiple representations of mathematics (Duval, 2006) while transforming their observation from concrete objects (i.e., visual image) to the conceptual world (i.e., ghetto) through the sign and artefacts (Radford, 2003) which provides further support to 'how do' [did] students' sense-making evolved during their interaction with the social simulation applet.

To conclude this sub-section, students' engagement in the M&S-based research methods curriculum module was explorative, informed, and persistent. Further, students' activities demonstrate that they could identify boundary-objects that could help them bridge the understanding gap between the activity system of university studies and professional work practices. The evidence reveals that they have developed a sense of social science researchers' motivation for using M&S-based research methods through meaningful, rational, and systematic inquiry. Further, the evidence demonstrates that students can reflect on the applications of M&S-based research methods by developing a sense of problems in their field. Also, students' engagement with the Schelling applet (i.e., M&S-based tool) was observable through their interaction with the tools, their use of sign, symbol, or language in the socio-cultural context. I argue that the mediating role of such artefacts or tools enabled students in their evolution of mathematical and social science sense-making during their interaction with the tools. More importantly, students have advanced their awareness about M&S-based research, such as key processes of the methods, opportunities, limitations, and challenges, by imagining a problem situation in which M&S-based research methods could be applied in their field.

6.8 Chapter Summary

This chapter has discussed how this current study addresses the guiding research questions, first individually, and then the main research question. The chapter

also describes several instances that illustrate how students purposefully interacted with the tools, sign/symbols, and objects. Further, the evidence documented in this chapter showed that students had utilised their opportunities to learn about M&S-based research, such as key processes of the methods, opportunities, limitations, and challenges. However, I find several issues that have an impact on the trustworthiness of the current research. These include contextual factors, researchers' knowledge of the local language, selection of theory, research methodology and methods. I attempt to illuminate these issues in Chapter 7.

7 Implications of the study, limitations, future recommendations, final reflection and closing remarks

Following the research summarised in Chapter 6, this chapter focuses on broader issues, such as how I hope the research might contribute to theory, didactics, pedagogy, and curriculum. In addition, I present a discussion on the implications of the present research, its limitations, future research recommendations, and final reflections and closing remarks about this study.

7.1 Theoretical implications

At the core of this study, I explore how social science students utilise the opportunity to learn about M&S-based research methods. Theories employed to frame this study include principally CHAT as an overarching, global theory. Other local theories, including legitimate peripheral participation (from the community of practice), the theory of objectification, and semiotic representation theory, were used heuristically to analyse and discuss the data. During the analysis, boundary-crossing (Bakker & Akkerman, 2014), boundary objects (Star & Griesemer, 1989), tension and contradictions within and between activity systems (Potari, 2013; Williams & Wake, 2007) were utilised. Furthermore, the notion of metaknowledge and metaknowledge of mathematics (Trouche, 2005), process and product mathematics, epistemological analysis of simulation-based educational tools (cf. Paper 4) were explicated to understand the data, explore the meaning and anchor discussions.

Whilst the construct of boundary-crossing has been widely used to explore the boundary between students problem-solving in the university and the workplace (e.g., Bakker & Akkerman, 2014; Roth & Radford, 2011; Swanson & Williams, 2014) very few studies have looked into an interdisciplinary context, in which social science students utilise the opportunity to learn about M&S-based research methods. This study explored the role of boundary-objects as mediating artefacts facilitating the interaction between two different but interacting communities of practices, i.e., university students and M&S-based professional. The present study also exposed students' awareness about the lack of exposure to coding and programming knowledge, which could delay their future practice as becoming M&S-based professionals in their field.

On the one hand, by acknowledging the tensions, it was helpful to expose the hidden rules that regulate the use of tools and artefacts; for example, social science study programs rarely offer computer programming and mathematics. On the other hand, by exposing contradictions, it was helpful to understand the contrasting motives of students' and M&S-based researchers' engagement in the M&S-based research methods module. In this, there is some paucity of further indications about how the contradictions might be addressed or resolved; however, these findings might contribute to the theoretical and operationalization development of boundary-crossing, boundary-objects, tension and contradictions and CHAT.

Drawing on communities of practice theory, I argued that students in the university context are the legitimate peripheral participants in a community of practice that includes their teachers, M&S-based researchers, and M&S-based professionals in their field (Lave & Wenger, 1991). The on-going professional trajectories are unknown, but the students are at the periphery of those mentioned. As such, students' opportunity to participate in the M&S-based research methods module provides possibilities of the apprenticeship model of research methods courses, firmly rooted in social science study programs. Further, the students' active participation also emphasises that learning/knowing is inseparable from practice (Wenger, 1998). These findings offer empirical evidence of the value of applying the framework of communities of practice theory in the research context.

Likewise, the CHAT framework offers a useful way of describing students' activities systematically, and it resonates with efforts to create opportunities to learn about M&S-based research methods. In doing this, the mediating tools of simulation-based educational software helped students' evolution of mathematical and social science sense-making. Further, students' sense-making processes appear to entail meaningful, systematic interaction with the tools. The epistemological analysis of simulation-based educational tools (i.e., Schelling applet) provides a model of the students' (mathematical and social science) sense-making processes. Besides, the students' evolution of mathematical and social science sense-making was possible to observe through their utilisation of metaknowledge, metaknowledge of mathematics, process and product mathematics during their interaction with the Schelling applet.

Furthermore, the findings exposed that epistemological analysis of the Schelling applet was a helpful lens through which to observe students' interaction with the tools (i.e., Schelling applet), their use of sign, symbol, or language in the socio-cultural context. In this connection, Dienes (1971) argued that various interactive activities are useful for students to transform their understanding from concrete to abstract representations. The evolution of students' sense-making during their interaction with the Schelling applet aligns with Dienes's (2010) theory of mathematics learning. Dienes explains six critical stages of learning mathematics: (i) free play (trial and error), (ii) experimentation (utilise different materials), (iii) comparison (making sense of rules through discussion), (iv) representation (developing expression to represent abstract concept), (v) symbolisation (seeking for terminologies to characterise the properties), (vi) formalisation (properties deduce into theory). The finding of this study exposed the evolution of students' utilisation of metaknowledge, metaknowledge of mathematics, process, and product mathematics during their interaction with the Schelling applet. The epistemological analysis tool may contribute to the literature when it comes to the analysis of learners' engagement with simulation-based educational tools for teaching, learning and research in higher education.

I want to be clear; this research did not set out to explore how students utilized a digital tool that was presented to them to mediate some new mathematical concept. My purpose was rather to explore how students called on their metaknowledge, in particular, their knowledge of mathematics as they engaged in novel research methodology based on modelling and simulation. Consequently, my aim has been to connect with and build onto the growing literature of M&S based research in social sciences.

7.2 Pedagogical implications

An important pedagogical implication of this study is related to the impact of simulation-based educational tools in creating opportunities to learn about research methods curricula in social science study programs. The M&S-based educational tools have been widely used in instructional practices and innovative interventions in higher education study programs (e.g., Holter & Schwesinger, 2020; Marriott et al., 2015). These studies revealed that M&S-based methods increase intrinsic motivation, facilitate discussion, create an opportunity of decreasing or controlling complexity utilising virtual phenomena. However, very

few of the reported study programs offered M&S-based tools to facilitate students studying social phenomena such as spatial thinking, individual and community mobility, social segregation, in/exclusion, civic and community engagement, geospatial representation and social change (e.g., Hostetler et al., 2018). When this study was initiated, no such study programs, to my knowledge, had introduced M&S-based tools to create opportunities to learn about M&S-based research methods, as done in this study. In this present study, the innovatory M&S-based research methods curriculum module aimed to create students' opportunities to learn about M&S-based research methods. Further, the current study adds value to available knowledge on teaching and learning by utilising M&S-based educational tools (e.g., Hostetler et al., 2018; Ku et al., 2016; Lee et al., 2002; Marriott et al., 2015).

A second pedagogical implication of this study concerns the epistemological analysis of simulation-based educational tools (i.e., Schelling applet), which was helpful to expose students' evolution of mathematical and social science sense-making processes. For this reason, based on the findings of the study, I believe the epistemological analysis tools could offer an example for future studies to analyse learners' engagement with simulation-based tools in teaching, learning or research in higher education.

The third pedagogical implication of this study concerns the curriculum innovation in the M&S-based research methods course. The research methods curriculum module entails four components: seminar, tutor session, meet-the-expert, and writing an essay about M&S-based research methods. The seminar was a mixture of lecture and workshops that used teacher-designed materials. At the same time, the tutor sessions entail semi-guided activities aiming to support students towards knowing and understanding about M&S-based research methods. The meet-the-expert session was a round-table discussion in which students took turns to pose questions to experts regarding the usefulness, opportunities, challenges and limitations of M&S-based research methods. Finally, students were asked to write a short (300-word) essay[17], which was to be submitted along with the end-of-semester essay. The task was optional.

[17] A short (300-word) essay was part of the M&S-based research methods curriculum module. However, the essay's analysis was not included in the results of the study because, this study focuses on the students' learning activity in a social setting.

7.3 Curriculum implications in higher education

This study adopts a design-based intervention approach to implement an M&S-based research methods curriculum module and evaluate its effectiveness. The intention is to derive recommendations for future possibilities of developing such courses within social science study programs. As established earlier in Chapter 6, the M&S-based research method curriculum module helped students advance their awareness about M&S-based research methods. The findings revealed that they had developed critical processes of the methods, opportunities, limitations, and challenges by imagining situations that M&S-based methods that could be applied in their field. The M&S-based research methods curriculum module utilises simulation-based teaching tools, which provide interactive simulation-based learning environments to engage students in developing conceptual understanding and analytical skills. The current study focuses on the iteration of research design with different cohorts of students–religious studies and development studies, undergraduate (bachelor) and post-graduate (master) Norwegian and Nepali students. The diversity of context indicates the potential utility of the findings beyond the contexts researched.

In this study, I chose to use the Schelling applet (i.e., social simulation applet) to present some basic ideas about social phenomena such as the social in/exclusion, segregation without making the simulation and visualisation overwhelmingly complicated for novice learners. The current study's findings demonstrate that the Schelling applet (i.e., simulation-based educational tool) enables students to experiment on behaviour patterns of a virtual city populated by people with definable social attitudes through simulations. Therefore, based on the findings of the current study, I propose, in planning the future research methods curricula, social science study program leaders consider the incorporation of M&S-based educational tools to move beyond lecture-based teaching into hands-on, active learning approaches. Besides, the curricula can be further enriched by incorporating exposure to M&S-based professionals and academic researchers to ensure opportunities to learn about M&S-based research methods in the contexts of professionals and practitioners in their field. In this sense, students are apprentices to active researchers who provide opportunities to learn about M&S-based research methods by entering their community of practice with specific values, habits of mind, and routine (Lave & Wenger, 1991; Wenger, 1998).

7.4 Limitations of the research

This current study has several limitations. Repeatedly stated, this design-based study focused on the design, implementation, and evaluation of an M&S-based research methods curriculum module within a social science study program. The prototype of the M&S-based research methods curriculum module was implemented, targeting a modest number of participants. More specifically, there were 22 students in the first intervention, three students in the second intervention, and 11 students in the third intervention at a single university context.

7.4.1 Concerning contextual factors

A limitation of the study is concerned with contextual factors of the M&S-based research methods module. I acknowledge that the contextual influences, repertories or instructional strategies may limit the M&S-based research methods curriculum module's generalizability. More so, the *M&S-based research methods curriculum module* is a prototype that is open to modification based on the particular context of an educator or researcher.

7.4.2 Concerning knowledge of the local language

Another limitation of this study is related to my limited knowledge of the students' native language. Although the seminars, tutor sessions, meet-the- expert were conducted in English, I believe that those seminars and workshops would be more beneficial and powerful if they allowed students to express themselves in their native language. Keeping this in mind, I had organised students' interaction with the social simulation applet in their native language (i.e., Norwegian). However, due to my limited knowledge of the Norwegian language, I had to involve a translator to transcribe students' interaction with tools and peers, as these took place in Norwegian.

7.4.3 Concerning the choice of the applet

My study utilised the Schelling applet as a pedagogical tool for this study. Although I have explored a few simulation-based educational tools, the Schelling applet:

> "Was selected owing to the following three reasons: (i) the applet is freely available and accessible for use related to educational purposes, (ii) the

applet covers a teaching theme relevant to the interests of the students, and (iii) the applet entails only a few parameters, which makes it easy to understand and use" (as cited in Paper 4, pp. 3-4).

On the one hand, the Schelling applet could be re-designed to make it more appealing to students; for example, individual blocks could portray housing units and simulation features, including changing the colour of blocks when they appear unsatisfied/satisfied. In this study, I could utilise a similar applet to strengthen the generalization of the usefulness of simulation-based pedagogical tools.

My study concerns the utilisation of M&S-based tools while learning about M&S-based research methods. However, the study is limited because the Schelling applet is only one example of M&S-based tools used by M&S-based researchers, and a key element of the applet is the visualisation. This present study could utilise an M&S-based tool that M&S-based researchers utilised in their workplace practices, but these lack the visualization element. Besides, I did not explore how research methodology teachers could use simulation-based educational tools to establish such devices' value within methodology curricular practices.

7.4.4 Concerning theory used

In this current study, students utilise digital technologies such as M&S-based tools (i.e., Schelling applet) while learning about M&S-based research methods. Although I found the CHAT framework facilitated the study of various forms of human practices mediated by artefacts/tools. In this regard, Monaghan and his colleagues are discontented with CHAT because of the way the framework theorises tools in mathematical activity (Monaghan, Trouche, Borwein, & Noss, 2016). They argue CHAT provides "insight on tool use when the unit of analysis has mediated action tools but when the unit of analysis is the activity system itself, AT [CHAT] does not provide great insight on tool use " (Monaghan et al., 2016, p. 262). In this sense, CHAT does not provide vivid visions on the tool use. Hence, I encounter a lack of analytical power to adequately to operationalise the interaction between an M&S-based tool, students, and teachers. For this reason, I developed an epistemological analysis of the Schelling applet to supplement the analysis. Also, I adopt the theory of knowledge objectification and the theory of

multiple representations to analyse the evolution processes of students' mathematical and social science sense-making.

7.4.5 Concerning research methodology and methods

The design-based research was implemented as a doctoral research project within a limited time frame of 3 years. Instead, a long-term iterative design intervention could help to refine the theoretical claims. As such, I must acknowledge that this study's findings should be considered as being the beginning of a long-term iterative process in the larger research scheme to influence the social science study program's research methodology curricula. Thus I acknowledge the current study lacks evidence of a long-term effect of the M&S-based research methods curriculum module.

On the other hand, I acknowledge that students had minimal exposure to M&S-based professionals' practices. In this sense, the student's more extensive exposure to M&S-based professionals could broaden students' boundary-crossing experience while utilising their opportunities to learn about M&S-based research methods.

7.5 Implications for future research

The present research revealed that the proposed M&S-based research methods module helped develop students' awareness about M&S-based research methods. Students have developed awareness about M&S-based research methods such as critical processes of the methods, opportunities, limitations, and challenges by imagining a situation in which M&S-based methods could be applied in their field. Future research is needed to investigate the potential of M&S-based research methods curricula to address students' need or future careers options in local contexts. In the following, I offer eight suggestions for future research.

Recommendations for future research

1. Explore the affordances of M&S-based tools within the research methods curriculum module. These studies could substantiate the present research findings in the sense of instructional affordances within social science study programs. Furthermore, this could be action research.
2. Implement the epistemological analysis tools to interpret students' interaction from other courses, such as language learning, history, and teacher education. As such, this could enable a researcher to modify the

epistemological analytical tools on the influence of local, context-specific or discipline specifics aspects.

3. Implement tools to analyse how simulation-based tools enhance students' learning and teaching experience who dislike mathematics or statistics.
4. I am very interested in using alternative theoretical approaches to examine students' use of M&S-based tools. For instance, the instrumentation approach (e.g., Artigue, 2002; Trouche, 2005) would provide a means to analyse how students (and indeed teachers) develop their capacity to make use of M&S-based tools for mathematical purposes. Likewise, through the lens of the anthropological theory of the didactic (e.g., Chevallard, 2019), a researcher would be equipped with a framework to analyse the teaching implementation of M&S-based research methods curriculum module in social science study program aiming to report institutional dimension of human activity.
5. I recommend including other social simulation applets that enhance the curricula of research methods. For example, applets that depict low economic countries' migration pattern could help learn and research migration dynamics.
6. I am interested in incorporating social simulation software used by M&S-based researchers in their workplace practices. In doing so, students can utilise real-world data to examine their inquiries on social dynamics.
7. I recommend a semester-long M&S-based research methods curriculum modules to understand its effectiveness broadly.
8. I recommend a follow-up study to understand better how useful was the M&S-based research methods curriculum module. In this regard, I am interested in conducting a qualitative study to explore the current study's participants' further research choices and their career interests.

7.6 Final reflection

The present study aimed to explore how social science students can utilise the opportunity to learn about M&S-based research methods to understand social dynamics. The study entails three consecutive design-based interventions. I began the first intervention to examine the effectiveness of the design of the M&S-based research methods curriculum module. In this, I adopt Engeström's (1987) version of CHAT as the theoretical framework.

In the second intervention, I introduced the notion that students could gain metaknowledge of M&S-based research methods. Considering this, I did not have an analytical framework to analyse the extent and approach taken by students to gain the metaknowledge of M&S-based research methods. In both the first and second intervention, Engeström's version of CHAT was helpful to analyse students' participation through four different socio-cultural worlds:

> "(1) participants in a learning context (university students, seminar participants),
> (2) future professionals in workplace context (social worker, urban planner),
> (3) member of a research community (within a university, publishing academic articles),
> (4) citizens in the real world (as consumers, migrants, etc.)" (text reproduced from Poudel et al., 2019, p. 4).

At one point, I had little idea about questions such as 'what does this study have to do with mathematics education research?' During my first-year seminar and other formal/informal meetings, I used to get an obvious question like 'what is metaknowledge? How do mathematical competencies relate to the use of M&S-based tools? Further, I was challenged through several items that are around my study. For instance, if my work is to deal with two disciplines (i.e., social science and mathematics education), and then what was my strategy to deal with the notion of interdisciplinarity. I must be thankful to my colleagues, friends, and experienced researchers for asking tough questions and pushing the boundaries of my own thinking.

Arriving at this point, I realised that my work progress was only focused on social science students' learning about M&S-based research methods in general. I was unaware of questions such as 'what is the difference between thinking like a mathematician and thinking like a social scientist?' 'How does one form of thinking complement the other? Later at the end of the third intervention, I had a working definition of metaknowledge, metaknowledge of mathematics, processes and product mathematics, and *epistemological analysis of the Schelling applet* (cf. Chapter 3).

In the third intervention, my focus was to analyse data to understand how undergraduate students of religion utilise an opportunity to learn about M&S-based research methods. I did differentiate my research questions concerning the research strand I and II. Strand, I entail research sub-questions 1 and 2, and

strand II entails research sub-questions 3 and 4. At this point, I adopted local theories such as communities of practice, boundary-crossing, boundary-object to supplement the CHAT framework. Also, I found Roth and Radford's (2011) version of CHAT provided an appropriate theoretical framework for my study because:

> "Radford put forward the "theory of objectification" as an elaboration and extension of Leont'ev's (1978) version of activity theory that emphasised teaching and learning of mathematics (Roth et al., 2012), in which human actions are the goal-oriented substance of human activity. Radford (2014) further elaborates that the artefacts and sign (verbal or gestures) are not only mediators but also the essential elements of goal-oriented students' actions that lead towards the evolution of mathematical and social science sense-making" (text reproduced from Paper 4, p. 9).

The CHAT framework was helpful to characterise how students utilise mediating artefacts/tools to learn about M&S-based research methods. Further, artefacts/tools play a critical role in connecting students' learning goals, norms, community and other collaborators. Besides, the CHAT framework was helpful to reveal tensions between the activity systems of university studies and researchers' activity system.

It was a turning point when I realised that the notion of sign plays a crucial role in analysing students' interaction with the Schelling applet. Accordingly, I was motivated to adopt Steinbring's (2006) illustration that a sign typically has two functions: (i) a semiotic function, "something that stands for something else," and (ii) an epistemological function, indicating "possibilities with the signs are endowed as means of knowing the objects of knowledge" (p. 134). Steinbring's approach offered a foundation for developing an epistemological analysis of simulation-based educational tools (i.e., Schelling applet).In this approach, "the Epistemological Triangle (Steinbring, 2006), where concept development is seen as an interaction between sign/symbol, object/reference context and concept" (Rønning, 2013, p. 201). In this sense, I interpret the evolution of students' mathematical (and social science) concepts that emerge in the interplay between sign/symbol and reference contexts.

The Schelling applet's epistemological analysis helped expose students' evolution of mathematical and social science sense-making processes by

partitioning knowledge's function into four categories. They are procedural knowledge, operational knowledge, mathematical knowledge, knowledge about social dynamics. Further, the analytic procedures became even more conducive when I used the notion of multiple representations of mathematics (Duval, 2006) and the theory of objectification (Radford, 2003) while analysing students' mathematical and social science sense-making processes. On the one hand, the theory of knowledge objectification helped to characterise students' mathematical discourse concerning their choice of natural verbal languages and reifying mathematical and social science meaning/concepts. On the other hand, the theory of multiple representation was helpful to analyse instances in which students encounter multiple representations in their interaction to sustain mathematical thinking and meaning-making processes.

7. 7 Closing remarks

I conclude this study by acknowledging that this was a very modest study. The principal goal was to test the proposed M&S-based research methods curriculum module that elucidates how M&S-based tools can add experimental knowledge dimension to traditional empirical and theoretical knowledge. Despite its modest intention and outcomes, seen from a global perspective, I will first and foremost recognise the significant strides I have been able to take in becoming a researcher. Despite small contributions, I hope this study can make a broader contribution, as I summarise here.

This study has explored how social science students utilised the opportunity to learn about M&S-based research methods. In this regard, students have advanced their awareness about M&S-based research methods such as critical processes of the methods, opportunities, limitations, and challenges by imagining situations in which M&S-based research methods could be applied in their field. The design-based research approach was significantly helpful in designing and implementing innovative M&S-based research methods curriculum module. The innovatory curriculum model helped create a new learning environment to explore future possibilities in teaching, learning and development of the M&S-based research methods module. The study's findings showed that students' engagement in the M&S-based research methods curriculum module was explorative, informed, and persistent. Furthermore, the study's findings revealed that they could identify boundary-objects that could help them bridge the

understanding gap between the activity system of university studies and professional work practices. This study contributes to the literature on teaching, learning and research in higher education, primarily in three ways: (i) offering empirical-based M&S-based research methods curriculum module development, (ii) providing an epistemological analysis tool (i.e., epistemological analysis of Schelling applet) to exemplify how such tools are helpful to analyse learners' engagement with software or technological tools in teaching, learning or research in higher education, (iii) the study additionally reveals how students need to utilise mathematical knowledge in apparently non-mathematical contexts.

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9 Appendices

Appendix 1: Epistemological analysis of the Schelling applet

Procedural knowledge (i.e., pre-operational experience, getting ready to interact with the applet) / Operational knowledge (i.e., meaning that exists between control and what happens in the applet)	An object in Schelling applet	Mathematics		Social Science	
		Semiotic function "Stands for"	**Epistemological function "Meaning/concept"**	**Semiotic function "Stands for"**	**Epistemological function "Meaning/concept."**
	N (a number symbol)	In the app, it is used in the "cardinal" sense; that is, to represent "how many." It is used as a quantifier rather than an ordering or naming symbol.	Characterisation of phenomena with squares. A numeral (semiotic function) is used as an adjective as it quantifies the noun, tells how many of that "thing" are present. The meaning or concept is that it places the "thing" into a set in which all members share the same characteristic property of "quantity," the shared and equal "numerosity." However, on the slider bars, the ordinal meaning is also called on because the numbers increase uniformly as the slider is moved from left to right.	Agent A is an entity within the neighbourhood that shares a social characteristic with (A) In the applet, it is used in several contexts: It could stand for the number of squares surrounding a central square (which may share the same colour); it could stand for the dimensions of the whole square grid; it could stand for the proportion (%) of a community sharing a characteristic; etc. In all these situations, the "N" stands for "how many."	Agent (A) lives in a neighbourhood that shares, to some extent, a critical social characteristic. The characteristic is distributed throughout the neighbourhood, and agent A tends to prefer living with neighbours that share the same characteristic. The distribution of these units is not static and can change throughout time because the agent in those units (households) have an agency to move to another (more amenable) location if they find the surrounding community is not like one they prefer to live in. The meaning of "N" can be linked to the density of the other units (households) in the neighbourhood that share the characteristic with A.
	Proportion/ fraction	Symbolic representation of a part of a whole The proportion (in this context) will be a rational number.	The proportion of squares within a grid that share the same characteristic (colour) The whole may be divided into a given number (N) of equal parts; some (m) of these parts may be identified as sharing a characteristic not possessed by the remainder. The proportion of the whole	A quantity of "units" within a given community expressed as a fraction of all the "units" within the given community	The identified fraction/proportion of Agents (A) that share a characteristic which is not found in the remainder of the community. The characteristic is linked to the behaviour of Agent (A)

				sharing the given characteristic is represented by the rational number m/N		
		%	The symbol for the proportion or fraction in which the whole is considered as 100 equal parts	Indicating that the numeral preceding this symbol represents the quantity of parts out of one hundred equal parts.	In a neighbourhood, the number of agents (A) out of every 100 surrounding that share the same social characteristic as (A)	Agent (A) is among a group that represents the proportion (expressed as a fraction of 100) of agents that share the critical social characteristics
		30%	30 out of every 100 parts of a phenomenon share a characteristic not possessed by the other 70	The proportion of squares (30 out of 100) bordering a single square that shares the same colour as the single central square. However, there are only eight squares that border a given square, so the eight squares are considered a single unit and then divided into 100 equal parts. Thirty of these parts are identified as sharing a characteristic not possessed by the others. Also, in the complete square grid, this would represent an approximation to the fraction of component squares that share (one of) the same colour.	In a neighbourhood, 30 out of every 100 agents surrounding an agent (A) share the same social characteristic as (A)	Agent (A) will want to relocate when the proportion of agents sharing the same critical social characteristic surrounding is less than 30%
		Slider bar	A variable (the slider) that can be moved along the bar that represents a measurement scale. The value of the variable increases uniformly (from 0 to 100) as the slider is moved from left to right along the scale. Or increasing dimensions of the larger square grid.	Moving the slider along the scale means changing the value of the given variable. Conceptually, the slider represents a continuous variable, but the numeral annotation and the meaning is discrete. Increasing or decreasing the proportion of squares bordering a single square that shares the same colour as the single central square. Or increasing the proportion of component squares sharing a colour in the whole grid. Or a variable representing the length of one side of the square grid.	In a neighbourhood, the variable (discrete) represents the proportion of agents/units that share a characteristic or perhaps the size of the neighbourhood. "Moving the slide" stands for increasing or decreasing the number of like agents/units (or size) in neighbouring agents of (A) from lower to higher that share the same social characteristic as (A).	The variable (discrete) represents a characteristic of the neighbourhood and the willingness or otherwise of Agent (A) to live within the neighbourhood. Values will determine whether Agent (A) wants to relocate or stay at the same location based on the proportional increase or decrease of agents sharing the same critical social other characteristics
		"At least"	The symbolic representation that stands for "the minimum (lower)" value that meets a given criterion.	The number of squares bordering a single square is not less than a particular number (or proportion) and probably more than that number (or proportion). When a square can have at least 30 % similarly coloured neighbours it means, the square can have $\frac{3}{10}$ (or probably more) squares surrounding that share the same characteristics as the single central square.	In a neighbourhood, the minimum fraction or proportion of units neighbouring agent (A) that shares the same social characteristics as A	Agent (A) will want to relocate when the number (or proportion) of agents sharing the same critical social other characteristics surrounding are less than the particular number (or proportion.)

		Square (geometrical representation)	A symbol for a plane figure with four straight sides and four right angles. In the applet, the unit tiles are squares. Also, the whole grid is a square composed of smaller squares.	The notion of a unit of measurement equal to the area of a square. In the applet, 10×10-unit squares is the area of the plane. It means the length and breadth of the plane are divided into ten equal units in each dimension. We can list a few probable reasons for choosing square shapes in the applet: i) squares share boundaries with other shapes, ii) squares are used to tile the plane without gaps, iii) it is easy to program with a computer.	In a neighbourhood, Agent A is a household unit within a community with household agents (i.e., red or blue) and empty /vacant property (i.e., white). The unit household agents can move into the unit vacant unit property. The smaller squares stand for individual households/agents, the larger square stands for the neighbourhood or community.	Agent (A), within the neighbourhood, is a unit household agent share the same critical social characteristics. The distribution of these unit characters is not static and can be changed throughout time. The unit household has agency to make choices to move if their neighbouring agents are unlike to them.
		3×3 square grid	Set of square grids with 3 unit in rows, 3 unit in columns and 3 units in diagonals.	A central square tile is bordered by 8 square tiles that forms the symmetric shape. Colour can be distributed around the eight squares in any combination. Any distribution of n (<9) colours in the squares around the central square is equivalent to all other distributions of n around the centre.	Agent (A) lives within a neighbourhood with eight immediate neighbours that may or may not share the same social characteristic as (A)	Agent (A) will have as many different possibilities to move to a vacant block within the community and will chose to move to a square where the proportion of unlike neighbours is lower. Agent A has different possibilities to share critical social other characteristics such as colour, race, ethnicity, sexual orientation.
		n × n square grid (m and n known) **(In the Applet only square grids with equal sides are possible)**	Set of squares grids with n unit rows, n unit columns.	The field is covered by n×n squares shares bordering. The total number of squares proportionally increases for n = 1,2,3… (n > 2). In Schelling applet, the size 10×10, … 50×50, n×n, denotes the increase in numbers of squares proportionally inside the field. An increase in the number of squares means a decreases the size of the constituent unit squares. Further, each square has (n×n)-1 possibilities to place within the n×n square grid	Agent A is a household unit within the community of n×n blocks that share borders with the neighbouring agent.	Agent (A) is resident in a neighbourhood some of whom share the same critical social characteristic with A. It means each agent A has a number of possibilities to move to another location which has been determined by the number of vacant blocks within the community and is likely to do so if the number of A's neighbours are unlike A exceeds the minimum value.
		Red/blue/white-coloured squares	Unit square tiles with red, blue, and white colour codes	Square units with characteristic colour (Three – red, blue, and white). Colours are intended to represent a different "type" of square.	Agent (A) is a household unit with a certain social characteristic within a community of	Agent (A) is among the neighbourhood that includes diverse neighbouring agents within a community. The

					neighbourhood in which the characteristic is distributed. Red and blue represent household blocks with or without the characteristic, and white squares represent a vacant property into which red or blue can choose to move.	distributions of agents are not static and change over time, and every agent has agency to choose to be in a neighbourhood in which a given social characteristic is shared.
		Coloured square grid	Coloured squares in a network to form a series of squares	A network of unit squares within a grid that share the same characteristics that lead to forming clusters of same colours The grid represents a dynamic situation that changes iteratively as coloured squares are moved to locations where they are surrounded by more squares of the same colour. The iterations could lead to a stable and static "solution" or could result in a pattern of movement that never stabilises.	Agent (A) within a networked phenomenon of household agents with or without the same social characteristics as A	Agent (A) is among the neighbourhood with networked household agents that share (or do not share) the same critical social characteristics. Agent A has a preference to create a network within a neighbourhood of agents that share the same critical social other characteristics.
		Variable	Representation for a number, amount, or situation that can change. In the Schelling applet, the slider bar represents the variable of parameters (i.e., similarity, number, size, time, the proportion of red/blue squares population)	It indicates a phenomenon that shows change or difference in characteristics. The moving of the slider indicates the change of characteristics. In the Schelling applet, the proportional increase or decrease in slider bar indicates the change of characteristics in terms of parameters to see the outcome in the form of visualisation.	In a neighbourhood, the proportional change (or difference) in characteristics of agent (A) from lower to higher that share the same social characteristic as (A)	An agent (A) wants to relocate or stay at the same location based on the proportional change (or difference) in characteristics of neighbouring agents. For agent A, changing characteristics of neighbouring agents could be colour, race, ethnicity, sexual orientation, country of origins etc.
		Iteration/round	It is the process of doing something repetitively. It is an act of problem solving or computational method in which one builds on the one preceding.	It is a different version or form of something. The repetitive phenomena offer an opportunity to enhance the degree of accuracy by building on the result from the previous run/calculation/round/solution attempt.	Agent (A) within a community finds a more favorable location after moving to a location where other neighbouring agents share the same social characteristics as A. However, in moving other units surrounding A's original location possibly find themselves less settled.	Agents (A) are likely to relocate in successive rounds as the social character of the community changes with each move of an agent to another location. Moving continues until all agents are content with the overall critical character of the neighbourhood in which they dwell.

Appendix 2: Introduction seminar with students of Development Studies

Aim: To study how to teach Modelling and Simulation (M&S)-based research methods to students of Development Studies.

Central hypothesis: Students could understand the ways social simulation can assist researchers in the field by gaining a meta-knowledge about M&S-methods, that is, background knowledge about the research methods, its rationale, the way it is conducted, and the extent to which it can provide policy-relevant information (Brown & Stillman, 2017).

I aim to organise one session on "Using simulations in development studies research", especially for development studies students. The session is an adapted version of an earlier intervention seminar organised by Prof. Dr. Pauline Vos for the students of religion at the University of Agder. This session is further improved in consultation with Professors Pauline Vos and F. LeRon Shults.

Date: 20th May 2018 at University of Agder

Time: 15:00 – 18:00

Participants: Students of Development Studies at the University of Agder, Kristiansand

Technology: Computer for students, video camera, voice recorder, Kaltura's CaptureSpace Desktop App

Room: U031 (Room with multimedia facilities)

Session leader: Amrit B. Poudel, PhD fellow LaSiRM

Equipment: A video camera will be placed at the corner to capture overall session activities.

The session will be guided by a PowerPoint presentation (Using simulations in development studies research). There will be time for students to practice on the Schelling Segregation model with the applet from http://nifty.stanford.edu/2014/mccown-schelling-model-segregation/ .

Emphasis is on:

1. Research approaches to
    a. social and physical phenomena
    b. aiming at students' identity as future researchers

2. M&S-based research methods as a research approach to better understand social processes
3. How simulations could be a viable approach to development studies students as future professionals, researchers, and what are the limitations

Focus research questions:

1. To what extent and how do students develop a sense of social science researchers' motivation for using M&S-based research methods?
2. To what extent and how do students develop an understanding of the opportunities, limitations, and challenges by utilising M&S-based research methods?

Data collection strategies: observation, field notes, record of student screen activities and video records.

The project received permission from NSD with reference number 59290.

Time planning (approximately)

15:00 – 15:10 Brief introduction of the research project 'LaSiRM' with research aim.

15:10 - 15:30 Presentation "research approaches to social and physical phenomena" through PowerPoint

15:30-15:45 Break

15:45-16:00 Introduction to simulations for social phenomena

16:00-16:20 Practice on the segregation model (1)

16:20-16:35 Discussion

16:35-16:55 Practice on the segregation model (2)

16:55-17:30 Discussion

18:00-18.10 Students questions and comments

18:10-18: 20 Final reflection

Threats:

I. The teacher is the LaSiRM researcher, need to wear different hats at the same time, e.g., teacher, researcher, participants

II. The presence of video equipment and observers may disturb spontaneous reactions or induce students to give socially wanted answers
III. Technology does not work as intended

Appendix 3: Tutor Session Plan (REL 206 -Religious radicalization, extremism, and violence)

Time	Activity in detail	Resources
5 min	Sharing guidelines to make sure students have understood the writing task (i.e., 300-word essay) Aim of the tutor session: Opportunity to reflect the possibilities and challenges of M&S as a research approach for studying religious conflict Inviting students' comments/ideas on the use of social simulation in studying religious and social conflicts (if they have ideas)	Student information sheets Tutor session guides
10 min	Students share their reflection based on the following reading: Can Artificial Intelligence Predict Religious Violence? "I lose sleep at night on this." https://www.theatlantic.com/international/archive/2018/07/artificial-intelligence-religion-atheism/565076/ (*hard copy of Atlantic article will be distributed, they can read it if they have no got chance to read the article*) Session leader starts discussion highlighting 1or 2 key points from the article	Hard copy of reading resources
40 min	Students' reflection on the following questions. *What do you see as the most promising aspects of this approach?* *What do you see as the most challenging aspects of this approach?* *How might this approach be applied to other contemporary social issues related to religious conflict?* *If mentorship was available to help you learn this method, might you be interested in using it in your future research?*	
5 min	Closing	

Appendix 4: Calls for Extra paragraphs (student essay)[18]

The extra paragraph on the essay goes at the end of the 5-page essay, which you will be submitted to << head of the department of Religion, Philosophy and History>> by October 30th, 2018. You are encouraged to write 300 words. You can put the title as appropriate. For example: 'Use of social simulations in studying religious conflicts. With this in mind, we are running tutor sessions to assist you in writing the paragraphs. The detail schedules will be out via student email. The following notes will help you to participate in the tutoring session.

Social Simulation as a Research Approach for Studying Religious Conflict

Although research in the social sciences has traditionally been limited to methods such as literature reviews, interviews, ethnographic observations, and survey analysis, in recent years, many social scientists have begun to embrace more novel and interdisciplinary methods. One of these is computer modelling and simulation. A growing number of scholars are using these tools to study topics like religious conflict, extremism, and radicalization. Please read this short article from *The Atlantic* about some of the projects here at UiA that engage in this sort of research.

https://www.theatlantic.com/international/archive/2018/07/artificial-intelligence-religion-atheism/565076/

In your written essay for this course and in the tutoring sessions led by Amrit B. Poudel, you will have the opportunity to reflect on the opportunities and challenges related to modelling and simulation as a research approach for studying religious conflict.

Here are some questions for reflection:

- What do you see as the most promising aspects of this approach?
- What do you see as the most challenging aspects of this approach?
- How might this approach be applied to other contemporary social issues related to religious conflict?

[18] Note: Prof. LeRon Shults suggested the inclusion of some reflection questions. The assignment was prepared in consultation with Professors Vos, Shults and Høeg (Prof. Ida Marie Høeg at that time was Head of the Department of Religion, Philosophy and History). Prof. Høeg circulated the document to students through Canvas. I copyright belongs to the department.

- If mentorship was available to help you learn this method, might you be interested in using it in your future research?

Note: Essay is an optional assignment

Suggested References

Shults, F. L., Lane, J. E., Wildman, W. J., Diallo, S., Lynch, C. J., & Gore, R. (2018). Modelling terror management theory: Computer simulations of the impact of mortality salience on religiosity. *Religion, Brain & Behavior, 8*(1), 77-100.

Samuel, S. (2018, July 23, 2018). Can Artificial Intelligence Predict Religious Violence? *The Atlantic*. Retrieved from https://www.theatlantic.com/international/archive/2018/07/artificial-intelligence-religion-atheism/565076/

Appendix 5: Comments from the independent observer[19]

RE: The Friday meeting with the students

[redacted]@uia.no>
Tue 11/13/2018 7:39 AM
To: [redacted]@uia.no>; [redacted]@uia.no>
Cc: Amrit Bahadur Poudel <amrit.poudel@uia.no>
Dear[redacted]

Here are my answer to your questions.

- Something about the level of understanding of the students

From the questions of the students, I got the feeling they were not entirely sure what an ABM was. They seem to have an idea, but they kept on asking on whether they could see one, which makes me wonder whether they have really conceptualized what an ABM actually is.

- What surprised you in the students' questions and remarks?

What surprise me the most is that they wondered how come nobody else but the research community has access to ABM models. They were very eager in to see and play with the models. I also got the impression that they were surprised that the models were not being used to help steered policies or help educate people. It seems to me like they think that the models are offering a solution to most society problems but that they were kept away in the scientific community and not being access by lay people.

- What was clearly misunderstood?

To pick up on the last point of my previous answer. I believe they don't entirely understand that most models out there are clearly not a reflection of society, that most of them are not good enough to make policies, that their results can be completely misunderstand by lay people, as has happened so many time when press release of a model comes out, and therefore, I believe it is better to keep them away from lay people. To make an analogy, when producing drugs, a researcher make claim he/she has found a cure for a certain illness, but the drug is not release to the public till many studies and trials on animals and humans have been performed. Releasing the drug without doing these tests would be entirely irresponsible and dangerous. I see more less the same with ABMs. I believe they are very helpful to generate insights and new hypothesis about a certain phenomenon, and may help inform new policies, as long as the interpretation of the results of the model is done correctly and most importantly being aware of the limitations of it. I believe this was not entirely clear for the students.

- Anything else that you noticed about the students and that could be relevant to Amrit's research

I think I have covered everything in my previous answers. I something else comes to my mind I will write you guys back.

[redacted]

[19] E-mail from Post-doctoral researcher, Dr. Ivan Puga Gonzalez

Appendix 6: Student's reflection after a seminar[20]

3/3/2021 Mail - Amrit Bahadur Poudel - Outlook

Lecture on computer modelling

[redacted]@hotmail.com>

Mon 9/25/2017 1:29 PM

To: Amrit Bahadur Poudel <amrit.poudel@uia.no>

Hi Amrit

I found the lecture on computer modelling and simulations very interesting. It was nice to try it out on my own, like we did with the segregation model. It made it easier for me to remember afterwards, so when I hear about segregation now I have the model in my head. It has also made it easier to understand when LeRon has talked about computer modelling in the lectures. I found it exciting to talk about the possibilities for the method, and could imagine using it myself one day. I was a little worried beforehand that it would be hard, since my mathematic skills are not very good. But I didn't find it hard to understand, it was nicely explained and made interesting and relevant for our course.

Hope this is okay, and just let me know if there's anything else I should write about :)

Best regards,

[redacted]

https://outlook.office.com/mail/search/id/AAQkAGE0YTM4YjJlLWMyNmQtNDg0Yy04MzFkLTQ0OTdjNzlxNzEwZgAQAA6mgSzeea9luLRRFCuOBtU%... 1/1

[20] E-mail from participating student.

Papers 1-4

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Students of Development Studies learning about modelling and simulations as a research approach in their discipline

Amrit B. Poudel[1], Pauline Vos[1] and F. LeRon Shults[1]

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Researchers in the social sciences are increasingly using modelling and simulation (M&S) as a research approach. They create virtual worlds to discover relations across variables, and to test theories and potential policies. We introduced this research approach to students in the department of Development Studies at our university. The goal was to investigate the way in which such students can gain meta-knowledge about M&S-based research, that is, general knowledge about its nature and rationale. We organized a seminar to introduce the research approach and illustrated it with a simulation of the behaviour of agents with varying levels of tolerance towards their out-group neighbours (based on Schelling's segregation model). We analysed students' interactions through a socio-cultural lens. Students were able to gain meta-knowledge about M&S-based research, which they judged as useful for their future as professionals when working on development projects.

Keywords: Development studies, mathematical modelling, meta-knowledge, Schelling's segregation model, simulation-based research.

Introduction

A growing number of universities are running programs in *Development Studies*, a relatively new, interdisciplinary field building on economic and social sciences. This discipline focuses on issues regarding regional, national, and global development, such as food security, health, energy, and migration. Graduates from Development Studies departments often find placement in organizations whose agendas relate to social responsibility, sustainability and economic development (e.g., UNESCO, FAO). Research published in the *Journal of Development Studies* utilizes both quantitative and qualitative methods to shed light on both macro and micro variables that impact economic and social development, typically focusing on less affluent regions. Increasingly, researchers in Development Studies use mathematical models to simulate complex social and economic systems. For example, Kumar and Venkatachalam (2018) used survey data from bank loan applicants of various castes in rural India to create a model that enabled them to run simulations of different hypothetical scenarios; they found that lower loans were given to farmers from lower castes but, surprisingly, this discrimination did not affect owners of small farms. This research approach, in which modelling and simulation (M&S) is utilized, typically involves the following steps. Researchers begin with a real-world problem revealed by statistical, ethnographic or other analysis. Often, these problems are of particular interest to politicians and others attempting to improve the conditions for those in less affluent contexts. Researchers then identify relevant variables and construct a *causal architecture* that reflects both insights from theoretical literature and findings from empirical data. This work results in a mathematical or computational model. Using software such as NetLogo, they then simulate in the virtual world the phenomena observed in the real world. In this way, the real world data help to validate the model. However, the main goal

of M&S-based research approaches is not to create models, but to answer *'what if?' questions* by varying parameters in the model. Researchers can create a variety of scenarios and run a large number of simulations, often visualized in graphs, in order to discover complex interactions in the relevant socio-economic systems and, in some cases, to 'predict' the future behavior of those systems under certain conditions.

The steps in a M&S-based research approach can be illustrated by the modelling cycle in Figure 1, which is an adaptation from Greefrath, Hertleif, and Siller (2018), and based on earlier work by Blum (2015) and Kaiser (2014). Researchers start by investigating real world data and potential causalities to build a mathematical model, after which they run simulations to control whether the model aligns with the real data. They will iteratively improve the computational model until it fits the data, thereby repeatedly 'going through' the modelling cycle. In a subsequent phase, they ask 'what-if' questions and experiment, based on givens in the real-world (e.g., possible policy measures). By varying parameters in the model, and running new simulations, they obtain mathematical results that they translate into real results. After publishing, their results may be implemented and, possibly, solve real world development issues.

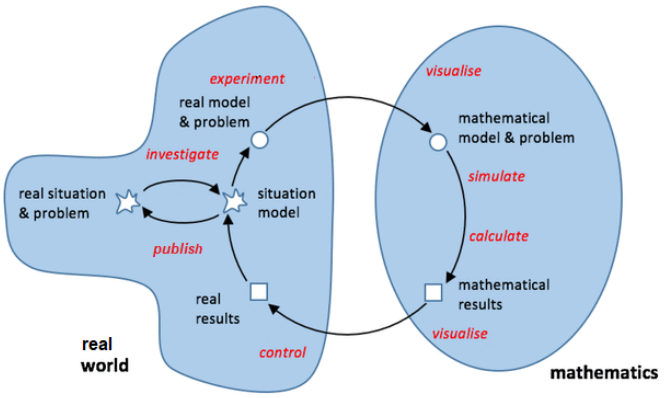

Figure 1: The modelling cycle, with visualizing and simulating digitally

Curricula of Development Studies differ across universities. According to Djohari (2011) and Engel and Simpson Reeves (2018), curricula emphasize the teaching of academic theories (e.g. social justice theories), critical and anti-colonial thinking, or skills useful for future development workers (e.g. project management). Most universities offering Development Studies include a course on research methods, typically focusing on qualitative methods. Only a few require statistics, since quantitative methods are known to be a hurdle for many social sciences students (Onwuegbuzie, 2004; Zeidner, 1991). At this point, curricula in Development Studies rarely incorporate the newer M&S-based research approaches, although these are increasingly used in this discipline. This lacuna in the curricula challenged us. We hypothesized that any Bachelor or Master's student could understand generally how social simulations can assist academic researchers in their research. In other words, they can gain a *meta-knowledge* of M&S-based research, that is, general knowledge about the nature of such research, its rationale, the way it is conducted, and the extent to which it can provide policy-relevant information. For our definition of meta-knowledge, we borrow from Brown and Stillman (2017), who also used the term meta-knowledge in relation to modelling. To explore our hypothesis, we organized a voluntary seminar aimed at giving students a 'feel' for the

explanatory power of simulations, so they could gain meta-knowledge about the research approach without a technical introduction to the simulation software, the computer codes, etc.

Theoretical frame

We based our analysis of students' interactions in the seminar on Cultural-Historical Activity Theory (CHAT) (Engeström, 1987). This theory focuses on the way in which, for example, the learning environment and students' social backgrounds interact with what students think and how they communicate. Within mathematics education, CHAT has proved useful in various studies; e.g., in research on how college students negotiate a workplace's and school mathematics' worlds (Wake, 2014). Following CHAT, the students in our seminar are understood as *actors* participating in different *worlds*. In the first place, they are participants in a learning context (in a Development Studies program, attending lectures, pursuing a degree). Second, they are oriented toward becoming professionals within a development organization (e.g. an urban planner in a less affluent country). Third, they might have the ambition to become member of a research community (within a university, publishing academic articles). Fourth, they are citizens in the real world (as consumers, migrants, etc.). Each of these worlds has its own conventions, norms, jargon, tools, etc.

When connecting the above CHAT-based *worlds* to insights from research on mathematical modelling education, we observe that in the modelling cycles of Blum (2015) and Greefrath et al. (2018), there are two worlds: the real world and the mathematical world. These are two *worlds* that both an M&S-researcher and a student in a mathematical modelling classroom *negotiate*. As Doerr et al. (2017) pointed out, describing modelling activities in terms of real and mathematical world is challenging. For example, the real world is far larger than the context of a modelling problem. Students and researchers participate in this larger world, and they may or may not have experiences with the problems addressed in M&S-research or in the classroom. Employees within development organizations also participate within this larger real world, but professionally they focus on a narrower world of specific problems in less affluent contexts. Researchers using M&S-based approaches operate primarily within the mathematical world of Figure 1; their work consists of identifying variables, creating relations between these, creating computer codes, running thousands of simulations, creating numerous graphs, and writing technical academic articles. So, although they work typically for the sake of the real world (global, national and regional development issues), the world of M&S-based research is mainly a mathematical world. The distinction between real world and mathematical world as depicted in Figure 1 has emerged from research into mathematical modelling in classroom contexts. However, this differs in several ways from the modelling activities of professional researchers. Students in classrooms often only 'go through' the modelling cycle once rather than several times, they use existing models rather than create new ones, they work with descriptive models rather than explanatory ones, they use educational digital tools if any (e.g., Geogebra) rather than professional computational programs, and their errors are less likely to have social and political implications (Doerr et al., 2017; Vos, 2018). In our study, we didn't ask students to engage in modelling activities, but rather to learn about the work of researchers utilizing M&S-based approaches. Therefore, we were not expecting to observe them operating in a mathematical world.

Our overarching research question was: to what extent can students in a Development Studies program gain meta-knowledge about the relevance of M&S for their discipline during a short intervention seminar? We had several sub-questions: to what extent can this interactive process enable these students 1) to understand the way in which these research approaches describe and explain social dynamics, 2) to grasp the basic benefits and limitations of M&S-based research, 3) to gain a sense of how researchers in Development Studies use such research approaches, and 4) to imagine themselves as future researchers using M&S-based approaches?

Methods

We used a design-based research approach for this project. This involved designing a seminar, implementing it, evaluating it, and then planning to repeat iteratively the intervention. Design-based research aims to improve educational practice in cases where new content is taught (Plomp & Nieveen, 2013). The study reported here was the first of its kind; in forthcoming iterations, we intend to have improved seminars on the same topic with another group of students. In this study, the participants were three Nepali students from a master's program in Development Studies: we refer to them as Student B (female), Student K (female), and Student S (male). The first author of this paper was the leader of the seminar, which was conducted in Nepalese. The seminar was designed to last 3 hours and consisted of three sections. The first section introduced some relevant social problems (e.g., the 2015 earthquake and its social consequences, segregation and violence) and the impossibility of using experiments to study this sort of phenomena (i.e., exposing participants to exclusion or violence is unethical), and a first introduction to M&S-based research approaches. The second section involved a semi-guided activity, described in more detail below. The third section consisted of a discussion triggered by probing questions by the seminar leader. To illustrate the research approach, we included a hands-on simulation experience regarding an issue relevant for Development Studies: the migration and segregation of a city's inhabitants. In this part of the seminar we used an educational applet, which offers a simulation of the well-known Schelling Segregation model from Nobel Prize laureate Th. Schelling (Schelling, 1971). This applet, available from http://nifty.stanford.edu/2014/mccown-schelling-model-segregation, see Figure 2, begins with a random distribution of a population with two groups of *agents* (indicated by red and blue blocks). Depending on an agent's wish to live with same-colour neighbours (in other words: its tolerance for living with neighbours from the out-group), it will move to a new location. In Figure 2 the slider for similarity tolerance is set to 54%, which means that an agent is 'satisfied' when at least 54% of its neighbours share its colour. If the number of same-coloured neighbours falls below this threshold, an agent moves to an empty spot (a white block). The simulation famously shows that even with a relatively high level of tolerance at agent-level, clustering quickly begins and segregation takes over in the city.

Students' interactions were video recorded and transcribed. We analysed these in light of the theoretical frame by going through the transcripts and identifying utterances, in which the students positioned themselves in a *world* (for example, by their use of the term 'we' or by their description of experiences). We coded when the students engaged (1) as participants in a learning environment, (2) as future development professionals, (3) as potential M&S-researchers in Development Studies, or (4) as citizens in a dynamic society. The analysis resulted in clear, and sometimes multiple codes.

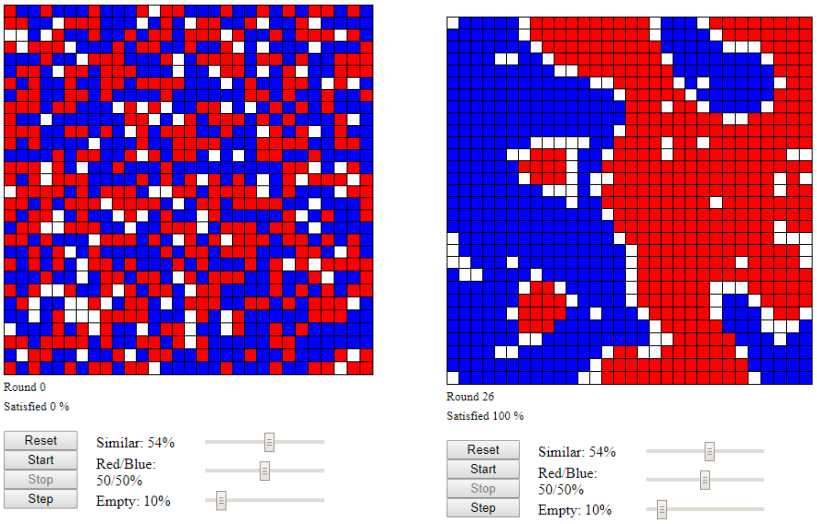

Figure 2: The Schelling Applet, at the start (left), and after 26 simulation rounds (right)

Results

The first part of the seminar was basically a lecture, which we didn't code due to the absence of students' utterances. The second part was a semi-guided activity with the Schelling Applet. The students sat together at one laptop, and interactively ran simulations to see the effects of varying the tolerance parameter. They tried many scenarios, and consistently found that raising agents' bias leads quickly leads to segregation, and that even relatively low levels achieved the same result, albeit more slowly. They also tried removing the empty spaces and discovered that no segregation could occur since *"no options are available anymore"* (Student S). They had experienced that in times of crises, people need to be tolerant: in the case of the Nepalese earthquake, people moved in with each other or lived peacefully in overcrowded tents. Student S was critical of the applet, commenting that in real life the space of a city is not restricted, and people would move beyond the city borders to build bigger houses. Student B mentioned that she knew of an influential person who moved to another place after the earthquake, after which his whole clan soon followed; in this case, the clustering tendency was already present before the segregation. In terms of the CHAT framework, the students were primarily participants in a learning environment (discovering the effects of changing sliders in the applet), but also expressed their real-world experiences as citizens. During this second part of the seminar, we observed the students speak neither as future professionals nor as researchers. The third part of the seminar was a discussion guided by probing questions, the first of which was: "what questions from Development Studies could be answered by studying virtual worlds?" Student S suggested that the different clusters of people could be studied with respect to their socio-economic status. The seminar leader realized that such a study would likely require a survey, rather than a simulation, but did not comment so the others could respond. Student B then said that simulations provide a dynamic visualization of phenomena and enable researchers to observe long-term changes visually. She suggested that simulations could be a medium for communication *"for those who hate large data sets"* and do not have a strong background in mathematics. At this stage, the students were participating as potential future Development Studies researchers, in a world in which they anticipated executing and publishing quantitative research.

To focus on their future professions, the seminar leader asked the students to think as *urban planners*; how might the latter make use of simulations? This triggered a lively discussion on how urban planners could promote a tolerant community. The students agreed that the Schelling Applet represented a certain underlying structure in society, although agents' movement in the real world is related not only to the colour of their neighbours but also to other factors, such as economic concerns, or a desire to live close to relatives. They then discussed ways in which a simulation of road networks could show how certain groups have better facilities (e.g., close to hospitals, accessible to firefighters), and how M&S-research could contribute to improve urban lives:

Student B: We can find out the road conditions, specifically in Kathmandu. Because they are constructing roads in different places. I want to know whether it [the road network] is effective or not, basically, already at the planning stage.

Leader: How effective is that planning? Any examples?

Student B: For example, roads in Kristiansand [Norway] are well planned. If you walk in this city, nobody gets lost. But in Kathmandu, we always get lost or run into a wall [dead-end]. With these [simulations], we can study the trend of urbanizations. We can compare the situations. Find out the areas where more housing is needed.

Student B was imagining ways in which a simulation could help her understand and predict dynamics of urban life. This triggered the other students to identify additional scenarios, in which simulations could be used. Here, the students were thinking of themselves as potential researchers who might use M&S methods for urban planning. In addition to seeing themselves as citizens (travellers, migrants, etc.), they also perceived themselves as future professionals contributing to developing their communities through simulations to analyse and predict social dynamics.

Student B: Here is a different thought… If I have a virtual Nepal, I think we can find vulnerable places for a natural disaster. We can find out how likely it is.

Student K: If we talk about health facilities, there is one health post in a VDC [Village Development Committee; Nepalese term for a rural organization unit]. Isn't that right? Any VDC has 9 wards and the health post will be in one ward. For [people in] other wards, it is far. So, if we can see distance virtually, then it will help us to decide whether there is a need for an additional health post.

Student B: For example, in the Artificial Intelligence Systems course, we studied the PredPol model [an Artificial Intelligence system used by the police in Los Angeles]. If we borrowed the PredPol model, which will be helpful to identify key places where crime is increasing. It will be helpful to estimate sufficient armed forces for those identified places. Find out the crime spots observing past situations. This PredPol model is helpful to predict future crime using previous data.

Student K: A predictive tool

Leader: (…) Is that model a simulation?

Student B: I think it is a simulation model, because it helps us to predict.

We see here that the students used "we," speaking as future policy makers who assist their societies prepare for natural disasters, set up health posts, or fight criminality. At the same time, they speak as researchers, using verbs such as "find." When asked to identify the limitations of M&S-based research, Student S pointed out that simulations do not produce realistic pictures, Student B wondered whether M&S methods were sufficiently scientific, and Student K asked about the expense and training required for creating models. However, Student B noted that a simulation's visualizations could be helpful for communicating with less-educated people. All three agreed that simulations can serve as a tool for prediction in guiding critical decisions, as well as facilitating understanding of the social dynamics of urban life, enabling governments to develop better policies. The students grasped that development professionals might implement the recommendations of M&S-based researchers even if they did not use the tools themselves. Finally, when asked if they could imagine themselves doing M&S-based research, Students K and S were silent, but Student B said *"your presentation made clearer what a model is. Before coming here, I didn't know what a model is. I am interested."*

Conclusion, discussion and recommendations

We observed that the students were largely able to understand the opportunities and challenges of studying social dynamics through M&S-based approaches, connecting it to prior knowledge of artificial intelligence systems that simulate future scenarios. They described possibilities for using simulations for planning roads or identifying places vulnerable to natural disaster or crime spots. Mostly, they expressed themselves as future professionals in development projects who would use results from M&S-based research. In the process, they shifted roles from learners, to citizens, and future development professionals, but not to researchers at a university using M&S-based approaches. Thus, the seminar assisted them in gaining meta-knowledge about the relevance of M&S for development professionals, but to a lesser extent for researchers in their discipline. The students understood that the Schelling Applet was an example of a simulation, which simplified real life processes, but that despite its limitations the simulation had explanatory power for certain social dynamics. Thus, the applet served as an educational tool helping students to transcend the learning environment into other worlds and to imagine what other simulations could look like when used by development professionals. However, students' erratic interchanging of terms like 'model' and 'simulation' showed that they had only a cursory sense of M&S-based approaches. Their capacity to gain meta-knowledge was restricted by their lack of experience in creating models and running simulations. Since we didn't ask students to engage in modelling activities, we kept them away from the mathematical world. So, they learned about M&S, but not the advanced aspects of the real work done by M&S-based researchers (identifying variables, creating relations, coding, etc.). How best to introduce novices to creating simulations remains an open question.

In a future iteration of the seminar we could put more emphasis on how and why researchers in Development Studies increasingly embrace M&S. Inspired by a comment from one student, we might also show how M&S provide a powerful tool for communication. Further, we could stress the way in which M&S-based approaches can capture link the micro- and macro-level (e.g., tolerance between individuals and the segregation of a city), as well as their relevance for their future as professionals studying issues such as urban planning, disaster preparation, or crime prediction.

CHAT provided a productive framework for understanding the way in which students engaged in the seminar as participants in different worlds. This study revealed that a seminar was sufficient for promoting meta-knowledge about the nature and relevance of M&S in Development Studies but highlighted the additional competencies that will be required if they pursue these approaches as professionals. These findings will help us improve future seminar iterations with other students.

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