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

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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.

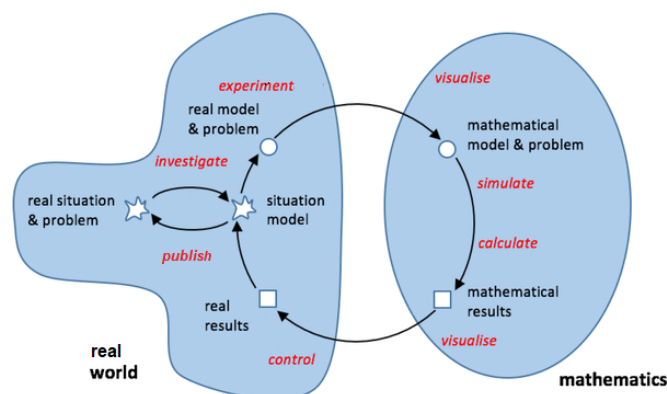


Figure 1: The modelling cycle, with visualizing and simulating digitally

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.

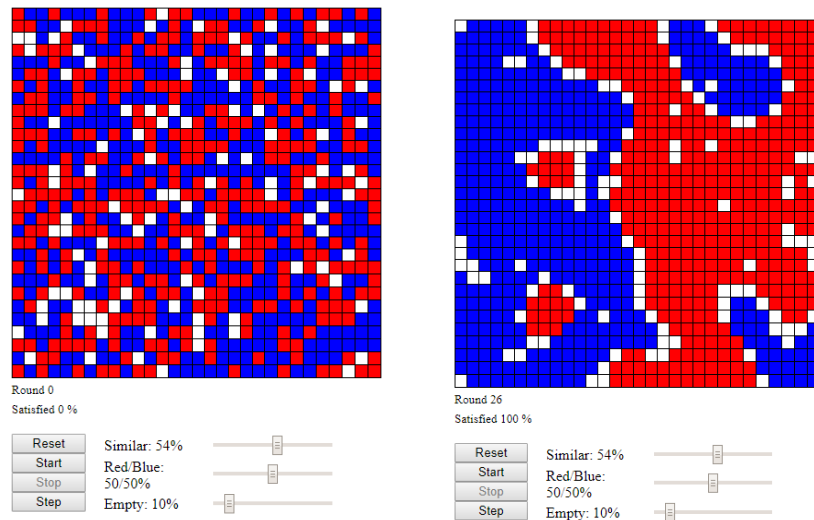


Figure 2: The Schelling Applet, at the start (left), and after 26 simulation rounds (right)

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 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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