Redesigning Your City
- A Constructionist Environment for Urban Planning Education

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Abstract
In spite of decades of use of agent-based modelling in social policy research and in educational contexts, the two have never been married. This paper accounts for a proof-of-concept single case-study conducted in a college-level Social Policy course, using agent-based modelling to teach students about the social and human aspects of urban planning and regional development. The study finds that an agent-based model helped a group of students think through a social policy design decision by acting as an object-to-think-with, and helped students better connect social policy outcomes with behaviours at the level of individual citizens. The study also suggests a set of new issues facing the design of Constructionist activities or environments for the social sciences.

Keywords agent-based modelling, NetLogo, social policy education

1. Theoretical Framing
It has been argued many times that a cornerstone of democracy is a well-educated citizenry that is able to participate in discussions about how to organize society through the design and implementation of policies [1], [2]. However, research shows that citizens struggle with identifying policies that they themselves support, and that they often vote for parties that do not support the same policies as they do [3], [4].

Shtulman and Calabi’s [5], [6] work suggests that part of the explanation to this paradox is that citizens fundamentally do not understand the underlying issues, and that they therefore are unable to reason about policies to address them. Ranney et al.’s [7], [8] work on global warming policies suggests that taking a mechanism-based approach to explaining the underlying issues to citizens may help address this gap; in their studies, the better people understood the mechanistic relationship between infrared light, energy, CO$_2$, and global climate change, the more likely they were to shift their opinion towards support policies that would reduce CO$_2$ emissions.

However, decades of research in complex systems thinking suggests that ‘simply’ knowing the individual, mechanistic interactions of a system does not necessarily mean that people are able to reason correctly about the aggregate level behaviour of the system. Rather, it shows that reasoning about complex systems is extremely difficult, and that people often ascribe properties at the individual level to the aggregate, system-level [9], and that people often apply incorrect intuitions or heuristics when thinking about them [10]. This can lead to difficulties with grasping how simultaneous and interdependent interactions can produce ‘butterfly effects,’ and difficulties with reasoning about critical thresholds or ‘tipping points.’

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To help these failures in complex systems thinking, agent-based modelling has gained increasing use over the last two decades, particularly in educational contexts [11]. Agent-based models are computer-based simulations in which the modeller specifies behaviours or interactions at the agent-level and then lets the system- or aggregate-level outcomes emerge from these interactions. The focus of agent-based models on individual-to-aggregate-level interactions make them particularly well-suited for mechanism-based approaches to teaching and thinking about complex systems.

In educational contexts, agent-based models have been deployed in domains as diverse as physics [12], evolution [13], animal biology [14], chemistry [15], [16], material sciences [17], and robotics [18]. This educational research combining agent-based modelling and complex systems thinking has often taken a Constructionist approach. Constructionism is a theory of design and learning developed by Seymour Papert [19], [20]. Constructionism extends Piaget’s view of knowledge as ‘structure’ on which we can perform cognitive operations, and argues that building, sharing, and discussing external structure can change our internal, cognitive structure. The function of agent-based models in this work has been to act as this external structure, an object-to-think-with that helps learners construct and share their thinking on a particular issue.

2. Research Questions

Taken together, these bodies of research suggests that taking a mechanism-based approach to explaining underlying policy issues combined with an agent-based model as a tool to think with, may be a productive way of teaching social policy. Agent-based modelling has been used in social policy research for decades [21] and is increasingly being used in policy research [22]–[24], even focusing specifically on urban or regional development, e.g., [26], [27]. However, agent-based modelling is still to make its way into social policy and urban planning education. This proof-of-concept study sets out to address this gap in the literature and addresses the following questions:

1. How do learners use agent-based-models as an object-to-think-with in a social policy educational context?
2. Do agent-based models help learners better connect behaviour at the individual level to policy outcomes at the aggregate level?

3. Study Design

3.1 Context & Sample

The study ran over the span of three days, as part of a unit on regional development in an Introduction to Social Policy-course at a private, mid-sized university in the American Midwest. The whole class of 39 students participated in the modelling curriculum, and out of these, 12 students (in four groups of three) consented to being video recorded.

3.2 Activity Design

On the first day during class, the professor (not a researcher) would start class with a 20-minute class-discussion about why people live where they live. Students were asked what they liked about where they grew up, what they didn’t like, and why they thought their parents moved to where they did. This was done in an attempt to forefront behavioural mechanisms at the individual level that lead to the formation of fairly homogenous neighbourhoods, even in heterogeneous cities. This discussion was supported by a map programmed in NetLogo [28] and using the GIS-extension [29], illustrating concentrations of poverty, minorities, and population density in the city in which the
university is located [Figure 1]. The professor then discussed with the students how the design of land-use policies, and decisions about infrastructural design affected the behaviour of citizens, which in turn affected how the city emerged.

Students were then given a model, also written in NetLogo, of the same city. In groups of 2-3, they were asked to redesign the city, focusing on one of three policy outcomes (‘commute times,’ ‘access to leisure,’ or ‘access to high quality education’). By changing the land-use law (either ‘dense urban,’ ‘medium urban,’ ‘suburban’ or ‘subsidized housing’), placing industrial zones, and adding or removing railway and highways, students were asked to re-grow their city and achieve whatever policy outcome goals they set for themselves. Students were asked to spend one hour on this activity after class, and to go through as many iterations of their city design as time allowed.

3.3 Brief description of the Model
When the model is started, students are given a barebones version of the city’s infrastructure in which only the most important railroads and highways are present [Figure 2]. This was done for a number of different reasons: First, to help activate concrete knowledge about the city; second, to give the model an air of realism; and finally, to create some constraints on the possible designs, and nudge student thinking in the direction of ‘improving on their city’ rather than coming up with an entirely new one. Students had to zone enough residential areas and enough industrial zones to provide housing and jobs for 2.7 million people (the actual number of residents in the city), and add whatever infrastructure they wanted. Finally, students could put in as much infrastructure as they wanted – we were curious to see how they would redesign the city without any constraints.

Once students had zoned enough residential and industrial zones, and they felt their city was ready to be populated, they would press the “Grow!” button, and citizens would start populating the city. Citizens were created with an income drawn randomly from a distribution similar to the US income distribution. Each citizen would be given a job in an industrial zone, and each citizen would then make a decision about where to live based on three principles:

1. It must be affordable
2. It should be as close to their spending maximum as possible
3. It should be as close to their workplace as possible

In plain language, people want to live in a place that they can afford, that is about as ‘nice’ as they can afford, and that is not too far away from their workplace. Whenever a citizen moved into a residential zone, the housing prices would change to reflect the mean income of citizens who live there. The poorest 15% of the population does not have cars, and can therefore not use highways. As people populate the city, roads get congested, slowing down traffic, increasing commute times, and in turn, changing the desirability of surrounding residential areas. Areas with parks or the lake nearby are more attractive, and will therefore tend to attract more wealthy people. Running the model and populating the city takes somewhere between 30 and 90 seconds, depending on how big the city is. This allowed students to quickly and incrementally iterate their different city designs.

Figure 2: The interface of the model, and the barebones version of Chicago’s existing infrastructure and land use.

3.3 Data collection

Three kinds of data were collected during the study. First, Google forms were used to collect student thinking in writing before and after each design iteration. In these forms, students were first asked which of the policy outcomes they would focus on, what they wanted to accomplish with the outcome, and how they hypothesized they should design their city in order to achieve that; then they were asked whether they achieved the outcomes they hoped for, to reflect on what worked or didn’t work, and whether their city would be a good city if it were a real one; and finally they were asked what they would improve or change next time around. Second, every time a group had finished a design and ran their model, they would submit a screenshot and the entire state of the model of it to a server. Third, Camtasia was installed on student computers, so that we could get recordings of what they did on- and off-screen during the activity, in order to capture the students’ group work process.

4. Findings

In this paper, we will focus on one group consisting of three female freshmen or sophomore students; Laura, Beth, and Kim. In this section we will go over their two iterations of designing their city, and discuss what we see as changes in their thinking for each of the iterations, and what that means for our research questions.
1st Iteration

Our group first set as their goal that they wanted, “[…] to lower the commute times for everyone in the Chicago area. We want to get the commute time for everyone below 35 minutes.” When asked how they would achieve this goal, they stated that they would, “[…] put houses near [industrial zones], highways and public transportation stops. We will put the subsidized housing by the railroads in order to have easier access for those without cars.” Their reasoning seemed to be that as long as there are transportation options near all residential zones, commute times will be low for everyone, which at least at the surface level is correct. Based on this, they designed their city [Figure 3]. They started out by first expanding on the three existing residential areas from Figure 2, and then adding a fourth residential area. When they had zoned all the necessary residential areas, they added some industrial areas near each of their four residential areas. Finally, they connected all four areas with a circular railroad, and then with an X-shaped highway system. They later in their reflection explain that their reason for creating four “epicentres” is that they wanted people to be able to live and work in the same local communities. However, when they ran the model, they ended up with very long commute times [Bar chart, Figure 3], with the middle-income decile having an average commute of around 80 minutes. They correctly reason that this happened because, “[…] people did not necessarily live in the epicenter where their work was, which we couldn't really control,” and that they “[…] underestimated the distance between each epicenter and thought that the connecting railways would easily reduce the commute time.”

![Image of Figure 3](image)

**Figure 3:** The group's first design. Four distinct suburbs creates long commute times for people who do not work and live in the same place.

The part about distance is somewhat banal – their city is in real terms around 45 by 60 miles in size. Having space in the middle with neither residential areas nor workplaces increases the distances that citizens must travel, thus increasing commute times. What is more interesting is their realization that creating equality in commute times is about creating equality in both infrastructural design, and in the attractiveness of living in various neighborhoods (or ‘epicenters’). Because they only focused on infrastructural decisions, they ended up creating neighborhoods that were only attractive (or, conversely, affordable) to particular groups of the population, and thereby created a situation in which people either chose not to live near their work, or could not afford to live near their work. A good example is the part of their city containing just suburban areas (marked with
‘L’) in the top right along the lake. Although it is not that well connected to infrastructure, it is attractive because it is suburban and because it is right on the lake. As a result, most high-income people decided to live there, and therefore ended up with long commute times.

2nd Iteration
In their second attempt, the group decides to start from scratch, rather than attempting to modify their previous design. As they begin to re-design their city, Laura says, “We’re trying to reduce commute times…” and Kim continues, “so the closer everything is, the better” [00:39:15-00:39:26]. It seems clear that this heuristic was developed from the mistake they made in their last attempt in which their residential areas were too far spread out. It should be noted that while this heuristic is true at the surface level, it is not necessarily always true; the more compact a city is, the shorter the distance people must travel which of course will reduce commute times, but the more people will have to share the same roads which increases commute times. So even with a dense city, it is important to make sure that workplaces are spread out, and that the density of the population is evenly spread out. The group starts discussing how to connect the two suburbs that are part of the pre-existing infrastructure in the model, in order to “not have suburbs”. In an interesting contrast to their first attempt in which they first zoned all residential areas, then zoned industry, and then zoned infrastructure, this time they continuously shift between all three kinds of areas. By doing so, they are able to create rings of industry and residential areas around the city. As a result, they end up with a drastically differently designed city [Figure 4] than in their first attempt. The city is denser, and all industrial and residential areas are adjacent to each other, i.e. “suburbs”.

![Figure 4: The group's second design, colour coded by commute times. Because of smaller distances and greater spread of industry, commute times are much lower.](image)

This time, while the city is populating, the three students look intently on the screen, offering comments as people move in and the results start emerging. They start out by visualizing their model by income, but later change it to show commute times. When they see that the area in the top part of the city is turning red (i.e. that people living there have long commute times), Kim says, “It’s okay, they’re rich. They’re fine.”[00:43:37-00:43:40] At this point, it is hard to tell how much of this is a joke, and how much of this comes from a sense that these people chose to live far away from their workplaces, and that in a sense they don’t deserve a short commute time. Neither of the
other two group members responds to the comment, though. As soon as the city is done populating and it is clear that people living in the northernmost part of the city have much longer commute times, Laura says, “Oh, we should have put industry in [the northern part]!” Beth responds, “Yeah, we’ll put that in our reflection”. They then look at their outcomes on the bar chart, and Kim says, “Hey look, the poor people have the shortest commute times!” and Laura continues, “And then everybody else is pretty much equal. That’s cool!” [00:44:05-00:44:13]

In their reflection, the group notes that they should have put industrial areas in the northern part of the city, but that they overall felt they achieved their policy outcome goals of lowering commute times for everyone. However, more interestingly, they also add that currently it would not be a good city to live in, “because it is so dense and everyone would be on top of each other and there are no parks.” While this may be true, this is, strictly speaking at least, unrelated to the policy outcome goals that the group had decided to focus on.

Planning-wise, their lesson from the 2nd iteration is that they need to put industry all over the map – including in the northern parts of the map. But more importantly, they are now diverging from their initial goal of getting everyone’s commute below 30 minutes, and are instead happy that the poorest citizens have the shortest commute times. This is one area in which agent-based modelling curricula on social policy-education diverge from the hard hard-sciences topics in which agent-based modelling has been used: Decisions about social policy outcomes are inevitably tied in with political or ideological beliefs. The group is not ‘just’ trying to maximize a particular measurement in an emergent, complex system – the finished model is a social artefact, and they assess it through the lens of a particular set of values that they seem to agree on, and that makes it more acceptable to them that low-income citizens have shorter commute times while everybody else do not – at least relatively. This importance of the social aspects of the modelling activity, at least to this group of students, is further exacerbated by their inclusion of parks and leisure areas in their assessment of the model outcomes, and by their comment that everybody would be living on top of each other: Had we asked students in a hard sciences class to maximize a particular outcome in a model, we would not expect them to bring up the other outcomes in their self-assessment. However, we speculate that social issues may be more difficult to cognitively disentangle and think about in an isolated manner – or maybe it simply shouldn’t be disentangled.

**Discussion & Design Implications**

The case-study data presented in this paper suggests that agent-based modelling activities may be productively deployed in social policy education – particularly on topics that lend themselves well to being represented as complex systems, such as the emergence of cities and neighbourhoods within cities, e.g. [26], [30]. Using the model, students were able to reason about their city as a complex system. Through their iterative experiments, they increasingly connected the behaviours of individual citizens through their choice – or lack of choice – about where to live, through the formation of economically heterogeneous neighbourhoods, to the system-level outcomes and commute times of the city as a system.

In many ways, the findings from our case-study echo those found in existing Constructionist literature in which agent-based models are used as educational tools: students were able to articulate productive intuitions about the topic, and by using an agent-based model as an object-to-think-with, were able to apply them in series of iterative model constructions. Through these
constructions, students articulated heuristics based on their intuitions, tested them, and experienced the strengths and shortcomings of their intuition, thereby slowly building up a richer understanding of the topic.

Existing Constructionist educational literature has focused primarily on hard sciences subjects. By taking the leap into social sciences, we face a new set of problems relating to the design, and assessment, and analysis of modelling curricula. While in the hard sciences there is typically only one canonical, scientific explanation to a particular phenomenon at any one point in time, in the social sciences there are typically many different contemporary explanations. In part due to this, political theorist Michael Freeden says that policy issues are essentially contestable, meaning there are many valid but mutually exclusive ways to think about them [31], [32]. Taking a Constructionist approach means designing an object-to-think-with, and this necessitates that students are able to express their thinking with that object. For the design of social policy models, this means that we must take into consideration all, or most, reasonable (whatever that means) interpretations of a particular social issue and the ways in which it can be addressed. In our case, on the outcomes-side, we only provided three policy outcomes, but we may as well have included pollution or traffic safety issues. We further assumed on the policy intervention-side that the solution would be a central planning approach, rather than a free-market approach in which the construction of infrastructure is left to private companies looking for profit, or left to local municipalities looking to maximize a set of local outcomes. If, for instance, a student with a libertarian outlook used our model, they might disagree so fundamentally with these assumptions that they would be unable to think-with the model because they are unable to express their thinking with it. Second, for the design of activities, we chose to ask students to focus on just one outcome. However, our group seemed to, consciously or not, read things into their outcomes that weren’t actually in the computer model – like assuming a lower quality of life for citizens because of the density of the city, or due to lack of parks. This may suggest that social issues should not be disentangled or isolated, but may better lend themselves to a more holistic approach, and that the design of activities shouldn’t artificially attempt to separate them.

Conclusion
In this paper, we first argued that the use of Constructionist learning in the social sciences, particularly in social policy, is understudied. We then presented a case study on students’ use of a computer modelling-based curriculum unit on urban planning and social policy. The unit was designed to take a social mechanistic approach to explaining and thinking about urban and regional development, forefronting human behaviour as a driving force behind the emergence of neighbourhoods in cities. Our data showed that students increasingly connected micro-level interactions with macro-level outcomes, and that they activated and productively used their intuitions when reasoning about how to better design their city. Throughout their experiments, the NetLogo model helped them redirect their intuitions in those cases where their intuitions turned out to not be entirely appropriate. We finally discussed some of the issues relating to designing Constructionist environments for policy issues.

The present study is limited to a single group of three students. We are therefore not making any grand claims about learning effects or generalizability. However, we believe that there are exciting
new opportunities and challenges in taking Constructionism to the social policy education, and we hope that this study can help inform this move.

References


