Patterns of use of an agent-based model and a system dynamics model: The application of patterns of use and the impacts on learning outcomes

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Abstract
A classification system that was developed for the use of agent-based models was applied to strategies used by school-aged students to interrogate an agent-based model and a system dynamics model. These were compared, and relationships between learning outcomes and the strategies used were also analysed. It was found that the classification system could also be applied to the use of the system dynamics model, with the addition of criterion. This means that a classification system exists for both styles of models. The fact that the strategies could be identified, despite differences in the actual model, and the model type, compared to the original study, means that there are implications for training teachers or systems to also identify the strategies. Initial findings of this study identified links between prior knowledge and the strategy chosen, as well as links with learning outcomes.

1. Introduction

Buckley et al. (2004) suggest that use of simulation models, such as deciding which perceptual cues to attend to, deciding how to interact with the representation and monitoring and evaluating the results of those interactions, are important metacognitive processes that play an important part in model-based learning. If this is the case, learning outcomes should depend, amongst other factors, on the ways in which students interrogate simulations, although there are very few studies that investigate the use of simulation models and compare learning outcomes (Kennedy & Judd, 2007; Levy, Kim, & Wilensky, 2004; Moxnes, 1998). Levy and Wilensky (2005) investigated the patterns of use of an agent-based model. They identified three distinct strategies for interrogating the model. In the study reported in this paper, video screen shots of students’ use of an agent-based model, a system dynamics model, and both combined were analysed in order to meet four aims: (1) to determine whether Levy and Wilensky’s strategies could be applied to other agent-based models, and to a system dynamics model; (2) to investigate the relationships between these strategies and general measures of use of the models to help to further define the classification system; (3) to investigate relationships between prior knowledge and the strategy chosen; and (4) to determine whether the strategy used was related to the learning outcomes.

The following literature review will outline the use of models for science and environmental education, provide details of the use of agent-based and system dynamics models, and discuss Levy and Wilensky’s strategies in more detail. The methods, including the design of the models, the experimental procedure and the instruments used to assess prior knowledge and learning outcomes, will also be explained. The results and discussion will follow.

1.1. Learning with pre-built models

Models are representations of ideas, objects, events, processes or systems (Gilbert & Boulter, 1998), and are generally simplifications of reality (Coyle, 2000; Jonassen, 2000). Computer-based models allow complex systems to be represented efficiently and constructed in a relatively short amount of time. Technology can be used for learning by modelling (Rohr & Reimann, 1998; Woolsey & Bellamy, 1997) and learning with models (Milrad, Spector, & Davidsen, 2003) to allow improved understanding of complex, dynamic systems. Many authors (see for example Stylianidou, Boohan, & Ogborn, 2004 refer to these types of learning as exploratory learning activities (students are able to explore pre-existing models) and expressive learning activities (students create their own models). A further step is for students...
to critique other students’ models (Gobert & Pallant, 2004). Understanding scientific models is quite different from the ability to reason with scientific models (Gobert & Pallant, 2004).

1.2. System dynamics modelling

A system dynamics model was one of the types of model investigated in this study. “System Dynamics is a methodology for analysing complex systems and problems with the aid of computer simulation software” (Alessi, 2000, p. 1) and includes cause and effect relationships, time delays and feedback loops. Systems can be represented by causal loop diagrams and by stock and flow diagrams, and in this study, students were given access to the stock and flow diagram (see Fig. 1).

Although much is written of the value of system dynamics modelling in education in schools, very little empirical data exists to confirm this (Doyle, Radzicki, & Trees, 1998; Stratford, Krajcik, & Soloway, 1998). Instead, case studies and anecdotal accounts from teachers who have used such models are available on the web (see for example Guthrie & Fisher, 1999; Ragan, 1999; Verona, Ragan, Shaffer, & Trout, 2001). The Core models project was a large scale implementation of system dynamics modelling in a number of schools, and evaluation of the project, while focusing on teacher support, did find that while students did improve understanding of the scientific concepts underlying modelling, they did not improve their ability to interpret the models (Maryland Virtual High School, 2001). Studies make recommendations as to how to teach system dynamics modelling (Schaffernicht, 2006; Stuntz, 2000), or how to incorporate it into a class (Draper, 1993).

Students do have trouble understanding complex systems using system dynamics models. One study found that the majority of participants in four separate studies (167 subjects in total) had biased views of the dynamics of the environmental system that they were examining which suggested that they were using a static (rather than a dynamic) mental model (Moxnes, 2000). Another study found that graduate students had very poor understanding of the processes involved in climate change, a common misconception was that stabilising emissions would “fix the problem”, showing a poor understanding of dynamic processes (Sterman & Booth Sweeny, 2002). While a number of studies have investigated learners’ inability to correctly model a natural resource problem (Booth Sweeney & Sterman, 2000; Diehl & Sterman, 1995; Moxnes, 2004), Kainz and Ossimitz (2002) determined that students did not have difficulties in determining between stocks and flows, and instead found it difficult to represent this information in a flow chart, and similarly that students were better able to interpret information from a table than from a graph. This suggests that perhaps the representational affordance of the system dynamics model, or the way in which the assessment is asked, needs to be examined.

1.3. Agent-based modelling

An agent-based model is the other type of model that was investigated in this study. In agent-based modelling the focus is on the interaction between the agents, and their environment. An agent is defined as an object that controls its own behaviour, and could be individuals of a species, individuals at a particular stage in the life cycle (a cohort), or a group of individuals that can be considered identical (Ginot, Le Page, & Souissi, 2002). The rules that apply to the agents determine the behaviour of the whole system, called emergence. By laying...
down the rules for the agents and the system, behaviour may emerge that would otherwise not have been predicted (Bousquet & Le Page, 2004; Ginot et al., 2002; Parrott & Kok, 2001; Schieritz, 2002).

When used in education, agent-based models allow students to explore the relationship between the agents’ rules of behaviour and the patterns that emerge (Stieff & Wilensky, 2003). Students are able to make predictions and test them by exploring model outcomes as they manipulate variables (Stieff & Wilensky, 2003). The use of agent-based models in education “narrows the gap” between school biology and research biology (Wilensky & Reisman, 2006). The main advantage of using agent-based models is that students are able to employ their knowledge of the behaviour of individuals in the construction of theories about the behaviour of populations (Wilensky & Reisman, 2006). Agent-based models are able to be quite realistic. Using a realistic computer simulation can be motivating for students because they are entertaining and evocative (Goldstone & Son, 2005).

1.4. Patterns of use

Levy and Wilensky (2005) investigated the patterns in how students used an agent-based model to learn about Chemistry. The four main statistics measured were successive settings in running the model, observation time, the average time between actions, and the number of runs. Students were engaged in a relatively ‘open’ activity (only able to change one setting, but to whatever value they chose), and Levy and Wilensky were able to identify three distinct exploration patterns: Straight To The Point, Homing In, and Oscillating.

The Straight To The Point strategy had a shorter overall observation time, but longer observation time per run; longer time between actions; and fewer runs. Levy and Wilensky identified this as an efficient mode to use the model, which may allow students to develop a deeper understanding of each state of the model. However, using a Straight To The Point strategy may mean that learners miss critical settings or transitions that would have been discovered by a wider range of values chosen. These critical settings are an important part of understanding a system from using a model (Lowe, 1993).

Students who used the Homing In strategy exhibited a shorter overall observation time, and shorter observation time per run; shorter time between actions; and more runs. These students were identified by the authors as “click happy”. The third strategy identified was Oscillating, which consisted of a longer overall observation time, but shorter observation time per run; shorter time between actions; and an intermediate number of runs. Both the Homing In and Oscillating strategies involved speedy model changes and short observations, which implies that students were not able to detect and generalise complex relationships between variables. However, the many states of the model means that students examined many aspects of the model’s behaviour and students were more likely to detect a critical setting. Of the two, the Homing In strategy is more planned, whereas students would struggle to keep the previous state in mind for comparison when using the Oscillating strategy.

Strategies for interrogating models have been discussed, in some respect, in the system dynamics modelling literature; however no formal classification system has been developed. Moxnes (1998) discusses the combination of mental models and analysis. In terms of the analysis, he discusses a trial-and-error heuristic, a consistent analysis, and a gradient search, which can be loosely mapped to the Oscillating, Straight To The Point, and Homing In strategies noted by Levy and Wilensky. However, there was no further investigation into the links between the strategies and the decision-making and mental model development. Moxnes (1998) also investigated the use of explanatory features such as additional information that scaffolded students in how to model the system. Students were able to utilise the extra information given about growth, but not about the stock.

Another issue with regards to the use of the models is the role of prior knowledge in the use of models. The only study to specifically investigate the role of prior knowledge in the use of the model was the Levy and Wilensky (Levy & Wilensky, 2005) study discussed in some detail above. They suggested that prior knowledge about the domain may shorten the exploration time, resulting in a student focusing on a few key settings, such as the Straight To The Point strategy.

2. Methods

2.1. Modelling the system

2.1.1. Use of the models

The system dynamics model was constructed in Stella™ (see Thompson & Reimann, 2007 for a more detailed description) and can be seen in Fig. 1 below. The user interface of the system dynamics model contained three screens analysed in this paper: the information screen, containing the text information describing the system; the explore screen, which allowed students to explore the model “step-by-step” using Stella’s™ storytelling feature (see Systems™, 2007, chap. 1), or in full which provided students with the entire model and the experiment screen, in which students could interact with the model (Fig. 1).

The agent-based model was built using NetLogo™. The combination of features seen in Fig. 2 is typical for a NetLogo model with a graphics window, plotting window and sliders and buttons that students can manipulate (Stieff & Wilensky, 2003).

In NetLogo, the screen on which students can interact with the model is called the Interface screen. For the purposes of comparison with the system dynamics model, this screen will be referred to as the Experiment screen for the remainder of the paper. The agent-based model had two screens that were analysed in this paper: the information screen (with the same information as that available in the system dynamics model); and the experiment screen (see Fig. 2). The proportion of time spent off task was also calculated for each model.

The experiment screen in both models contained a slider and two items in a table allowing students to input values for variables. The variables that could be changed were: the number of pieces of rubbish each person left (npr), the proportion of rubbish collected by the garbage collection person (prc); and the garbage collection time (gct). Changing the number of pieces of rubbish allowed students to examine the extremes of what could happen in the system. The other two variables were decisions that a park manager could make. Other activities that were analysed were the number of times the model was run, and the total activity. Specifically from the system dynamics model, and related to the explore the model screen were two more variables: explore the model step by step (SbS) and explore the model in full (IF). Students selected “go” to run the model, and “reset” which set the values back to their original values. On the system dynamics model there
was also an “ideas” option, which repeated information given at the end of the text description, reminding students of the available values to which the variables could be changed. The total activity included all of the above, as well as other activities not discussed in this paper.

To make sense of the patterns of use in this study, they were classified according to Levy and Wilensky’s (2005) strategies (see Table 1).

The time observing the model was taken as the time spent on the experiment screen. The time spent observing the model in each setting was calculated by dividing the total time spent observing the model by number of times ‘go’ was selected. The time spent off task and spent reading the text/instructions were also included. The number of runs was equal to the number of times ‘go’ was selected. Time per action was calculated by dividing the time observing the model by the number of changes made. And the number of changes made was equal to the total activity.

After examination of the individual cases, it was decided that the strategies for changing the three variables would also be determined. The use of the model was then compared between the strategies that students used in order to determine whether any more factors could be used to make each classification. Finally, learning outcomes were compared between the classifications to investigate the effect of the strategy used to interrogate the model, regardless of the model used.

2.2. Instruments used to assess knowledge and understanding

Students in each group completed a domain knowledge and system dynamics knowledge test in a pre- and post-test design. The pre-test was administered before interaction with the materials. Students completed the post-test after the treatment, and students were given the opportunity to change their original answer, or to keep it. They also completed a final assessment task to assess understanding of the system that was modelled.

2.2.1. Environmental knowledge test

Three questions were analysed as part of the environmental knowledge test. Direct Knowledge 1 (9 marks) questioned students about the types of activities that could cause an increase in the number of introduced animal species, and asked them to name one effect of such an increase. Direct Knowledge 2 (8 marks) asked students to identify the types of activities that could cause an increase in the number of introduced plant species, and what the effects of such an increase might be. Transfer of Knowledge (12 marks) asked students to describe the impact of building a road, littering and bushwalking in terms of the initial impact, the time scale involved in that impact, any further im-

![Fig. 2. Agent-based model interface screen.](image)

<table>
<thead>
<tr>
<th>Name</th>
<th>Strategy</th>
<th>Homing in</th>
<th>Oscillating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Straight To The Point</td>
<td>The most informative state is accessed directly</td>
<td>The model oscillates between two regimes, back and forth between high and low values</td>
</tr>
<tr>
<td></td>
<td>Homing in</td>
<td>The most informative state is gradually approached through decreasing increments</td>
<td></td>
</tr>
<tr>
<td>Overall observation time</td>
<td>Lower</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Observation time per run</td>
<td>Higher</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Time between actions runs</td>
<td>Higher</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Runs</td>
<td>Lower</td>
<td>Higher</td>
<td>Medium</td>
</tr>
</tbody>
</table>
pacts, and their associated time scales. The Transfer of Knowledge question allowed students to apply the system-specific knowledge assessed in the Direct Knowledge 1 and 2 questions, to another system.

2.2.2. System dynamics knowledge test

The system dynamics knowledge test (12 marks), contained eight questions. These questions assessed general system dynamics concept knowledge, and one question asked students to identify a system based on a stock and flow diagram. These concepts are important in the field of system dynamics, and prior knowledge may influence interpretation of a system dynamics model. In addition, assessment of these concepts after the treatment would also be useful to determine whether simple exposure would help to improve knowledge of these areas.

2.2.3. Final assessment task

The final assessment task focuses on understanding of an environmental system. The final assessment contained five questions that allow students to assume the role of a national park manager. These questions were grouped into sections. The section Describe (8 marks) included the answers to: describe the park and what happens in the park. The Issues section (16 marks) included answers to What are the management issues that are involved in looking after this area of the National Park? and: what are the main issues are. The Higher Level Thinking section (24 marks) included answers to: what decisions would you make if you were the manager of this park? if this description (the model/s and the text) of the National Park was more detailed, what do you think would happen next? What are the possible problems that could occur for the environment? and what are the consequences of the management options? The purpose of these questions was to assess understanding of the system itself, rather than more general environmental knowledge.

2.3. Limitations

This study had one main limitation in the context of this paper, the small sample size. In all relevant instances in this study, effect sizes were reported which take sample size into account, the sample size limits the generalisability of the study, and conclusions are limited to this study.

2.4. Sample and procedures

Class lists were provided before the first author went into the classrooms, and students were randomly allocated to one of four groups. Five students were given only a text description, they will not be further discussed in this paper. Seven students were given the system dynamics model and the text description (SDM group), five students had access to the agent-based model and the text description (ABM group), and six students were given both models and the text description (SDM and ABM group).

Students came from two schools, the first was an academically selective girls high school; students who participated from this school were in Year 10. The second was a girls 7–10 middle school; students who participated from this school were in Year 9. Students were novices with respect to both system dynamics and visitor use of national parks. This eliminated potential complications due to misconceptions about impacts in a national park. The exercise was incorporated into normal class work, and the experiments performed in the schools. This design may be limited in its generalisability, however it was practical in terms of logistics and acquiring an appropriate sample.

Students were given 20 min to complete the pre-test. Students were then introduced to the experiment (10 min). Students examined the materials for 20 min. They were then asked to complete the post-test (15 min), and the final assessment task (15 min).

Video screen shots were collected and coded with respect to times, activities and screens. Users were classified using the same parameters as Levy and Wilensky, and some additional parameters are suggested.

2.5. Analysis

To make sense of the patterns of use, the strategies used by the students to interact with the model were classified according to Levy and Wilensky’s (2005) strategies. After examination of the individual cases, it was decided that the strategies for changing the three variables would also be determined. The use of the model was then compared between the strategies that students used to determine whether any more factors could be used to make each classification. Finally, learning outcomes were compared between the classifications to investigate the effect of the strategy used to interrogate the model, regardless of the model used.

The use of the model was compared between groups using the Kruskal–Wallis test (and Mann–Whitney tests post hoc if required (Field, 2005)). Kruskal–Wallis tests were used to compare the use of the model between students who used different strategies to change the variables (with Mann–Whitney tests post hoc if required), and similarly for learning outcomes. Due to the small sample size, large effect sizes were taken into account in addition to significance, and are noted throughout the Section 3. Pearson’s correlation coefficient $r$ was used (Field, 2005), and calculated by dividing the $z$ score by the square root of $n$. Field identifies the following parameters: $r = .10$ is a small effect size, $r = .30$ is a medium effect size, $r = .50$ is a large effect size. Only large effect sizes are reported in this paper.

3. Results

3.1. Application of the strategies of use

Table 2 shows that in the ABM group, only two patterns were identified. Two students used the Straight To The Point strategy; the remaining students used the Oscillating strategy.

Students’ patterns of use of the model in the SDM group were recorded and classified using Levy and Wilensky’s method. Table 3 shows that in the SDM group, all three patterns were identified. Three students used the Straight To The Point strategy; two students used the Oscillating strategy; and two students used the Homing In from one side strategy.
Students’ patterns of use of the model in the SDM and ABM group were recorded and classified separately for the two models using Levy and Wilensky’s method, however, most students used only one model rather than changing between the two. The results for the overall use of models can be seen in Table 4 below.

Table 4
Patterns of use – SDM and ABM group (models combined).

<table>
<thead>
<tr>
<th>Strategy</th>
<th>SDM and ABM 1</th>
<th>SDM and ABM 2</th>
<th>SDM and ABM 3</th>
<th>SDM and ABM 4</th>
<th>SDM and ABM 5</th>
<th>SDM and ABM 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation</td>
<td>11:34 (M)</td>
<td>15:49 (H)</td>
<td>17:33 (H)</td>
<td>13:14 (M)</td>
<td>16:26 (H)</td>
<td>10:50 (M)</td>
</tr>
<tr>
<td>Time observing the model</td>
<td>11:34 (M)</td>
<td>15:49 (H)</td>
<td>17:33 (H)</td>
<td>13:14 (M)</td>
<td>16:26 (H)</td>
<td>10:50 (M)</td>
</tr>
<tr>
<td>Time spent off task</td>
<td>0:43 (L)</td>
<td>0:19 (M)</td>
<td>2:30 (M)</td>
<td>13:14 (H)</td>
<td>5:29 (M)</td>
<td>0:59 (L)</td>
</tr>
<tr>
<td>Time spent reading text/instructions</td>
<td>0:43</td>
<td>0</td>
<td>1:11</td>
<td>0</td>
<td>0:42</td>
<td>2:26</td>
</tr>
<tr>
<td>Number of changes made</td>
<td>4 (L)</td>
<td>22 (H)</td>
<td>26 (H)</td>
<td>20 (H)</td>
<td>4 (L)</td>
<td>2 (L)</td>
</tr>
<tr>
<td>Time per action</td>
<td>0:26 (M)</td>
<td>0:17 (L)</td>
<td>0:15 (L)</td>
<td>0:15 (L)</td>
<td>0:12 (L)</td>
<td>0:40 (M)</td>
</tr>
<tr>
<td>Number of runs</td>
<td>22 (M)</td>
<td>53 (H)</td>
<td>65 (H)</td>
<td>49 (H)</td>
<td>30 (M)</td>
<td>17 (M)</td>
</tr>
<tr>
<td>Pattern</td>
<td>STP</td>
<td>HI</td>
<td>Osc.</td>
<td>HI</td>
<td>STP</td>
<td>STP</td>
</tr>
</tbody>
</table>
| Note | SDM and ABM n = student n in the SDM and ABM group. H = high. M = medium. L = low. Osc. = Oscillating strategy. HI = Homing In strategy. STP = Straight To The Point strategy.

Students' patterns of use of the model in the SDM and ABM group were recorded and classified separately for the two models using Levy and Wilensky's method, however, most students used only one model rather than changing between the two. The results for the overall use of models can be seen in Table 4 below.

Students' patterns of use of the model in the SDM and ABM group were recorded and classified separately for the two models using Levy and Wilensky's method. Table 4 shows that in the SDM and ABM group, all three patterns were identified. Two students used the Oscillating strategy; two students used the Homing In strategy; and two students used the Straight To The Point strategy.

The strategies used by students to change the three variables were also determined using graphs of the changes in addition to the parameters outlined above. Table 5 shows the classification of the strategy for each student.

The patterns used to change each of the variables, in the main, was the same as the overall pattern as determined by Levy and Wilensky’s classification scheme for the overall pattern. Examination of the graphs of use over time determined that an additional category should be used – that of Oscillating over time. The graph for one such student can be seen below (Fig. 3).

The strategy used for changing the garbage collection time and changing the percentage of rubbish collected was classified as Oscillating over time. Changing the number of pieces of rubbish was classified as Oscillating. The differences in the strategies are clear in Fig. 3. The
number of pieces of rubbish was increased, decreased, and increased again in the 20 min that students were given to interact with the model. Both the garbage collection time and the percentage of rubbish were increased and decreased during the course of the 20 min, however the changes were so gradual, and the time limited, that it is expected that they would have increased the variable again had the time allowed.

The patterns used to change each of the variables, in the main, was the same as the overall pattern as determined by Levy and Wilensky’s classification scheme. Table 6 shows that most students used the Straight To The Point strategy for changing the percentage of rubbish collected. Only two students used this approach to interrogate the model as a whole. Other students made many changes, and either homed in on an outcome from one direction, while making specific changes to other variables, or chose to vary the other variables in an Oscillating pattern. One example of this is the SDM 2 student as seen in Fig. 4 below.

The strategy used to change the garbage collection time and, to a lesser extent to change the number of pieces of rubbish, was Homing In. This is typified by the steady increase in the value used, and the model was run after each change. This student used a Straight To The Point strategy to change the percentage of rubbish collected. The student made a change to the percentage of rubbish collected, ran the model, and continued changing other variables to investigate the effects of changing both (see Table 7).

The patterns used to change each of the variables, in the main, was the same as the overall pattern as determined by Levy and Wilensky’s classification scheme.

<table>
<thead>
<tr>
<th>Variables</th>
<th>SDM 1</th>
<th>SDM 2</th>
<th>SDM 3</th>
<th>SDM 4</th>
<th>SDM 5</th>
<th>SDM 6</th>
<th>SDM 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change the garbage collection time</td>
<td>HI</td>
<td>HI</td>
<td>OOT</td>
<td>HI</td>
<td>STP</td>
<td>STP</td>
<td>STP</td>
</tr>
<tr>
<td>Change the percentage of rubbish collected</td>
<td>STP</td>
<td>STP</td>
<td>STP</td>
<td>HI</td>
<td>STP</td>
<td>STP</td>
<td>STP</td>
</tr>
<tr>
<td>Change the number of pieces of rubbish</td>
<td>HI</td>
<td>HI</td>
<td>Osc.</td>
<td>HI</td>
<td>STP</td>
<td>STP</td>
<td>Osc.</td>
</tr>
</tbody>
</table>

Note. SDM n = student n in the SDM group. Osc. = Oscillating strategy. HI = Homing In strategy. STP = Straight To The Point strategy. OOT = Oscillating over time strategy.
The data presented above also indicates that the only possible relationship between the type of model and the strategy used was that students in the ABM group tended not to use the Homing In strategy, and did use the Oscillating strategy. Students in the other groups used all strategies.

3.2. The relationship between the strategies and general measures of use

The relationship between the strategies and the measures of use was investigated. For this part of the analysis, the representation was ignored, and data was divided according to the strategy that the student used to interrogate the model. However, use of specific models was taken into account as well as general use. Kruskal–Wallis tests compared measures of the use of the models between the strategies used. Only those measures for which a significant result was found are reported below.

The findings in Table 8 indicate that the overall strategy was important with respect to the overall use and more particularly the use of the system dynamics model. The strategy for changing the garbage collection time was related to the amount of time spent on the agent-based model information screen, and changing the garbage collection time in any model. The strategy for changing the percentage of rubbish collected was related to the explore the model step by step activity. The strategy for changing the number of pieces of rubbish was related to the overall measure of this activity, as well as the time spent on the information screen on the agent-based model.

Table 9 shows the significance and direction of the relationships between activities for students using the different strategies overall. Students who used an Oscillating strategy overall had higher activity in either model than students using the Straight To The Point strategy (large effect size only applied to changing the npr). Similarly, large effect sizes were associated with the higher activity that students using the Homing In strategy had on the system dynamics model and in either model than students who used the Straight To The Point strategy.

The results for comparisons between the strategies used to change the individual variables are seen below.

Table 8
Results of the Kruskal–Wallis tests comparing the use of the model between the strategy overall, and the strategy for each of the three variables.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>InfSDM (time)</td>
<td>2.56</td>
<td>9.33</td>
<td>2.97</td>
</tr>
<tr>
<td>G0SDM</td>
<td>8.38</td>
<td>3.24</td>
<td>2.43</td>
</tr>
<tr>
<td>NPNSDM</td>
<td>7.04</td>
<td>2.13</td>
<td>3.42</td>
</tr>
<tr>
<td>G0GCTSDM</td>
<td>6.62</td>
<td>4.97</td>
<td>2.48</td>
</tr>
<tr>
<td>SBSGCTSDM</td>
<td>0.49</td>
<td>0.71</td>
<td>8.12</td>
</tr>
<tr>
<td>TA</td>
<td>11.12</td>
<td>3.90</td>
<td>1.83</td>
</tr>
<tr>
<td>Go</td>
<td>13.28</td>
<td>7.11</td>
<td>3.49</td>
</tr>
<tr>
<td>Npr</td>
<td>9.32</td>
<td>3.48</td>
<td>2.88</td>
</tr>
<tr>
<td>Gct</td>
<td>10.49</td>
<td>10.48</td>
<td>2.50</td>
</tr>
</tbody>
</table>

Note: Strategy gct = strategy used to change the garbage collection time. Strategy prc = strategy used to change the percentage of rubbish collected. Strategy npr = strategy used to change the number of pieces of rubbish. Inf = proportion of time spent on the information screen. Go = number of times the model was run. Npr = frequency of changes to the number of pieces of rubbish. Gct = frequency of changes to the garbage collection time. TA = total activity. SBS = number of times the activity: explore the model step by step was selected. ABM = specifically the agent-based model. SDM = specifically the system dynamics model.

...
Table 10 shows the significance and direction of the relationships between learning outcomes for students using the different strategies. Students who used the Straight To The Point strategy spent longer on the information screen on the agent-based model than students who used the Homing In strategy. Students who used the Straight To The Point strategy to change the garbage collection time changed the garbage collection time less often than students using any other strategy. Students who used the Straight To The Point strategy to change the number of pieces of rubbish spent longer on the information screen on the agent-based model than students using the Oscillating or Homing In strategies. Students who used the Straight To The Point strategy to change the number of pieces of rubbish changed the number of pieces of rubbish less often overall ($p < .05$) than students using the Oscillating or Homing In strategies.

3.3. Strategies and learning outcomes

Kruskal–Wallis tests compared learning outcomes between the strategies used. Only those learning outcomes for which a significant result was found are reported below.

The initial findings seen in Table 11 indicate that the overall strategy was important with respect to the direct knowledge that was apparent from the model, and identifying the issues present in the materials. Prior knowledge was important in terms of the strategy adopted for changing the garbage collection time. The strategy used to change the percentage of rubbish collected was important in terms of both understanding and system dynamics knowledge. The strategy adopted for changing the number of pieces of rubbish was not related to learning outcomes. Mann–Whitney tests compared individual strategies.

Table 12 shows the significance and direction of the relationships between learning outcomes for students using the different strategies. Students who used the Straight To The Point strategy overall had a higher post-test score for Direct Knowledge 1 than those students who used the Oscillating or Homing In strategies. Students who used the Straight To The Point strategy to change the number of pieces of rubbish spent longer on the information screen on the agent-based model than students using the Oscillating or Homing In strategies. Students who used the Straight To The Point strategy to change the number of pieces of rubbish changed the number of pieces of rubbish less often overall ($p < .05$) than students using the Oscillating or Homing In strategies.

Table 11 Results of the Kruskal–Wallis tests comparing learning outcomes between the strategy overall, and the strategy for each of the three variables.

<table>
<thead>
<tr>
<th></th>
<th>Agent-based model use</th>
<th>Combined model use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inf (time) U Mdn</td>
<td>Gct Inf (time) U Mdn</td>
</tr>
<tr>
<td>Osc. vs. STP</td>
<td>2.0 0:00 5.5</td>
<td>2.0 0:00 4.5</td>
</tr>
<tr>
<td>HI vs. STP</td>
<td>1.0 6:26 7.0</td>
<td>1.0 6:26 7.0</td>
</tr>
<tr>
<td>OOT vs. STP</td>
<td>0.0 6:26 4.0</td>
<td>0.0 6:26 4.0</td>
</tr>
<tr>
<td>Osc. vs. STP</td>
<td>1:10 5.0</td>
<td>1:10 5.0</td>
</tr>
<tr>
<td>STP vs. STP</td>
<td>2.0 5:21 17.0</td>
<td>2.0 5:21 17.0</td>
</tr>
<tr>
<td>HI vs. STP</td>
<td>2.0 5:21 17.0</td>
<td>2.0 5:21 17.0</td>
</tr>
<tr>
<td>STP vs. STP</td>
<td>0.0 5:21 3.5</td>
<td>0.0 5:21 3.5</td>
</tr>
</tbody>
</table>

Note. Strategy gct = strategy used to change the garbage collection time. Strategy prc = strategy used to change the percentage of rubbish collected. Strategy npr = strategy used to change the number of pieces of rubbish. Inf (time) = time spent on the information screen. Npr = frequency of changes to the number of pieces of rubbish. Gct = frequency of changes to the garbage collection time. Osc. = Oscillating strategy. HI = Homing In strategy. STP = Straight To The Point strategy. OOT = Oscillating over time strategy. Bold typeface indicates a large effect size ($r > |.50|$).

$p < .10$.

$p < .05$.

assessment task was higher for students who used the Oscillating strategy than students who used the Straight To The Point strategy, and higher for students who used the Homing In strategy than those who used the Straight To The Point strategy.

Table 13 shows that students who used the Oscillating strategy to change the garbage collection time had higher prior knowledge of the area assessed by Direct Knowledge 2 than students who used a Straight To The Point approach. This pre-test score was higher for students using a Homing In strategy than a Straight To The Point strategy.

Students who used the Homing In strategy to change the percentage of rubbish collected had a higher pre-test system dynamics knowledge score than those who used a Straight To The Point strategy. Students who used the Straight To The Point strategy to change the percentage of rubbish collected had a lower system dynamics post-test score than those who used a Homing In strategy. The score for the Issues section of the final assessment task was higher for students who used a Homing In strategy than a Straight To The Point strategy. Students who used the Homing In strategy had a higher score for the Higher Level Thinking section of the final assessment task than students who used the Straight To The Point strategy.

4. Discussion

4.1. Classification of strategies used

All strategies were used by students in the SDM group and the SDM and ABM group, and both the Oscillating and Straight To The Point strategies were used by students in the ABM group. An additional strategy was identified: Oscillating over time. This strategy is a combination of the Homing In and the Oscillating strategy. There is an overall Oscillating pattern, but with changes made between the extremes. This strategy is expected to have similar advantages to the Homing In strategy and the Oscillating strategy.

The classification scheme was examined because it was developed for the interrogation of agent-based models in an activity where students could move onto the next step once a conclusion was reached (Levy & Wilensky, 2005). More detailed investigation of the data revealed that the overall strategy did not always reflect the strategies used to change the three variables. In some cases, students used a combination of strategies, changing one variable using a Straight To The Point strategy while others were changed using one of the other strategies.
4.2. Strategies and general use

Analysis of the strategies with respect to other measures of use confirmed that the measurement of activities was a valuable classification. In particular, the amount of time spent on the information screen was important with respect to the Straight To The Point approach in this study, and indicates that students who used this approach were doing so in an informed way. This implies that students were making informed decisions about their strategy for changing these variables. It was thought that the proportion of time spent off task would add information to this classification scheme, however no relationship was detected.

4.3. Strategies and learning outcomes

The overall strategy and the strategies used to change the garbage collection time and percentage of rubbish collected were related to learning outcomes. Levy and Wilensky's original study suggested that the Straight To The Point strategy is a planned approach which may result in a deeper understanding of each regime, but that critical settings or transitions may be missed which are evident through a broader investigation of the model (Levy & Wilensky, 2005). The Oscillating approach involved students moving between extremes, constantly comparing results between now and previous, however the previous settings tend to disappear, unlike the Homing In strategy (Levy and Wilensky, 2005).

4.3.1. Overall strategy

Students who used a Straight To The Point approach overall had a lower Direct Knowledge 1 post-test score for than students who used an Oscillating or Homing In strategy; a lower Direct Knowledge 2 post-test score than students who used the Homing In strategy; and a lower score for the Issues section of the final assessment task than students who used the other two strategies. Students who used an Oscillating strategy had a lower Direct Knowledge 2 post-test score than those who used the Homing In strategy. These three learning outcomes address system-specific knowledge. The results suggest that students who used a broad strategy such as Oscillating or Homing In, rather than a deliberate, Straight To The Point approach, were better able to answer system-specific questions; and that students who used a Homing In approach, that allows students to keep previous system states in mind after small changes, were better able to answer system-specific questions than students who used an Oscillating strategy. These are supported by findings from the original study (Levy and Wilensky, 2005).

4.3.2. Strategy used to change the variables

In terms of the strategies used to change the garbage collection time and the percentage of rubbish collected, there were two main findings. Students who had less prior knowledge assessed by Direct Knowledge 2 used a Straight To The Point strategy for changing the garbage collection time. Perhaps students with lower prior knowledge in this area spent more time reading the text description, or perhaps they had a personal goal to learn about the subject matter. Students who had higher prior knowledge about plants used the Oscillating or Homing In approach.

The strategy used to change the percentage of rubbish collected was related to system dynamics knowledge and the Issues and Higher Level Thinking sections of the final assessment task. Students who used the Straight To The Point strategy to change the percentage of rubbish collected had lower pre- and post-test scores for system dynamics knowledge than students who used the Homing In strategy. Again, the Straight To The Point approach was not successful in terms of gaining general knowledge that should have been apparent by use of the model. The Homing In strategy was more successful than the Straight To The Point strategy in terms of identifying the issues in the learning materials. Finally, students who used the Homing In strategy to change the percentage of rubbish collected had higher scores for the Higher Level Thinking section of the final assessment task than students who used the Straight To The Point strategy. Once again, the planned, but broad strategy of changing this variable allowed to students to make management decisions, predictions, and identify the consequences of decisions made.

5. Conclusion

In conclusion, the classification scheme was able to be applied to the use of a system dynamics model; and an extra classification and an additional criterion were suggested. Prior knowledge had an effect on the strategy used to change specific variables. The proportion of time spent on the information screen was important for students who used the Straight To The Point strategy. Despite this more informed approach to the Straight To The Point strategy, students who used it overall, and to change specific variables (such as the percentage of rubbish collected) had lower post-test environmental knowledge scores. The Homing In strategy was the most successful of the three in terms of post-test scores associated with information that came from the materials and the score for the Higher Level Thinking section of the final assessment task.

Investigation of the strategies used to change the variables showed: that the classification system developed for use of an agent-based model could be applied to the use of a system dynamics model; that the strategies used to change variables were independent of the model used and independent of the learning environment; the role of prior knowledge and the use of the text description, in combination with the learning environment are important predictors of the successful use of risky strategies; and that a broad, planned strategy used to change the variables allowed students to increase system-specific and applied environmental knowledge scores, and improved understanding of the system.

This study has implications for teaching, learning and research. Firstly, the existence of identifiable strategies for the ways in which both models are interrogated, that can be applied to both agent-based and system dynamics models, means that teachers and systems can be trained to recognise the strategies. This is important because of the initial findings of this study that suggest that the ways in which students interrogate the models are related to learning outcomes. If teachers or systems can be trained to identify strategies, then interventions can be planned and designed to best facilitate the learning outcomes desired. The relationship between prior knowledge and the strategies adopted can help teachers and systems to predict and understand the choices that students make. Further research should con-
centrate initially on a broader study examining the prior knowledge–strategy–learning outcome relationship. In order to examine this relationship fully, the effects of discussing the strategies chosen with the students on their future choices should be included. In addition, research should also begin to automate the process of identifying strategies and intervention studies planned for training teachers in this identification, and determining the most appropriate strategy for any given learning outcome.

Acknowledgement

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References


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