Improving Students’ Performance through the Use of Simulations and Modeling: The Case of Population Growth

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Abstract: Internationally, students have difficulty interpreting and drawing conclusions from data. These skills are essential components of scientific reasoning, an ability that has been shown to correlate with conceptual change. Providing greater opportunities for students to engage in scientific practices such as modelling in order to collect and reason with data has the potential to improve scientific reasoning skills. However, in some subdisciplines of biology, such as population growth, data collection needs to occur over time scales that are unfeasible in a classroom setting. Computer-based simulations of biological phenomena are one way to overcome this limitation, but their effect on scientific reasoning has been under investigated. This study researched the effect on scientific reasoning of computer-based simulations in a context that employed a specific type of model-based reasoning (Modelling Instruction). Students who used computer-based simulations in a Modelling Instruction context showed increased scientific reasoning post-instruction compared to a comparison group. Moreover, shifts were observed in the intervention group towards more formal reasoning whereas no such change was observed with the comparison group. This result suggests that computer-based simulations should be further explored as a way to improve student scientific reasoning, particularly in contexts where laboratory investigations are not feasible.

1 INTRODUCTION

Internationally, research studies and educational policy groups have affirmed the need to have students learn higher order thinking skills in science classrooms (Mullis et al. 2016, p. 8; Organisation of Economic Co-operation and Development, 2016, pp. 103-109). The results from the Programme for International Student Assessment (PISA) have suggested that across nations, students not only have difficulty interpreting scientific data but also drawing conclusions from that data (Organisation of Economic Co-operation and Development, 2016, pp. 37-46). This deficiency might be caused by a lack of opportunity for students to practice new skills within the context of scientific laboratories. One contributor might be lack of facilities. However, a more common barrier, especially in Biology (and particularly in topic areas such as population growth and evolution), is likely to be difficulties in data collection because of the time needed to see multiple generations of data (Heaps et al. 2016, p. 221; Oswald and Kwiatkowski, 2011, pp. 469-471). One possible way to allow for the collection of data in these areas that require extended time is through the use of specially designed simulations (Huppert et al, 2002, pp. 809-812). However, there are few studies that attempt to use simulations in population growth within the context of secondary biology classrooms which emphasize scientific modelling.

Interpreting and drawing conclusions from data are essential components of scientific reasoning, a skill that has been shown to correlate with conceptual change (e.g., Coletta et al, 2007, p. 237; Moore and Rubbo, 2012, pp. 4-5). Thus, it is important to make sure that interventions improve students’ scientific reasoning skills as these skills can affect students’ lifelong learning. However, few studies have focused on assessing shifts in students’ scientific reasoning when using simulations in the context of a modelling instruction class in biology.

This paper attempts to fill this gap by describing a quasi-experimental study in the USA that tests the effectiveness of a simulation developed to introduce population growth within the context of a specific type of scientific modelling curriculum, Modelling

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Instruction. This study was guided by the following research goal:

1) Will Modelling Instruction students experiencing a population growth simulation outperform a comparison group in terms of scientific reasoning?

2 LITERATURE REVIEW

Within this section we will investigate past instructional interventions in population growth as well as the use of scientific modelling simulations and Modelling Instruction (MI) within science classrooms. In addition, we will specifically discuss the use of conceptual modelling and modelling simulations within the context of population growth. The end of this section will include a discussion of past studies focused on scientific reasoning and simulations.

2.1 Learning Challenges in Population Growth

Numerous studies show that at both the undergraduate and secondary levels, student conceptual knowledge about population growth is sprinkled with misconceptions. Brody and Koch (1990, p. 23) found that high school students consider an ecosystem's resources to be limitless. Munson (1994, p. 32) found that undergraduate students think that populations exist in two constant states: one of growth or one of decline. However, Munson (1994, p. 32) also discovered that students can also believe that populations increase till limits are reached then the population crashes thus going extinct. The effect of predator-prey relationships has also been shown to cause student difficulties since many think that two organisms can only affect each other if they share this specific relationship (Griffiths and Grant, 1985, pp. 430-431). Stammen (2018, pp. 149-151) found that middle school students believe that competition within an ecosystem always involves aggressive interactions. These alternative conceptions do not portend well for students learning a strong correct conception of population growth that would support learning in other biological concepts such as evolution and genetics.

2.2 Models, Modelling and Modelling Instruction in Biology

Science modelling is the process by which students are guided in the construction of science models or empirically testing the effectiveness of science models. A scientific model is not only a 2D or 3D representation of a science phenomenon but can include other representations such as graphical, pictorial, mathematical or verbal.

Little work has been done towards incorporating the use of models and modelling into biology either at the secondary or the undergraduate level. Passmore and Stewart (2002, pp. 186-194) designed the MUSE pedagogy for secondary school students that focused on students' comparison of previously determined models against empirical data. At the college level Dauer et al (2013, pp. 240-241) had undergraduates develop models in multiple biological areas (one of them population growth). While both determined that students understood models better neither study had a control group, nor did they test for conceptual understanding.

Modelling Instruction is a scientific modelling pedagogy that makes use of student generated models to develop multiple representations. See Figure 1 for an example of model representations in population ecology.

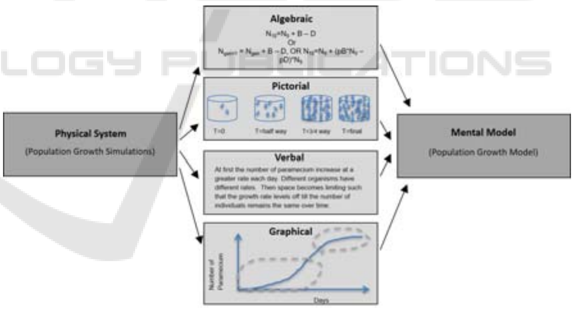

Figure 1: Scientific Model representations for Population Growth Model (adapted from Dukerich, 2015, p. 1315).

Modelling Instruction makes use of a Modelling cycle (see Figure 2) that focus on student development of scientific models from empirical data. The students use the data to produce a model that consists of multiple representations. The initial science model is used to make predictions about behaviour which can be checked against the initial empirical data. If predictions are not in line with the empirical data, then revisions to the model and its representations are produced. The revised model is then tested in other contexts. The cycle is continuous so that at any time predictions to not match data revisions of the model representations are considered. This allows students to develop a robust understanding of the concepts being developed.

The use of multiple representations alone has been shown in a number of studies to produce improved conceptual learning (e.g., Dori and Belcher, 2005, pp. 211-212; Won et al, 2014, pp. 863-864).

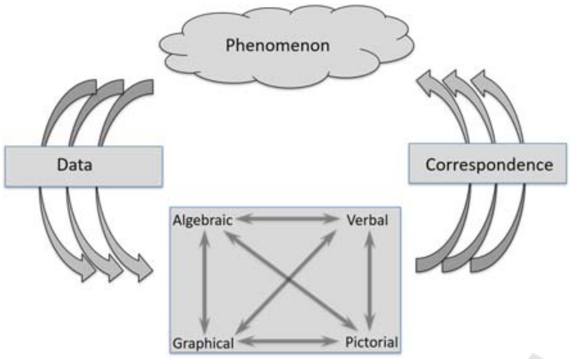

Figure 2: The Modelling Cycle (adapted from Malone et al, in press).

Modelling Instruction has been shown to be effective at increasing student conceptual understanding in other disciplines such as physics (Jackson et al, 2008, pp. 15-16; Malone, 2008, pp. 4-12, Malone and Reiland, 1995, p. 411), and chemistry (Malone and Schuchardt, 2016, pp. 4-5). However, only a single study has been published on the effect of Modelling Instruction in Biology (Malone et al, in press). Malone et al, in press) demonstrated that the use of Modelling Instruction and physical simulations can be effective in student conceptual understanding in evolution. They showed that not only did students show a decline in alternative conceptions but also there was an increase in their use of multiple representations to explain evolutionary concepts over that of the comparison group.

2.3 Simulations, and Modelling in Population Growth

A meta-analysis showed that simulations have a beneficial effect over that of units with no simulations in the secondary school (D'Angelo et al. 2014, p. 42).

In a review Smetana and Bell (2012, pp. 1362-1364) found that the use of computer simulations might depend upon how they are used in the classroom. They suggested that in order to be the most effective simulations should be used when incorporated into pedagogy and encourage reflection on the part of students. One study that tested the ability of a single secondary school student to produce a model about predation using a simulation produced with Net Logo (Wilensky and Reisman, 2006, pp. 203-205) had mixed results. While the student could produce a model of predation that was predictive of observed lab outcomes in the simulation, it was not consistent with real-life observations. Another study used a simulation in the seventh grade called WISE (Donnelly et al. 2016, pp. 1344-1359). The students did show a gain in conceptual understanding, but there was no comparison group. However, few studies focus on the effect of simulations which are embedded in a modelling-based curricula unit, especially in the area of population growth.

The use of models and modelling in the teaching of evolution and population ecology within the context of an engineering themed unit has been shown to be effective at the secondary level in terms of student conceptual understanding (Malone et al, 2018, pp. 42-44). This unit also incorporated a series of excel based simulations that looked at not only population growth but also natural selection. This quasi experimental study showed that there was a significant gain in student understanding of population growth and natural selection over that of a comparison group as well as an increase in student use of multiple representations. In addition, students demonstrated a greater fascination with science. However, this study did not test for shifts in student scientific reasoning skills.

The studies showing conceptual gains used simulations that were incorporated into specific pedagogical units. However, none focused on scientific reasoning skills of students.

2.4 Scientific Reasoning and Simulations

As mentioned in the introduction the link between scientific reasoning and science has been studied. However, fewer studies have focused on the link between simulation use in science and scientific reasoning.

The studies showing a link between scientific reasoning and science have been mostly conducted at the college level. For example, Coletta, Phillips and Steinert (2007, p. 236) showed that when active learning methods are used with STEM college majors, student scientific reasoning skill as measured by the Lawson's Classroom Test for Scientific Reasoning (LCTSR) was highly correlated to gains in physics knowledge. This study also demonstrated a similar correlation effect in one secondary school using Modelling Instruction. However, pre to post gains in scientific reasoning when using simulations in the context of a Modelling Instruction unit have not been assessed. Therefore, it is not known how modelling based simulation activities affect students’ shifts in scientific reasoning pre to post implementation.

This study attempts to fill these gaps by testing the effects on students’ scientific reasoning skills of a science modelling simulation embedded in a Modelling Instruction population growth curricular unit.

3 METHODS

This study is a quantitative evaluation study looking at the differences in scientific reasoning skills pre to post instruction between a treatment and a comparison group of students.

3.1 Research Questions

The study was guided by the following research questions.

1) Will Modelling Instruction students experiencing population growth simulations display a greater increase in scientific reasoning skills than comparison students?
2) Will Modelling Instruction students demonstrate a greater shift towards formal reasoning in terms of Piagetian reasoning stages?

3.2 Participants and Settings

The participants in this study were high school students located in the Midwestern region of the United States enrolled in regular level biology courses. All of the students attended a suburban school district but were from a mix of high schools within the district. The implementing cohort consisted of 205 students and were taught by a teacher in their first year of implementing modelling instruction. The comparison cohort of 141 students was taught by two different teachers. All three teachers had similar backgrounds and total years of teaching experience.

3.3 Population Growth Modelling Instruction Unit

The constructed unit started with a pre-assessment activity that asked students to consider what would happen if all the plants in the world died. This was used to draw out student preconceptions. No “correct” answers were given to the question. Students shared their initial thoughts and ideas. In addition, the implementation teachers requested that students supply their reasoning for any of the claims they were making.

The students were then introduced to two species of paramecium (P. caudatum and P. aurelia) using microscopes. The students were asked what they thought would happen to the size of each population after 100 years if they were in a place with no predators? The students were broken into groups to develop a prediction and to develop methods to represent or “show” their predictions to the rest of the class. This was the first Modelling Instruction modelling cycle for the implementation students. Thus, most drew pictures about what would happen over time and very few represented their predictions in a graphical form. During group sharing, if some students developed diagrams, storyboards and graphical representations of their predictions these were shared with the class during class discussion. Thus, after the consensus depending on student backgrounds the initial representations were quite diverse. In this case most of the graphical representations were in the form of bar graphs and pie charts. As students were sharing their representations, they were asked to describe the biological meaning behind them.

After the prediction phase the teacher asked the groups to consider how they might investigate this question using paramecium. The students had to go to the internet to find the life cycle of paramecium and consider the number of offspring. In addition, they were asked to consider which variables would be independent, dependent and which would be held constant. The students discovered that if they actually used live paramecium the time to collect data would be much too long to for their classes. Consequently, the teachers introduced the use of google sheet simulations to the students. The lab was conducted by either dividing the class in half so that each half worked with one or the other organism. This allowed groups to see what happened to the output due to the difference in growth rate between these two organisms.

The google sheet simulation consisted of an input sheet where students could decide upon a number of conditions, a graph and data sheet as well as an equations sheet. The equations sheet was there to show students the mathematical growth formula if the teacher desired to do so.

The google sheet simulations were designed to contain the variables that were requested by pilot students for either P. caudatum or P. aurelia. The input page asked students to select their initial population size, whether they had limited or unlimited resources, and the generation time. In addition, students had to input the container size, number of offspring produced per generation as well as the average number of offspring that die each generation. See Figure 3.

At this point, depending upon students' abilities with graphs, they either focused on just the data charts (see Figure 4) or the simulation generated graphs (see Figure 5). The ones that focused only on data charts were asked to hand graph their output data. This allowed for a comparison of graphing techniques between groups and the ability to discuss the reasons why a line graph was a better selection for the output data rather than a bar graph.

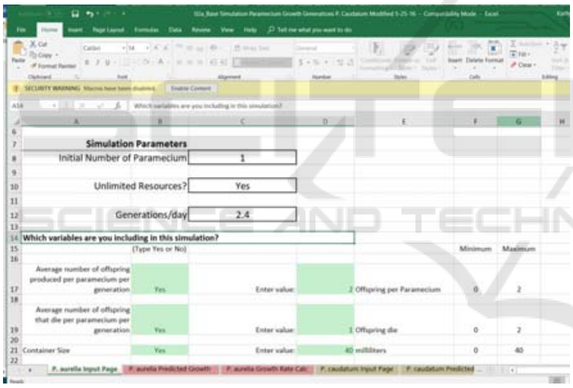

Figure 3: Simulation Input Page.

Generations	Days	Number of *P. aurelia* Observed	Predicted
0	0	1	1
1	0	1	2
2	0	1	3
3	1	2	5
4	1	4	9
5	2	8	16
6	2	16	28
7	2	34	50
8	3	57	90
9	3	119	162
10	4	204	291
11	4	408	523
12	5	660	941
13	5	1234	1693
14	5	2418	3047
15	6	4763	5484
16	6	8954	9871

Figure 4: Simulation's Data Output Page.

The output generated included the number of "observed" as well as "predicted" paramecium depending upon their input variables on the input page. The students were tasked with changing their input page in order to match the observed numbers on the graph (see Figure 5). When they did this, they were asked to discuss it with their teachers and explain why and what part of their prediction they were changing.

After the lab, students were asked to construct large poster displays which detailed how their predictions changed for both limited and unlimited food supplies, large vs small containers, etc. Each student group produced a number of representations of their findings and then the whole class with the guidance of the teacher developed a class consensus. The consensus consisted of graphical representations (see Figure 6), diagrammatic representations (see Figure 7) as well as verbal representations. An example of a verbal representation is as follows:

> As the days go by, the number of paramecium increase at a greater rate. The relationship is not linear so that when you double the days the number does not double. Different organisms have different growth rates.

At this point the class has not determined a mathematical representation. The mathematical representation was developed using the data from the two types of paramecium.

The unit then has the students deploy or test their new model for population growth in multiple contexts. This allows students to refine their model further after they discover what happens when two paramecia are living together in the same container.

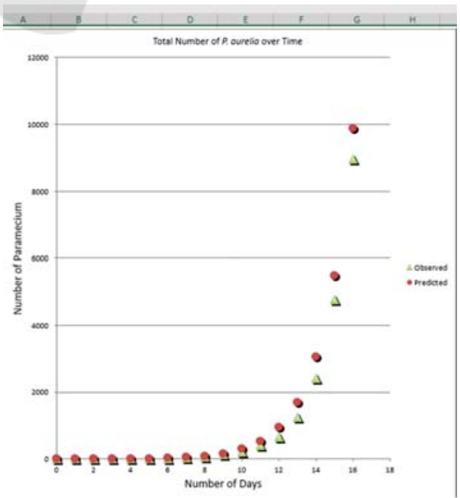

Figure 5: Simulation's Graphical Output Page - students' predictions almost match the observed graph.

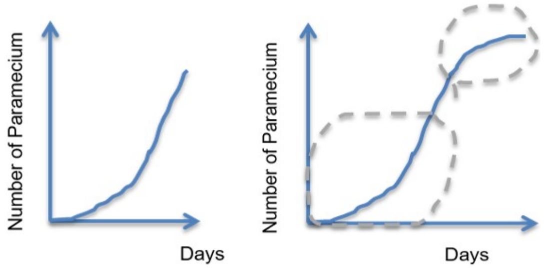

Figure 6: Sample of Graphical Representations of the Model.

Figure 7: Sample Diagrammatic Representation.

3.4 Research Instruments

This study made use of the 24 item two-tiered Lawson's Classroom Test for Scientific Reasoning (LCTSR) as a pre and posttest (Lawson, 1978, pp. 12-15). The LCTSR has been used in multiple studies across a number of contexts (e.g., Ding et al, 2016, p. 620; Lawson, 2000, pp. 11-12). This assessment can be used to not only assess overall scientific reasoning but also to look at specific scientific sub skills. These sub-skills consist of control of variables, correlational reasoning, proportional reasoning and hypothetico-deductive reasoning. In addition, the results can be used to determine the number of students at different Piagetian reasoning stages (i.e., Formal reasoner, Late Transitional Reasoner, Early Transitional Reasoner and Concrete Reasoner). Piagetian reasoning stages are based on student abilities to apply deductive reasoning skills to abstract hypothetical problems. Lawson's test allows one to identify learners as Level 0 (Piagetian formal operational reasoners), Level 1 and 2 (Piagetian transitional reasoner) or Level 3 (Piagetian formal operational reasoner). Thus, based on the student scores obtained students can be categorized into separate reasoning levels. Figure 8 compares the LCTSR to the Piagetian three levels of formal reasoning.

The pretest was given within the first 2 weeks of the school year and the post test was given during the last month of the school year.

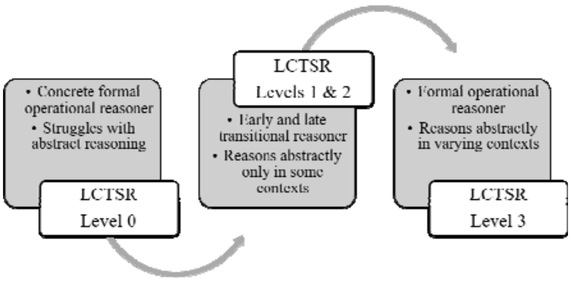

Figure 8: Comparison of LCTSR with Piagetian Reasoning Levels (from Stammen et al, 2018, p. 3).

3.5 Data Analysis and Results

Since this study is focused on population ecology only 20 of the 24 items on the LCTSR were analysed. The 4 items not analysed focused on conservation of mass and volume which were not considered pertinent to this study.

3.5.1 Single-tiered Question Analysis

In order to determine overall differences between the two cohorts a single-tiered analysis was completed whereby all 20 items on the LCTSR were treated as independent from one another.

Figure 9 shows the overall average pretest and postest scores for the two cohorts. The t-test results for a paired pretest to posttest comparison of scientific reasoning scores were significant for the treatment cohort (t (410) = 3.29, p < 0.001) but not for the comparison cohort (t (280) = 1.52, p < 0.13). The pretests of the treatment and comparison cohorts (M = 37.23 and 34.5, respectively) were not significantly different from each other (t (345) = 1.2, p < 0.23). The post test scores between the treatment and comparison cohorts (M = 43.25 and 37.34, respectively) were significantly different (t (345) = 2.92, p < 0.004).

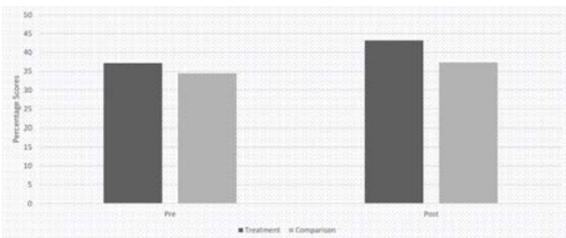

Figure 9: Single-tiered LCTSR Scores by Cohort.

The distribution of scientific reasoning subskills on the pre and posttest by cohort can be seen in Figures 10 and 11. Across all dimensions the posttest sub-skills developed by the treatment cohort were larger than that of the comparison cohort. The proportional reasoning subskill is a bit concerning given that it is the lowest score of all the subskills (see Figure 10). Given the simulations focus on the effects of one variable upon others one might expect this score to be much higher for the treatment cohort.

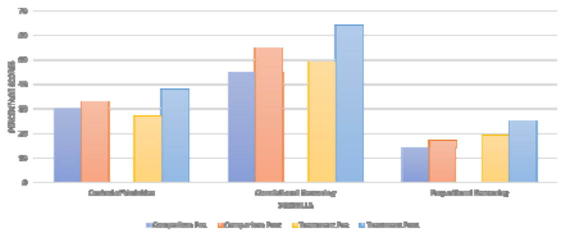

Figure 10: Scientific Reasoning Subskill Scores (Control of Variables, and Correlational and Proportional Reasoning) by Cohort.

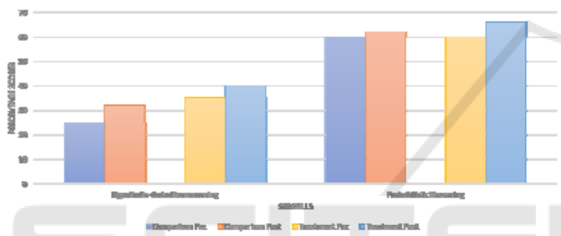

Figure 11: Scientific Reasoning Subskill Scores (Hypothetic-deductive and Probabilistic Reasoning) by Cohort.

3.5.2 Two-tiered Question Analysis

By using the two-tiered analysis (treating paired items as a group), the LCTSR scores can be categorized into Piagetian reasoning stages. In this method the largest score is 13. Therefore, students scoring from 11-13 are categorised as Formal Operational Reasoners whereas those scoring 0-4 would be categorized as Concrete Reasoners. Figure 12a and b show the shift in number of students in each reasoning stage per cohort. Figure 12 demonstrates that the treatment group showed a shift

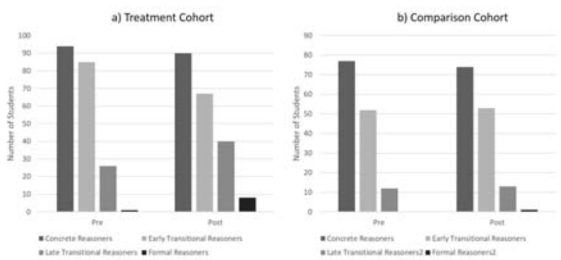

Figure 12: Pre and Post Student Reasoning Levels by Cohort.

towards more formal reasoners. Whereas, the comparison group only shifted one student into this category. In both cases there was not much change from concrete reasoners to other categories. However, the comparison cohort did not show much shift between any categories.

4 DISCUSSION

The single-tier item analysis demonstrated that gains in scientific reasoning were made by the treatment group using the population ecology simulation and modelling instruction between assessment administrations. However, the comparison cohort did not make any significant gains between administrations of the assessment. Therefore, the use of population growth spreadsheet simulations in conjunction with Modelling Instruction in the context of population ecology produced a shift in scientific reasoning skills.

The subskill scores demonstrated that the curriculum units used by the treatment cohort showed post assessment reasoning abilities that exceeded that of the comparison cohort. The two subskills showing the lowest values between cohorts was that of proportional reasoning and control of variables. This demonstrates that both groups need to be exposed to activities that allow them to master these subskills to a greater extent.

The two-tiered analysis demonstrated that the use of a simulation in conjunction with Modelling Instruction demonstrated the ability to assist over 6% of the students into becoming formal reasoners. Whereas, the comparison group did not demonstrate any major shift between reasoning levels. However, even though the treatment cohort showed much more positive results in terms of reasoning levels pre to post assessment there was still very little shift in the total number of concrete reasoners.

5 CONCLUSIONS AND FUTURE DIRECTIONS

Overall, the study demonstrated that the use of simulations in conjunction with Modelling Instruction pedagogy demonstrates positive results in terms of scientific reasoning gains versus that of the comparison cohort. In addition, the study demonstrated the ability of the materials to allow for student shifts in Piagetian reasoning levels towards more formal reasoners. Therefore, students using these materials should be better prepared for advanced science study.

However, the results also demonstrated that the materials need to be improved in order to allow for a more authentic ability to practice control of variables and to develop proportional reasoning skills. In addition, differences in the simulation use between high and low ability students should be studied in order to develop better simulation scaffolds. Better simulation scaffolds could allow all students show similar gains in reasoning levels across classrooms that contain students of varying abilities.

In addition, this study did not include cohorts that used just the simulation or Modelling Instruction materials without population ecology simulations in order to tease apart the effects of the two in terms of scientific reasoning skills. Future studies should also include an analysis of conceptual gains as well as that of scientific reasoning.

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