The Benefits of System Dynamics Simulation for Sustainability Education

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Abstract: Education for Sustainable Development (ESD) is vital to the success of the United Nation's Sustainable Development Goals, yet it has so far proved difficult to implement. One reason for this is the systemic understanding required to comprehend the intricate interplay of causal connections typically underlying sustainability issues. This research describes an experimental study conducted to investigate whether ESD can benefit from Systems Thinking and System Dynamics simulation, both in increasing understanding of a specific sustainability problem, and in transferring knowledge to a second sustainability problem with a similar systemic structure. The study was a randomised controlled trial using a two-by-two factorial design. 106 participants were randomly allocated to one of four groups: a Systems Thinking group, a Simulation group, a Systems Thinking and Simulation group, or a control group. Results demonstrated a significant increase in scores for the Simulation group for understanding a sustainability problem, with a large effect size, and a weaker but still significant increase in scores for transfer of skills to a second problem, with medium effect size. The Simulation group was the only group that demonstrated significant benefits.

Introduction: Sustainability education is an emerging field and requires Systems Thinking competence (Wiek et al., 2011, Soderquist and Overakker, 2010), innovative learning tools (Frisk and Larson, 2011, Cavana and Forgie, 2018), and methods for evaluating learning effectiveness (O'Flaherty and Liddy, 2018). It is vital to the success of the United Nation's Sustainability Development Goals and is necessary for all citizens (Rieckmann et al., 2017).

An online learning tool was designed to support a teaching approach that combines case studies with Systems Thinking and simulation (see sample screenshot in Figure 1). First, it describes the concept of sustainability in general, and then two specific problems are explored to increase understanding of sustainability in context. These two problems, deer herd management and sustainable fisheries, are both examples of renewable resource management. The topics are illustrated with historic cases of overshoot and collapse, namely the Kaibab deer herd collapse in the 1920s, and the Grand Banks cod fishery collapse in 1992. The learning tool also explores how to formulate sustainable solutions to these problems. The underlying deer herd model is adapted from that documented by Breierova (Breierova, 1997). The two sustainability problems have a similar systemic structure, a tendency to 'overshoot and collapse'.

The learning tool was designed for unsupervised online use in a single session. It was developed using Stella Architect and published via an interface on Stella Exchange. An open version of the learning tool is available here:

https://exchange.iseesystems.com/public/carolineb/sustainability-learning-tool

It differs from the original version used for research in that it does not require a login and does not collect user identification nor simulation data. Learners are no longer randomly allocated to treatment groups, but instead can choose which version of the tool they wish to see.

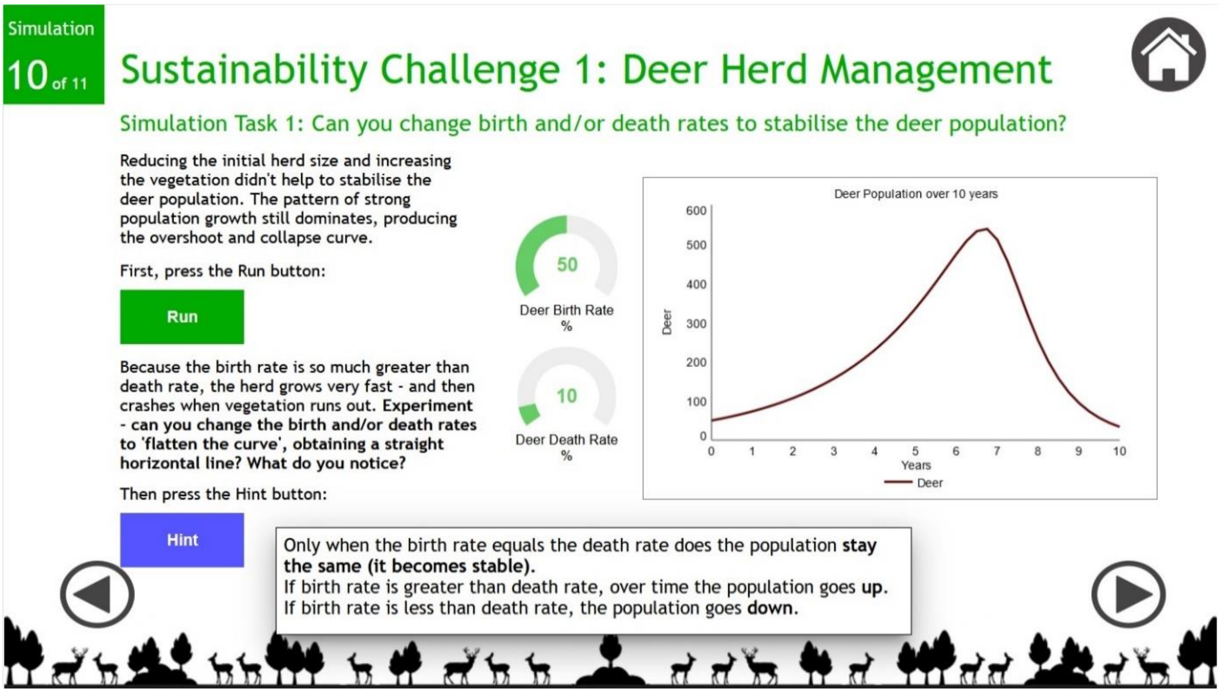

Figure 1 Sample screenshot from the simulation section of the learning tool

Methodology: Since this was a study concerning comparison of educational outcomes, the design was drawn from established practices in the field of Social Sciences research (Cohen, 2018). The investigation was an experimental study using a two-by-two factorial design. The two factors, Systems Thinking and Simulation, each had two levels, present or absent. The study aimed to discover the main effects, i.e. the effect of each factor on the learning outcome, and the interaction effect, or the combined effect of both factors.

Table 1 Two-by-two factorial design

Factors	No Systems Thinking	Systems Thinking
No Simulation	Control group	ST group
Simulation	Sim group	ST + Sim group

106 adults were selected using convenience sampling and were randomly assigned to one of four groups: a control group, a Systems Thinking only group, a Simulation only group, and a Systems Thinking and Simulation group (see Table 1).

Participants saw differing sections for the deer herd management problem according to their group (see Figure 2). All participants then saw the same non-systemic treatment of the sustainable fisheries problem. All participants took two quizzes, one for the deer problem and one for the fisheries problem. These quizzes were designed to measure sustainability understanding in the problem contexts and each resulted in a percentage score.

Depending on the group, the estimated duration of the learning session was 50 to 100 minutes. The duration of the Systems Thinking section was approximately 30 minutes, and the simulation session 20 minutes.

A significant increase in scores for non-control group members in quiz 1 performance would suggest that Systems Thinking and/or simulation improved sustainability learning outcomes for the first problem, deer herd management.

A significant increase in scores for non-control group members in quiz 2 performance would suggest that insights from Systems Thinking and/or simulation applied to the first problem resulted in a transfer of sustainability skills to the second problem, sustainable fisheries.

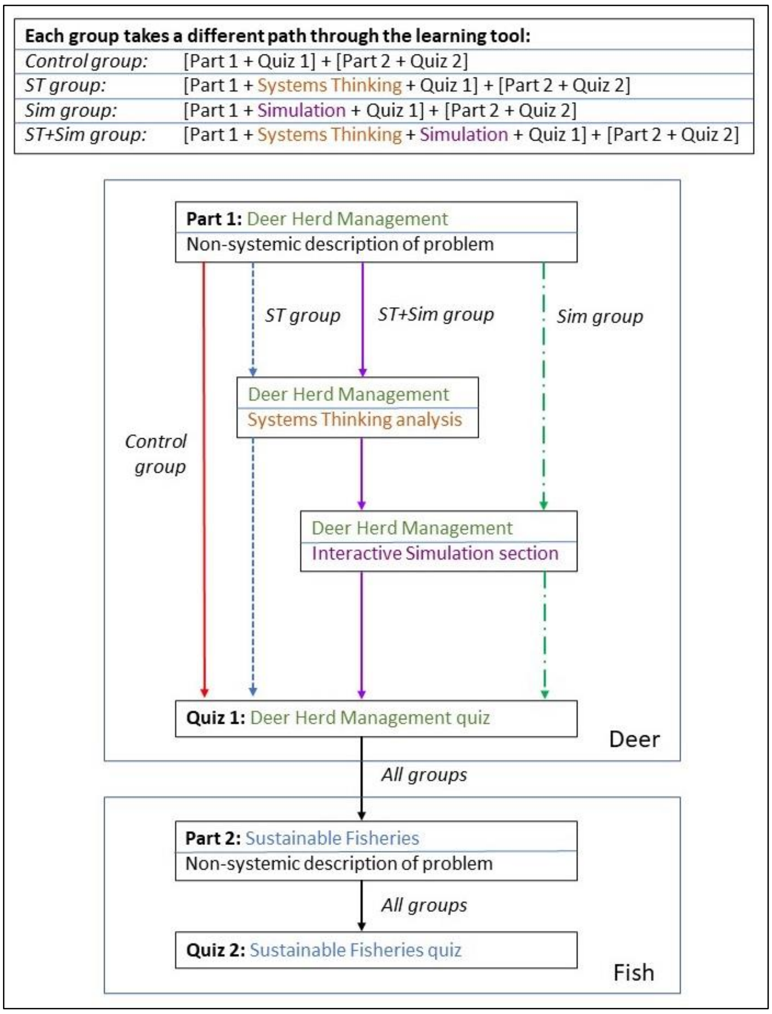

Figure 2 Paths through the learning tool for each group

Results: The relationship between the two categorical independent variables (factors Systems Thinking and simulation) and one quantitative dependent variable (percentage score in quizzes) was investigated using hypothesis testing. Statistical methods for comparing group mean scores comprised overall tests Factorial ANOVA, One-Way ANOVA and Kruskal-Wallis. Individual tests included unpaired two-samples Wilcoxon tests and an independent two-sample t-test.

The statistical programming language R was used to create descriptive statistics such as graphs, means, medians, variances and correlations, to check assumptions for parametric tests, to carry out the inferential statistics tests and to calculate effect sizes (Navarro, 2013).

Significance tests result in p-values, but these does not measure the strength of the relationship. A significant p-value indicates that an intervention works, whereas an effect size, such as Cohen's d, tells us how much it works (Sullivan and Feinn, 2012). Cohen provided basic guidelines for interpreting the effect size, namely 0.2 as small, 0.5 as medium, and 0.8 as large (Cohen, 1988). However, he advised that his benchmarks were recommended for use only when no better basis is available. In education research, the average effect size is d = 0.4, with 0.2, 0.4 and 0.6 considered small, medium and large effects (Cumming and Calin-Jageman, 2016).

The main findings were:

1. System Dynamics simulation had a strong effect (Cohen's d 0.6, large) on understanding a sustainability problem, significant at the 95% confidence level (p = .018).
2. System Dynamics simulation had a weaker (Cohen's d 0.4, medium) but significant effect at the 90% confidence level (p = .787) on transfer of understanding to another problem with a similar systemic structure.
3. Systems Thinking did not make a significant difference to mean scores in either case, although scores in quiz 1 were improved (Cohen's d 0.4, medium effect).
4. The interaction effect of Systems Thinking and simulation in the full treatment group proved significant (p = .045) and antagonistic . This could be evidence that the additional learning material pushed participants over a limit with respect to 'cognitive load' (Sweller, 1988) in this experimental setting (a single learning session).

Conclusions: Simulation has the advantage of causing a significant improvement in sustainability education outcomes in a single, short learning intervention. Systems Thinking, presented in a single 30 minute section, did not result in a significant improvement, but the medium effect size suggests that different methods of presentation could be investigated. Combining both Systems Thinking and simulation did not result in expected benefits in the context of a single learning session.

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