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A comparison of two methods of using a serious game for teaching marine ecology in a university setting

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ABSTRACT

There is increasing interest in the use of serious games in STEM education. Interactive simulations and serious games can be used by students to explore systems where it would be impractical or unethical to perform real world studies or experiments. Simulations also have the capacity to reveal the internal workings of systems where these details are hidden in the real world. However, there is still much to be investigated about the best methods for using these games in the classroom so as to derive the maximum educational benefit. We report on an experiment to compare two different methods of using a serious game for teaching a complex concept in marine ecology, in a university setting: expert demonstration versus exploration-based learning. We created an online game based upon a mathematical simulation of fishery management, modelling how fish populations grow and shrink in the presence of stock removal through fishing. The player takes on the role of a fishery manager, who must set annual catch quotas, making these as high as possible to maximise profit, without exceeding sustainable limits and causing the stock to collapse. There are two versions of the game. The "white-box" or "teaching" game gives the player full information about all model parameters and actual levels of stock in the ocean, something which is impossible to measure in reality. The "black-box" or "testing" game displays only the limited information that is available to fishery managers in the real world, and is used to test the player's understanding of how to use that information to solve the problem of estimating the optimal catch quota.

Our study addresses the question of whether students are likely to learn better by freely exploring the teaching game themselves, or by viewing a demonstration of the game being played expertly by the lecturer. We conducted an experiment with two groups of students, one using free, self-directed exploration and the other viewing an expert demonstration. Both groups were then assessed using the black box testing game, and completed a questionnaire. Our results show a statistically significant benefit for expert demonstration over free exploration. Qualitative analysis of the responses to the questionnaire demonstrates that students saw benefits to both teaching approaches, and many would have preferred a combination of expert demonstration with exploration of the game. The research was carried out among a mix of undergraduate and taught postgraduate science students. Future research challenges include extending the current study to larger cohorts and exploring the potential effectiveness of serious games and interactive simulation-based teaching methods in a range of STEM subjects in both university and school settings.

1. Introduction

Although the term "serious games" has no fixed definition, it is widely understood to refer to games "with a purpose", that is, games that move beyond entertainment alone to deliver engaging interactive media to support learning in its broadest sense (Stone, 2012). The use of serious games and interactive simulation in formal education, with sufficient support, has been claimed to be motivational and to help students in high level learning of complex skills (Ulicsak, 2010) (Connollly et al., 2012). Serious games and interactive simulations have been increasingly integrated into science education as part of the teaching-learning process (Ceberio et al., 2016). They have been used to teach physics, chemistry, biology, mathematics and other sciences (Adams, 2010). Our previous work (Ameerbakhsh et al., 2016) with undergraduates in the biological sciences has shown that students appreciate the experience of engaging with an interactive simulation. In the field of marine ecology, there has been some use of visual interactive simulations, for example, for research into the optimal

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management of aquaculture and mariculture systems (Halachmi et al., 2005), (Ellner et al., 1996). There are also several simulation-based games on the theme of marine ecology, mostly aimed at younger audiences (MarineBio Conservation Society, 2017; Springbay Studio, 2017), whereas little has been done on the use of such games for teaching advanced concepts in university settings. Existing examples include the Fishbank simulation game, which was used to teach concepts of sustainable fisheries (Ruiz-Pérez et al., 2011), and the Marine Spatial Planner, which simulates negotiations between stakeholders in marine planning and policy (Mayer et al., 2013).

Proponents of serious games for science education argue that they deliver many benefits, for example, increased concentrated engagement in learners, inspiring active learning, improving understanding of complex subject matter, and fostering collaboration among learners (Ke, 2008). However, more research is needed, both to test these claims, and to discover the most effective methods in which to integrate serious games into the educational process so as to realize their benefits. Some recent evidence is gathered in a meta-analysis (Clark et al., 2016) which found significant learning benefits for games compared to non-game approaches. Another meta-analysis (Wouters et al., 2013) found that game use was most effective when the game was supplemented with other instruction methods, multiple training sessions were involved, and players worked in groups. However, there is more to be learned in this area, particularly within the higher education context.

Our paper makes a twofold contribution. First, we present a new interactive computer-based simulation as a serious game, developed for use in undergraduate and postgraduate courses in marine ecology and aquaculture. The game is designed to help learners to explore a complex mathematical model of fishery population growth and understand the principles of managing a fishery sustainably. There are two versions of the game: a “white-box” (teaching) version, which exposes the values of all parameters and variables used in the simulation, and is used to help students explore and understand the workings of the mathematical model; and a “black-box” (testing) version, which shows only the data that is visible in the real world, and is used to test the students’ skill in fishery management. Secondly, we carried out a comparison of two different methods of using the teaching game within the classroom:

1. Student-led active exploration: students freely explored the white box game without a teacher demonstration. This was then followed by an assessment of the students’ understanding using the black box testing game.
2. Expert demonstration: the white box game was demonstrated by the teacher with passive viewing but no active exploration by the students. As with the first method, this was then followed by an assessment using the testing game.

A mixed methods study design was employed, using both quantitative and qualitative methods to compare the learning effectiveness of the two approaches, and the students’ preferences. The rest of this paper is organized as follows: Section 2 describes the game and the concepts it is intended to teach. In Section 3, we explain the design of the comparison study. Section 4 presents the results, followed by a discussion and comparison with other studies in Section 5. Section 6 concludes the paper with an outline of the limitations of the study and some directions for future work.

2. Game concepts and design

The sustainable management of fisheries is a key curriculum topic for students of aquaculture and marine ecology, and is covered in both undergraduate and postgraduate courses at the University of Stirling. There are two main difficulties to be addressed in teaching this topic. The first problem is due to the low level of mathematical ability among the students. The theory behind fishery management is based upon a mathematical model of population growth, expressed as a system of ordinary differential equations. Some students do not have the background to understand the model in this form; however it is important for them to grasp the basic concepts on which the model is based, and to have a working knowledge of how to use the model to estimate optimal catch quotas. The second problem is due to the intrinsic practical difficulties of the task itself. In the real world, a fishery manager has no direct knowledge of the amount of fish in the ocean, and cannot easily tell whether the stock is overfished and at risk of collapsing, or whether, on the contrary, the stock is under-exploited and catch quotas could be safely increased. The fishery manager must try to estimate the state of the fishery by tracking annual trends in the amount of fish caught. This real-world process is too lengthy to be carried out with students as a practical exercise in real time.

Both problems can be addressed through the use of an interactive simulation-based serious game. The simulation allows time to be compressed, and can give learners access to full information about the state of the simulated world, including the actual level of stock in the ocean, helping them to understand how the model works. Embedding the simulation within a game makes it interactive and engaging, and allows students to explore the model and understand how to use it, without having to engage with the mathematical details. Different kinds of games can be created for teaching and for assessment. In this section we first give some more detail about the concept that is being taught and then describe the games that we developed to teach this concept.

The simulation is based on a mathematical model derived from (Woods and Jonasson, 2017). The growth of fish populations is modelled using a system of equations that depend upon two key parameters: the carrying capacity (K, measured in tons), which is the maximum population size that the environment can sustain; and the maximum production rate (P_{max}, measured in tons per year), which is the maximum rate of production of new stock (through reproduction). If the population biomass is small, the production rate is low because there are few fish to reproduce. The production rate increases as the biomass increases, reaching the peak value P_{max} when the biomass equals half the carrying capacity, and then reduces again as the biomass approaches K, due to the reduced ability of the environment to support new recruits. This system is illustrated in Fig. 1.

The optimal condition for exploiting a fishery occurs when the biomass equals K/2 and the annual fishing quota (total allowable catch, TAC) is equal to P_{max}. This is a stable situation in which the maximum number of fish is caught while keeping the population level constant.

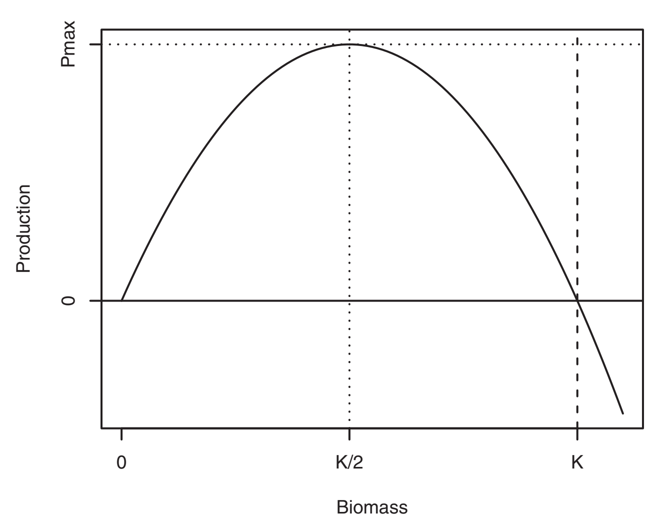

Fig 1. The relationship between production rate and biomass. The curve shows the production rate (tons of new fish produced per year) as a function of the current biomass. The maximum production rate (P_{max}, horizontal dotted line) occurs when the biomass is half of the carrying capacity (K, vertical dashed line).

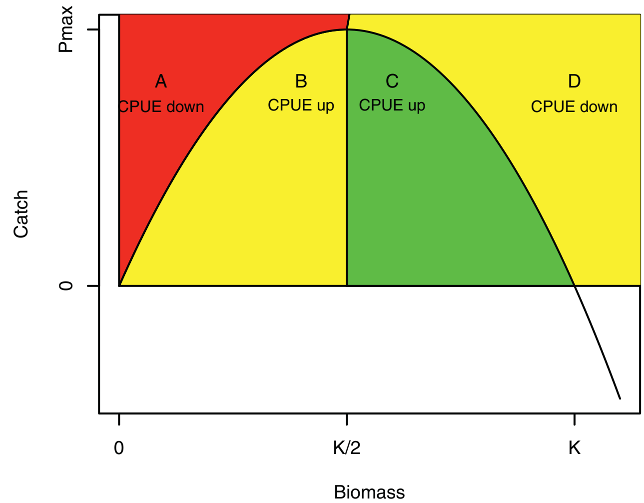

Fig 2. Estimating PMax by tracking catch per unit effort (CPUE). As in Fig 1, the curve shows the production rate as a function of the biomass. Additionally, the vertical axis also represents the total allowable catch (TAC) set by the fishery manager.

Note that in a real world fishery setting, the current biomass, P_{max}, and K cannot be measured directly. The fishery manager must attempt to estimate P_{max} by looking at the performance of fishing boats when attempting to catch a given TAC. The key value used is the catch per unit effort (CPUE), representing the tonnage of fish that is caught during one day of fishing. The fishery manager sets the TAC, and then looks at the trend in CPUE over a few years to try to infer the state of the fishery. There are four possibilities, shown by regions A-D in Fig. 2. Here, the horizontal axis again represents the biomass, as in Fig. 1, but the vertical axis now also represents the TAC. Table 1 describes the state of the fishery represented by each region, and explains how this can be detected by looking at CPUE, and what action should be taken by the fishery manager to avoid stock collapse and reach P_{max}.

The mathematical model described above was encoded within the NetLogo agent-based simulation tool (Wilensky and Rand, 2015) as an interactive game, and exported to HTML using the NetLogo Web extension so that it could easily be presented to students on a web page. Two versions of the game were created, shown in Fig. 3. The “white box” or teaching game exposes all parameters and variables used in the model, including the actual values of K, P_{max}, and the current biomass. In effect, the player gets to see “below the waves” and has access to the true condition within the fishery. The “black box” or testing game is derived from the “white box” version by making the ocean effectively opaque, exposing only the information that is available to the fishery manager “above the waves”. Both games are played in the same way. The aim is to guess the value of P_{max}. To do this, the player sets TAC (called “target catch” in the game) and then clicks the “Go Fishing” button to simulate a year of fishing. The player will usually use the same TAC repeatedly over a few years, looking at trends in CPUE, and use this information to adjust TAC up or down for subsequent years.

The game interface has been designed to be simple to use and to give an intuitive presentation of a complex set of information. The placement of elements in the interface is intended to separate the information available “above the waves” (CPUE and related information) from that available only in the white box version (P_{max}, K, and biomass). Key information is presented both as numerical values and plotted on graphs. A “Continue to year 100″ button is included, which automatically repeats the simulation for up to 100 time steps, using the same value of TAC. This allows players to easily simulate the long term consequence of the TAC they have chosen.

3. Experimental setup

The methodologies used in educational research could be qualitative, quantitative, or mixed methods that combine both quantitative and qualitative data (Harwell, 2011). The use of mixed methods is recommended (Ross et al., 2005) as a way of producing convincing evidence by using complementary approaches to address a research subject. In this study we adopt the triangulation design approach to mixed-methods research (Morse, 1991). This approach aims at acquiring different but balancing data on the same research question, thereby allowing cross-validation of results obtained using different methods. The reason for using this design is “to bring together the differing strengths and non-overlapping weaknesses of quantitative methods (large sample size, trends, generalization) with those of qualitative methods (small *N*, details, in depth)” (Creswell and Plano Clark, 2010). The design is used when a researcher intends to directly compare quantitative statistical results and qualitative findings or to validate or expand quantitative results with qualitative data (Creswell and Plano Clark, 2010).

3.1. Design of the study

Our study compares the learning effectiveness of two different methods for using the “white box” teaching game with university students in a classroom (computer laboratory) environment. The game is intended to help students better understand the workings of the biomass production model, and to develop the ability to estimate the optimal TAC by observing trends in CPUE. The research question being addressed is: will students learn more effectively if they are given the teaching game to use themselves to solve a given example problem, or will they learn more by viewing a demonstration by the lecturer of how to use the teaching game to solve the same problem? We call the first approach USE and the second DEMO.

The design of the study is illustrated in Fig. 4. The students were split randomly into two groups of roughly equal size (the DEMO group and the USE group). Participants were unaware of which group they were in, and both groups were treated identically, apart from the difference in the way they used the white box game. Both groups attended a lecture, given by the same lecturer, explaining the biomass production model and the relationship between CPUE and optimal TAC. The DEMO group then viewed an expert demonstration of the use of the white box game to solve a TAC estimation problem. The USE group were given access to the white box game themselves and were allowed to explore it freely to find the solution to the same problem. Both groups were then tested on their TAC estimation skills using the black box game. During the test, students were allowed multiple attempts and were asked to record on a data sheet their estimates of optimal TAC (P_{max}) at each attempt. Finally, students were asked to complete a questionnaire. This was in two parts. Part 1 comprised a Learning Effectiveness Survey

Table 1
Using CPUE to infer conditions in the fishery and estimate P_{max}.

Region	Description	How to detect	Recommended action
A	Biomass < K/2 and TAC > production. Biomass is heading for collapse.	Sharp and accelerating decline in CPUE.	Reduce TAC sharply to replenish biomass.
B	Biomass < K/2 and TAC < production. Biomass and production are growing.	Gradual, accelerating increase in CPUE	Carefully increase TAC to achieve P_{max}
C	Biomass > K/2 and TAC < production. Biomass growing, production slowing	Gradual, decelerating increase in CPUE	Carefully increase TAC to achieve P_{max}
D	Biomass > K/2 and TAC > production. Biomass is decreasing slowly	Gradual decrease in CPUE	Reduce TAC to achieve P_{max}

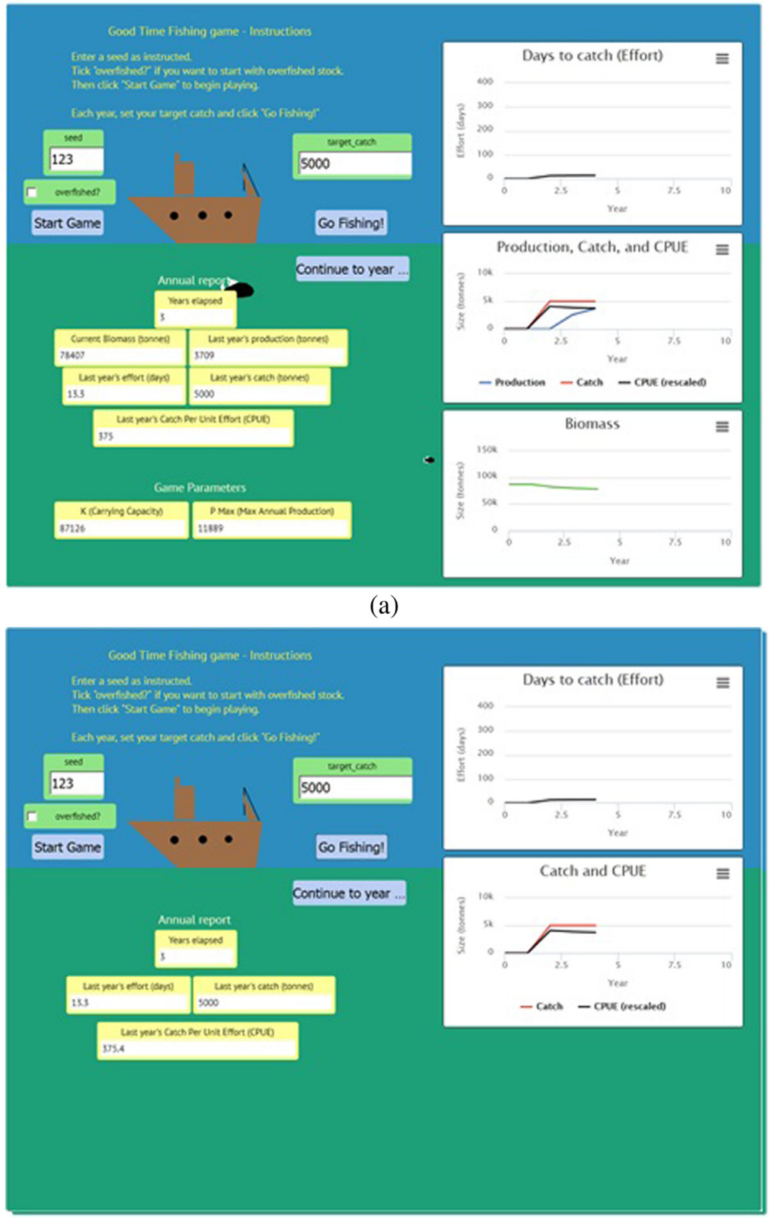

Fig 3. The Good Time Fishing game. (a) "white box" or teaching game, showing all parameters and variables used in the model. (b) "black box" or testing game, showing only the parameters and variables accessible in the real world.

(LES), based on an instrument developed by (Moody and Sindre, 2003) to evaluate the effectiveness of learning interventions. This consisted of fourteen questions with answers on a five-point Likert scale. An additional question measured students' problem solving self-efficacy, by asking them to rate their confidence in running the simulation and understanding the key concepts. The TAC estimates and part 1 of the LES questionnaire make up the quantitative data collected. Part 2 of the LES questionnaire contained 6 open-ended feedback questions, providing complementary qualitative data.

3.2. Study participants

Participants were recruited by advertising the experiment using mailing lists of undergraduate and taught postgraduate students studying Aquaculture and Computing Science in the academic years 2016–17 and 2017–18. 36 students took part in total. 13 participants were Aquaculture students on a master's program, 17 were undergraduate marine biology students, and 6 were Computing Science undergraduates. 23 participants were male and 13 were female. Based on the demographic data collected, none of the participants had studied the biomass production model before, or had any previous knowledge of the concept. The participants were randomly divided into eight small groups of roughly equal size, four of which were taught by active exploration (USE), and four of which were taught by expert demonstration (DEMO). The data was pooled from all the replicate groups to reach an adequate sample size for statistical analysis (Alhakim and Hooper, 2008; Bangdiwala et al., 2016). The results from comparison of the USE and DEMO groups are discussed in the next section.

4. Analysis of results

Participants completed a Learning Effectiveness Survey (LES), in which answers were selected on an odd Likert scale with the following five values: Not at all, Slightly, Moderately, Very much, and Extremely.

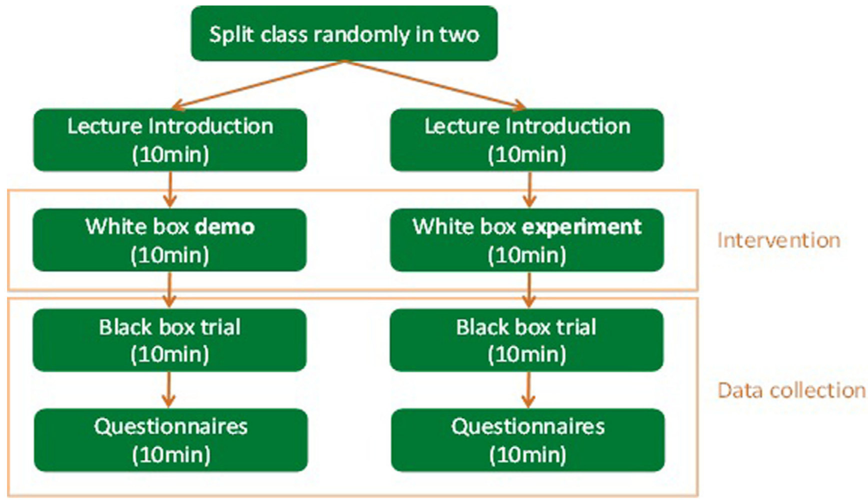

Fig 4. Experiment design. The left side shows the treatment received by the DEMO group, and the right side shows the treatment received by the USE group.

These five values were coded as numbers one to five, and analyzed using a Mann-Whitney test as the data was not normally distributed (Joost et al., 2010). The Mann-Whitney test was also used to compare the results of the question on self-efficacy (Bandura, 2006; Nachar, 2008). Participants were also tested using a black box game, which they were asked to play several times, recording on a data sheet their estimates of the optimal TAC, measured in tonnes. Space on the data sheet was given for six attempts but students were allowed to record extra attempts at the bottom of the page. Some students did not have time for 6 attempts. In summary, 21 out of 36 students each had 6 attempts, with the number of attempts ranging from 2 to 12. The error in each student's final guess was measured as the square of the difference between the guess and the true answer. Differences between groups of students were tested using ANOVA with the log transformed error-squared (Wonnacott and Wonnacott, 1990). Two students' final guesses were recorded as 0 and these students were excluded from the analysis. Qualitative data collected from the open-ended feedback questions were analysed using the NVivo software (Richards, 1999). The responses were coded into themes and sub-themes for reporting.

4.1. Quantitative results

Table 2 shows the results of using an independent *t*-test (Mann Whitney) to compare the LES responses from the USE and DEMO groups. The median Likert score for each group is shown. The results revealed that there were no significant differences between most of the variables tested. The table also shows the results of comparing the perceived self-efficacy scores. Again, there was no significant difference between the two groups.

A performance test was used to measure students' success at the black box testing game to show the difference between the student's estimate and the correct answer (which is known to the researchers but not to the students). Fig. 5 illustrates the error in students' estimates in both USE and DEMO groups across six repeat attempts at playing the black box test game.

Both groups of students improve in their estimates as they repeatedly attempt the game, shown by the reduction in error over time in Fig. 5. Fig. 6 shows the distributions of errors in the students estimates at the final attempt (sixth attempt for most participants) for the two treatment groups. The log of the error-squared for the two treatments were significantly different (ANOVA with two groups, $p = 0.02$).

Table 2
Comparison of quantitative results from a Mann-Whitney test comparing the USE and DEMO groups.

Variable	USE	DEMO	p Value
How much did you enjoy this class?	3	4	>5
The session began with a presentation by the lecturer. How useful was this for helping you to understand the biomass based production model?	4	4	>5
The lecturer then demonstrated how to estimate P_{max} using a "white box" simulation or you explored how to estimate P_{max} by using a "white box" simulation yourself. How useful was this for helping you to understand the biomass based production model?	4	4	>5
You then did an exercise using a "black box" simulation. How useful was this for helping you to understand the biomass based production model?	4	4	>5
How useful was the class as a whole at helping you to understand the biomass based production model?	4	4	>5
The lecturer showed you a demonstration of how to estimate P_{max} using a "white box" simulation or you explored how to estimate P_{max} using a "white box" simulation yourself. To what extent did you like this method of teaching?	4	4	>5
To what extent would you have preferred to explore how to estimate P_{max} using the "white box" simulation yourself, instead of watching the lecturer demonstrate how to do it or to explore how to estimate P_{max} using the "white box" simulation yourself, instead of watching the lecturer demonstrate how to do it?	2	3.5	>5
How well were you able to understand the user interface of the "white box" simulation?	4	4	>5
How attractive did you find the user interface of the "white box" simulation?	3	3.5	>5
How well were you able to understand the user interface of the "black box" simulation?	4	4	>5
How attractive did you find the user interface of the "black box" simulation?	3	4	>5
How enthusiastic did you feel about watching the lecturer demonstrate the "white box" simulation or How enthusiastic did you feel about using the "white box" simulation yourself?	4	3.5	>5
How enthusiastic did you feel about using the "black box" simulation yourself?	4	4	>5
How much would you like to have more exercises like this as part of your degree?	4	4	>5
How confident do you now feel about your ability to use information about CPUE to estimate P_{max}? Use the scale below to indicate your degree of confidence.	60	70	>5

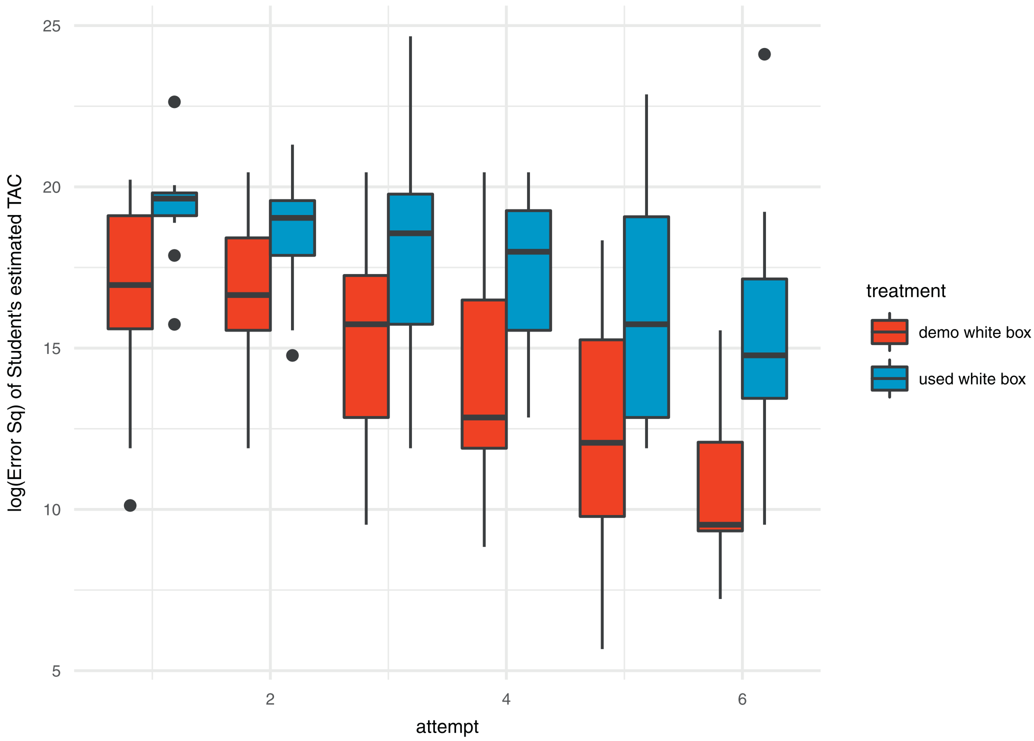

Fig 5. Box plots showing the distribution of log(Sq(error)) for the USE and DEMO groups across six repeat attempts at playing the black box test game.

4.2. Qualitative results

We used framework thematic analysis (Braun and Clarke, 2006; Srivastava and Thomson, 2009) to analyse the open ended responses collected from the feedback questionnaire. Framework analysis is a flexible process for analysing qualitative data, allowing the user to either collect all the data first and then analyse it, or to do data analysis during the collection process. In the analysis stage the gathered data is filtered, charted and sorted in accordance with key issues and themes (Srivastava and Thomson, 2009). In this study themes were identified

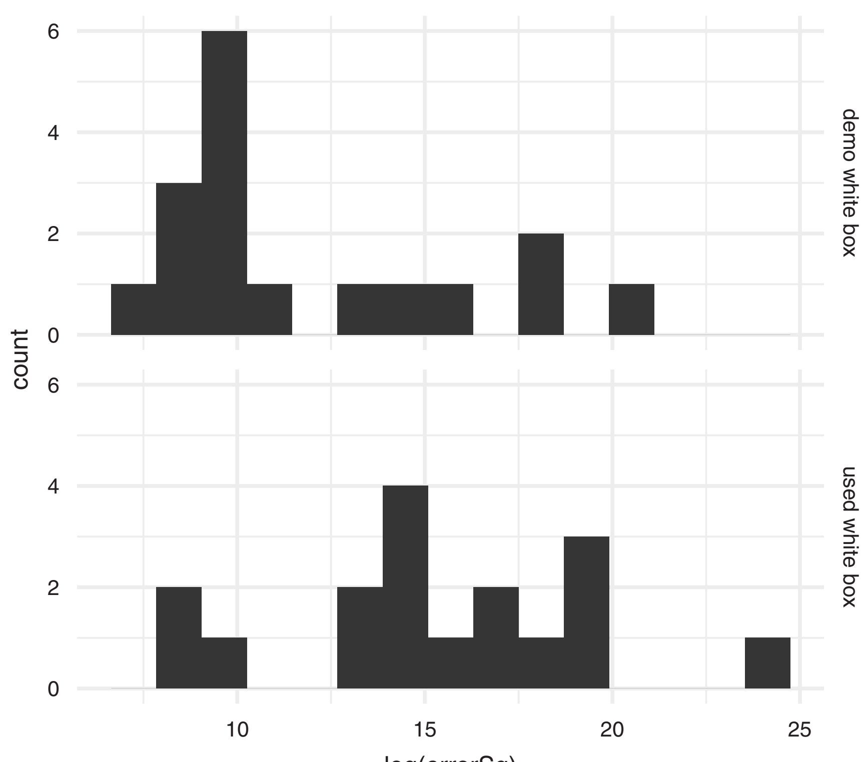

Fig 6. Histograms showing the distribution of log(Sq(error)) for the USE and DEMO groups at the final attempt at playing the black box test game.

from students responses to the open ended questions. Six themes were identified from the questions

- Effective way of learning
- Preferred way of learning
- Best part of the class
- Help in understanding the concepts
- Inclusion of games and interactive simulation in their studies
- Suggestions or comments

Effective way of learning

18 students out of the 36 participants were in the USE group and played with the white box game instead of seeing a demonstration from the lecturer. 16 students out of the 18 found this to be an effective way of learning. The following are some of the several reasons cited by the students for this.

Use of the white box simulation gave the students a better idea about what to look for in the black box simulation; it helped them understand some of the concepts effectively before playing with the black box simulation; it was easy to play with; it helped them to self-discover how to use the program and understand the aim of the simulation; it was a good teaching method about productivity in the fishing industry. One student also said that this would make him/her understand the concepts of the optimal TAC better:

> "I consider the white box exercise gave me the basics to understand what I should be looking for in the black box version, to estimate the optimum yield with the best provided." (Student A001)

18 students out of the 36 were in the DEMO group and saw an expert demonstration of the white box game instead of playing it themselves. 14 of these students found this to be an effective way of learning. Some reasons given for this were that: it was effective to have information provided from the teacher before playing the game; it helped them in the practice; it was inspiring, simple and useful; they learned more by following along with the lecturer instead of just watching him; it helped them understand the relationship between the biomass and the catch; watching the lecturer give a demonstration of the white box simulation helped the students understand some of the concepts effectively before playing with the black box simulation and it was easy to play with.

One student said that lecturers' demonstrations are an important step before independent learning:

> "I found it effective, as it was a way to understand concepts I didn't know before. For me, lectures demonstrations are all important step before independent learning, mostly where the student is not very familiarised with the concept to work with." (B011)

Preferred way of learning

18 students out of the 36 would have liked to have a lecturer demonstration as well as playing with the white box game. Their supported reasons for this preference include that: the lecture is necessary for learning the basics; they found the lecture material adequate, but would gain a better understanding by carrying out the white box simulation themselves; exploring the simulation was helpful and enjoyable; the lecture helped them see the bigger picture as they experimented with the numbers; they found that a lecture plus hands on white box simulation gave them a better learning experience; they believe a demonstration before using the white box simulation will help them learn better. One student said that he/she learned better from the lecturer, but would also have liked to explore the white box simulation unsupervised. His/her exact response was the following:

> "I may have learned more from watching the lecturer demonstrate one example after the exploration, and then have time to try it myself." (A001)

8 students out of the 36 said they would prefer playing with the white box simulation without seeing a demonstration. They found it more engaging; they liked the experience of trying and failing; they liked to play with the tools as it gave them more understanding about estimating the P_{max}; they liked learning by doing instead of watching a lecturer. One student said that he/she liked it because it gave an opportunity to try anything without embarrassment:

> "Much better to do it alone. You can try anything you want without making silly guesses in front of a class." (A012)

8 students out of the 36 preferred the lecturer demonstration of the white box simulation without wanting to explore it themselves. They stated that it gave them an idea of the simulation; the lecturer explained the examples himself in sufficient depth; it was helpful, it worked perfectly fine; the lecturer explained the examples himself very clearly. One student said the explanation of the theory beforehand made it easy:

> "It would have been helpful to watch the lecturer demonstrate because you can see what is actually ahead to do and you are able to see what your results are supposed to look like." (Student F01)

Best part of the class

18 students out of the 36 said that doing the exercise using the black box simulation was the best part of the class because it was the most interesting; felt very practical; they preferred the hands-on experience; it was interactive; they preferred doing it themselves instead of listening to it in detail; it was motivating for the students to find the correct number; they enjoyed learning by having their hands on the simulation and this helped them in understanding the simulation; having less information given to them encouraged problem solving and more thinking. One student said that the best part of the class was:

> "Doing the exercise using the "black box" simulation. (It was the most interesting. Had to be cautious about the biomass." (C001)

10 students out of the 36 said that exploring the model using the white box simulation was the best part of the class. Some of the reasons given for favouring this part of the class were: it was more intuitive to find out what the maximum sustainable yield may be; you can see exactly what's going on; it helped the student to remember what they were doing; I got to see how I affected everything more clearly; I gained the most relevant information from the white box simulation. One student said that he/she enjoyed playing with the white box simulation:

> "Exploring the model using the "white box" simulation. (The white box version better demonstrated the concept talked through in the lecture, I enjoyed the aspect of it." (A004)

5 students out of the 36 said that watching the demonstration of the white box simulation and then using the black simulation was the best part of the class. Reasons included: they liked the lecturer's explanation with having something visual; they could understand what was going on more fully; they understood the concept in a better way. One student said:

> "I liked the lecturer most because the lecturer explained the background of the simulation and the reason behind it as we got some information before starting to explore it ourselves. It would have been helpful if some demonstration were shown in the lecture as well to get an idea of what we are about to examine.)." (Student F01)

Help in understanding the concepts

4 students out of the 36 said that doing the exercise with the black box simulation helped them in understanding the concepts and made it easy for them. One student said:

> "Doing the exercise with the "black box" simulation. (The P_{max} produced by using different attempts is quite fun and meaningful."

(A001)

8 students out of the 36 said that exploring the model using the white box simulation helped in understanding the concepts because of: the easy introduction to the actual task, where they could see all the figures and could experiment with any numbers, helping them to understand the lecture more; it gave them a chance to practice for the black box simulation; the additional information available in the white box simulation allowed them to understand the concept better. One student said:

> "Exploring the model using the "white box" simulation. (Could play with the program and explore everything)." (C001)

15 students out of the 36 said that listening to the initial lecture helped them understand the concepts. Several reasons were mentioned, including that they were unfamiliar with some of the concepts and the lecturer explained them well; it helped them understand the difference between the white box and black box simulation before completing the exercise; and it explained the theory. The simulation was good to explore the theory however, it was well explained and helped to see what was happening and why in the simulation. The lecturer explained to them what they were doing and why; it helped in explaining the key concepts phases; the information given by the lecturer was useful to explain the theory and for students to practice it later and it was engaging; without the explanation it would have been harder to understand. One student explained his/her reasons by saying the following:

> "Listening to the initial lecture. I understood it best by the teacher explaining the concept because you get an idea of the background and usage of these models which helped me to understand the simulation more." (Student F01)

5 students out of the 36 said watching the demonstration of the white box simulation helped them in understanding the concepts. The following reasons were given: when the lecturer demonstrated the white box simulation, it was effective to understand as visible things in a study are very useful; the white box simulation showed how P_{max} could be estimated and the lecturer's comments put context to the simulation. Another student said:

> "Watching the demonstration of the white box simulation. Being able to see all the details and numbers while having the context explained made it easier to understand." (Student E05)

2 Students out of the 36 liked the three options of watching a white box demonstration, playing with the white box simulation and also playing with the black box simulation. However, they did not provide any reason for their preference.

Interactive simulation as part of their studies

35 out of the 36 students said they would like to have this kind of interactive simulation exercise as part of their degree. The key reasons for their preference included: effectiveness, enjoyable, helpful, interesting, different, more engaging, makes obtaining knowledge easy, helpful in understanding the concept, and shows a good example of real-world fishery management. One student said:

> "It could be good, as it gives you a snapshot on how things can develop overtime by changing different variables and experience it by yourself, rather than just being told by the lecturer about the theory of what might occur. It is also a good "mind-set change" from the typical classroom lecture." (A001)

Suggestions and comments

21 students out of the 36 made some suggestions and comments that include: the simulation exercise could be longer to explore deeper and harder problems; images used in the simulation could be improved; there could be a more detailed demonstration of how the simulation works; more analytical feedback could be provided; there could be more hands-on simulation and time for self-learning; there could be more interaction with the white box simulation; to allow attempts to use both simulations (white box and black box); have an introduction then try the black box version, then the lecturer can explain what they discovered; there could be less explanation and more walk-through; more graphs on the black box simulation like in the white box simulation; to be able to see a white box style graph after doing the black box simulation. One student said that he/she would like to be involved in the developing of the game and a prize for the winner:

> "I would enjoy a class learning how the game was developed. Maybe give a prize to the person who guesses the answer correctly as well." (B003)

5. Discussion

The aim of the study reported in this paper is to investigate the effectiveness of active exploration of interactive simulation without teacher involvement versus passive viewing of an expert demonstrating the interactive simulation. The study area was the teaching and learning of marine ecology in higher education, and the study focused on teaching students a challenging skill: how to manage a fishery sustainably by understanding a complex mathematical model of biomass production and relating it to real world observations. We find that students enjoy learning through using an interactive simulation-based game, and that expert demonstration was more effective for learning than active exploration in the case we studied.

The case study interventions were designed in an experimental way, where two different methods were compared. The two methods were titled "USE" and "DEMO". Each of the method was then evaluated using three evaluation tools namely, LES with self-efficacy, performance test and qualitative data. The results obtained using LES with self-efficacy demonstrate that though the students liked the "DEMO" method, no significant difference was observed. On the other hand, the results obtained using the performance test show a statistically significant difference in performance of the "DEMO" group over the "USE" group. Lastly, the analysis of the obtained qualitative data demonstrated that the majority of the students liked the exercise and indicated that having a teacher to walk them through the white box simulation made it more effective.

Our study may be seen as a comparison of active (student-centred) and passive (teacher-led) approaches for using interactive simulations in teaching. A number of other studies have also compared these approaches in a variety of contexts and with widely varying results. Some studies have found active learning approaches to be more effective than passive approaches, e.g. James et al. (2002), which compared using both approaches in a memorization task. Other studies have found no difference between active and passive approaches, e.g. Haidet et al. (2004), which compared the effectiveness of different methods for training clinicians. And yet other studies, e.g. González-Cruz et al. (2003) and Mosalanejad et al. (2012) have found benefits for a guided or semi-guided approach over a fully unguided exploration of a teaching simulation. Students themselves have been found to have widely varying opinions about the effectiveness of student-centred learning (Lea et al., 2003). There is no consensus about the value of these different approaches, and no general conclusions can be drawn. It is clear that there is no one-size-fits-all recommendation, and that the specific characteristics of each learning situation must be taken into account in choosing the most appropriate teaching method.

6. Conclusions, limitations and future work

This study compares two methods of using an interactive simulation game in an e-learning classroom environment. The key focus is to determine whether the use of the game is more effective with or without expert guidance. We conducted a case study with university students using a simulation game to teach a complex concept (a mathematical model of biomass production, and how to use this model to manage a fishery sustainably). Our key findings are that students enjoyed using the simulation game, and that learning effectiveness was greater when students received an expert demonstration of the game.

It should be emphasized that this is a case study of one specific set of simulation games with a limited number of students. Sample size in case study research is not necessarily relevant (Thomas, 2016) because the purpose of case study research is not to show a quality of the whole population. In case study research, the researcher is only looking at a selection of subjects without any expectations that they are representing a larger population. If the sampling procedure does not give some elements in the population the chance to be in the sample of the study, then statistical theories are not applicable in the determination of the sample size (Daniel, 2012). According to Purchase (2012) it is rare in HCI research to conduct studies where all members of the population can take part in the experiments.

Observations made in case studies cannot readily be generalized to the whole population. However, it is possible to apply “analytic generalisation” in which a previously developed theory or observation is used as a template with which the empirical results of the case study will be compared (Yin, 2010). Our case study contributes to the body of empirical evidence about the use of student-centered, active learning approaches. Future work to strengthen this evidence includes extending the current study to larger cohorts and carrying out further case studies to compare the student-led and teacher-led approaches in a range of STEM subjects with different learning outcomes, teachers, and students. A strong body of case studies will help to build a nuanced picture of the effectiveness of different methods of using serious games in teaching and will serve as examples to help instructors with choosing the right approach for their specific needs.

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References

Adams, W.K., 2010. Student engagement and learning with PhET interactive simulations. Nuovo Cim. della Soc. Ital. di Fis. C 33, 21–32. https://doi.org/10.1393/ncc/i2010-10623-0.

Alhakim, A., Hooper, W., 2008. A non-parametric test for several independent samples. J. Nonparametr. Stat. 20, 253–261. https://doi.org/10.1080/10485250801976741.

Ameerbakhsh, O., Maharaj, S., Hussain, A., Paine, T., Taiksi, S., 2016. An exploratory case study of interactive simulation for teaching ecology, in: 2016 15th International Conference on Information Technology Based Higher Education and Training, ITHET 2016. . https://doi.org/10.1109/ITHET.2016.7760725.

Bandura, A., 2006. Guide for Constructing Self-Efficacy scales, in: Self-Efficacy Beliefs of Adolescents. Information Age Publishing, pp. 307–337.

Bangdiwala, S.I., Bhargava, A., O'Connor, D.P., Robinson, T.N., Michie, S., Murray, D.M., Stevens, J., Belle, S.H., Templin, T.N., Pratt, C.A., 2016. Statistical methodologies to pool across multiple intervention studies. Transl. Behav. Med 6, 228–235. https://doi.org/10.1007/s13142-016-0386-8.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 77–101. https://doi.org/10.1191/1478088706qp063oa.

Ceberio, M., Almudí, J.M., Franco, Á., 2016. Design and application of interactive simulations in problem-solving in university-level physics education. J. Sci. Educ. Technol 25, 590–609. https://doi.org/10.1007/s10956-016-9615-7.

Clark, D.B., Tanner-Smith, E.E., Killingsworth, S.S., 2016. Digital games, design, and learning: a systematic review and meta-analysis. Rev. Educ. Res. 86, 79–122. https://doi.org/10.3102/0034654315582065.

Connollly, T.M., Boyle, E.A., MacArthur, E., Hainey, T., Boyle, J.M., 2012. A systematic literature review of empirical evidence on computer games and serious games. Comput. Educ. 59, 661–686. https://doi.org/10.1016/J.COMPEDU.2012.03.004.

Creswell, J.W., Plano Clark, V.L., 2010. Choosing a mixed methods design. Designing and Conducting Mixed Methods Research. SAGE Publications, pp. 58–89.

Daniel, J., 2012. Choosing the size of the sample, in: sampling essentials: practical guidelines for making sampling choices. . SAGE Publications, Inc., 2455 Teller Road, Thousand Oaks California 91320 United States, pp. 236–253. https://doi.org/10.4135/9781452272047.n7.

Ellner, S., Neori, A., Krom, M.D., Tsai, K., Easterling, M.R., 1996. Simulation model of recirculating mariculture with seaxeed biofilter iofilter ofilterr iofilterro-filterfilterer iofilte. Aquaculture 143, 167–184. https://doi.org/https://doi.org/10.1016/0044-8486(95)01241-9.

González-Cruz, J., Rodríguez-Sotres, R., Rodríguez-Penagos, M., 2003. On the convenience of using a computer simulation to teach enzyme kinetics to undergraduate students with biological chemistry-related curricula. Biochem. Mol. Biol. Educ. 31, 93–101. https://doi.org/10.1002/bmb.2003.494031020193.

Haidet, P., Morgan, R.O., O'Malley, K., Moran, B.J., Richards, B.F., 2004. A controlled trial of active versus passive learning strategies in a large group setting. Adv. Heal. Sci. Educ. 9, 15–27. https://doi.org/10.1023/B:AHSE.0000012213.62043.45.

Halachmi, I., Simon, Y., Guetta, R., Hallerman, E.M., 2005. A novel computer simulation model for design and management of re-circulating aquaculture systems. Aquac. Eng. 32, 443–464. https://doi.org/10.1016/j.aquaeng.2004.09.010.

Harwell, M.R., 2011. Research design in qualitative/quantitative/ mixed methods. SAGE Handb. Res. Educ. Pursuing Ideas as Keystone Ex. Inq 147–182. https://doi.org/10.4135/9781412961288.n380.

James, K.H., Humphrey, G.K., Vilis, T., Corrie, B., Baddour, R., Goodale, M.A., 2002. “Active” and “passive” learning of three-dimensional object structure within an immersive virtual reality environment. Behav. Res. Methods, Instruments, Comput 34, 383–390. https://doi.org/10.3758/BF03195466.

Joost, C.F., Winter, D., Dodou, D., 2010. Five-point likert items : t test versus Mann-Whitney-Wilcoxon. Pract. Assessment, Res. Eval. 15, 1–16. https://doi.org/citeulike-article-id:10781922.

Ke, F., 2008. A case study of computer gaming for math: engaged learning from gameplay. Comput. Educ 51, 1609–1620. https://doi.org/10.1016/j.compedu.2008.03.003.

Lea, S.J., Stephenson, D., Troy, J., 2003. Higher education students' attitudes to student-centred learning: beyond “educational bulimia. Stud. High. Educ. 28, 321–334. https://doi.org/10.1080/03075070309293.

Morse, J.M., 1991. Approaches to qualitative-quantitative methodological triangulation. Nurs. Res.

MarineBio Conservation Society, 2017. Marinebio kids - marinebio.org [www document]. URL . http://marinebio.org/marinebio/games/ accessed 8.28.17.

Mayer, I., Zhou, Q., Lo, J., Abspoel, L., Keijser, X., Olsen, E., Nixon, E., Kannen, A., 2013. Integrated, ecosystem-based marine spatial planning: design and results of a game-based, quasi-experiment. Ocean Coast. Manag. 82, 7–26. https://doi.org/10.1016/J.OCECOAMAN.2013.04.006.

Moody, D.L., Sindre, G., 2003. Evaluating the effectiveness of learning interventions : an information systems case study. In: ECIS 2003 Proceedings, pp. 17.

Mosalanejad, L., Shahsavari, S., Sobhanian, S., Dastpak, M., 2012. The effect of virtual versus traditional learning in achieving competency-based skills. Turkish Online J. Distance Educ. 13, 69–75.

Nachar, N., 2008. The Mann-Whitney U: a test for assessing whether two independent samples come from the same distribution. Tutor. Quant. Methods Psychol. 4, 13–20.

Purchase, H.C., 2012. Experimental Human-Computer Interaction. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511844522.

Richards, L., 1999. Using NVivo in Qualitative Research. Sage Publications.

Ross, S.M., Morrison, G.R., Lowther, D.L., 2005. Using experimental methods in higher education research. J. Comput. High. Educ. 16, 39–64. https://doi.org/10.1007/BF02961474.

Ruiz-Pérez, M., Franco-Múgica, F., González, J.A., Gómez-Baggethun, E., Alberruche-Rico, M.A., 2011. An institutional analysis of the sustainability of fisheries: insights from FishBanks simulation game. Ocean Coast. Manag. 54, 585–592. https://doi.org/10.1016/j.ocecoaman.2011.05.009.

Studio, Springbay, 2017. iBiome-ocean | fun educational games about nature [www document]. iTunes URL. http://www.springbaystudio.com/ibiome-ocean/ accessed 8.28.17.

Srivastava, A., Thomson, S.B., 2009. Framework analysis: a qualitative methodology for applied policy research.

Stone, R.J., 2012. Human factors guidance for designers of interactive 3d and games-based training systems.

Thomas, G., 2016. How to do Your Case Study, 2nd Editio. ed. Sage Publications.

Ulicsak, M., 2010. Games in education: serious games. A FutureLab Literat. Rev.

Wilensky, U., Rand, W., 2015. An introduction to agent-based modeling : modeling natural, social, and engineered complex systems with NetLogo.

Wonnacott, T.H., Wonnacott, R.J., 1990. Introductory Statistics. fifth. ed. Wiley, New York.

Woods, P., Jonasson, J.P., 2017. Bayesian hierarchical surplus production model of the common whelk Buccinum undatum in Icelandic waters. Fish. Res. 194, 117–128. https://doi.org/10.1016/j.fishres.2017.05.011.

Wouters, P., van Nimwegen, C., van Oostendorp, H., van der Spek, E.D., 2013. A meta-analysis of the cognitive and motivational effects of serious games. J. Educ. Psychol. 105, 249–265. https://doi.org/10.1037/a0031311.

Yin, R.K., 2010. Analytic generalization. Encyclopedia of Case Study Research. SAGE Publications, Thousand Oaks California Inc., 2455 Teller Road91320 United States. https://doi.org/10.4135/9781412957397.n8.