

Towards the Use of Interactive Simulation for Effective e-Learning in University Classroom Environment

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Declaration

I, Omair Ameerbakhsh, hereby declare that the work in this thesis is original and has been composed by myself, except where reference is made to other works, and has not been submitted for examination for any other degree at this university or any other learning institutions.

Stirling, March 2018

Omair Ameerbakhsh

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Abstract

In this PhD thesis, the utilisation of interactive simulation in a higher education e-learning classroom environment was explored and its effectiveness was experimentally evaluated by engaging university students in a classroom setting. Two case studies were carried out for the experimental evaluation of the proposed novel interactive simulation e-learning tool.

In the first case study, the use of interactive agent-based simulation was demonstrated in teaching complex adaptive system concepts in the area of ecology to university students and its effectiveness was measured in a classroom environment. In a lab intervention using a novel interactive agent-based simulation (built in NetLogo). For the purpose of teaching complex adaptive systems such as the concept of spatially-explicit predator prey interaction to undergraduate and postgraduate students in the University of Stirling. The effectiveness of using the interactive simulation was investigated by using the NetLogo software and compared with non-interactive simulation built using R programming language. The experimental evaluation was carried out using a total of 38 students. Results of this case study demonstrates that the students found interactive agent-based simulation to be more engaging, effective and user friendly as compare to the non-interactive simulation.

In the second case study, a novel interactive simulation game was developed (in NetLogo) and its effectiveness in teaching and learning of complex concepts in the field of marine ecology was demonstrated. This case study makes a twofold contribution. Firstly, the presentation of a novel interactive simulation game, developed specifically for use in undergraduate and postgraduate courses in the area of marine ecology. This novel interactive simulation game is designed to help learners to explore a mathematical model of fishery population growth and understand the principles for sustainable fisheries. Secondly, the comparison of two different methods of using the interactive simulation game within the classroom was investigated: learning from active exploration of the interactive simulation game compared with learning from an expert demonstration of the interactive simulation game. The case study demonstrated the effectiveness of

learning from passive viewing of an expert demonstration of the interactive simulation game over learning from active exploration of the interactive simulation game without expert guidance, for teaching complex concepts sustainable fishery management.

A mixed methods study design was used, using both quantitative and qualitative methods to compare the learning effectiveness of the two approaches, and the students' preferences. The investigation was carried out by running interventions with a mixture of undergraduate and postgraduate students from the University of Stirling in a classroom environment. A total of 74 participants were recruited from undergraduate and postgraduate level for both case studies.

This thesis demonstrated through two case studies effectiveness of the proposed novel interactive simulation in university e-learning classroom environment.

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Chapter 1 - Introduction

1.1 Motivation

The aim of this thesis is to investigate the effectiveness of interactive computer-based simulation in university classrooms as an e-learning tool. The thesis aims to answer two questions, the first question is: will introducing interactive computer simulation to university students to teach complex concepts of ecology enhance their learning experience, and would it be effective? The second question is: would introducing interactive computer simulation to university students to teach complex concepts of marine ecology enhance their learning experience, and which method of using the interactive computer simulation is effective? The aim of this thesis is to help computer scientists and e-learning system developers to develop interactive computer-based simulations that are effective and enhance the learning experience of university students.

Interactive computer simulation will be used as an e-learning tool by university students so that they can learn in an interactive simulation environment, and where they will immerse and participate actively in complex learning environments for an enhanced learning experience. Students will be performing complex problem-solving skills when running the interactive computer simulations, and they will evaluate the effectiveness of the interactive computer-based simulations which they used in the classroom environment.

The terms interactive simulation, interactive computer simulation and interactive computer-based simulation are used interchangeably in this thesis as they all have the same meaning.

1.2 Research Aim

The aim of this PhD thesis is to explore the utilisation and effectiveness of interactive simulation in a higher education e-learning classroom environment.

The key objectives are to:

- Explore and experimentally evaluate the effectiveness of e-learning methodology using interactive (agent-based) simulations, by engaging University students in a classroom setting.
- Explore and experimentally evaluate the effectiveness of interactive simulation games as a proposed novel e-learning approach, both with and without expert guidance, in a University classroom environment.
- Identify appropriate case studies for experimental evaluation of the proposed interactive simulation approaches, using complex adaptive system concepts from Natural Science subjects taught at Stirling University.

1.3 Organisation of Thesis

Chapter 2 will cover general background material for the thesis and will provide comprehensive reviews of related topics that are investigated in the thesis. Computer based simulations and games are already used in various fields as educational and instructional tools to enhance students' learning experience, which will be discussed in chapter 2 with detailed explanations and examples of how computer-based simulations are introduced in different fields for educational, instructional and training reasons. Effectiveness evaluation methods of the interactive simulation interventions will also be presented in chapter 3.

The interactive computer simulation is introduced to students of Stirling University who are studying complex ecology and marine ecology concepts. These students, will learn complex concepts of ecology and marine ecology using interactive computer simulation. Using a novel and different method from how previous students of the same modules were taught. Details of the case studies will be explained further in Chapters 4 and 5 of this thesis. These chapters will detail how the new interactive computer simulation was experimented with and evaluated by the students in a new setting and context. To compare between interactive computer simulation and non-interactive computer simulation. Also, to compare between active use of interactive computer simulation without an expert demonstration and passive use of interactive computer simulation with an expert demonstration was performed.

1.4 Original Contributions of this Thesis

1. The use of interactive simulation was experimentally evaluated in teaching concepts from complex adaptive systems in the area of ecology, as an e-learning methodology to teach university students. In the first study, the use of interactive agent-based simulation was demonstrated. As a teaching and learning tool to teach complex adaptive systems such as ecology in a university classroom environment. The study also evaluated the learning effectiveness of the agent-based interactive simulation. The new proposed interactive agent-based simulation was found to be more preferred by both students and the lecturer of the module as it allowed learners to interact and engage with the simulation more than the non-interactive

simulation and helped the students to learn the complex adaptive systems concepts such as ecological model in an easy and enjoyable way, with some students describing it as a game. We conclude that using interactive simulation is an effective tool to learn ecology complex subjects. Thirty-eight university students successfully used the NetLogo (Interactive) and R (non-interactive) models. Mixed methods (LES + Opinion Questionnaire) were used to collect data during the evaluating process.

2. The use of interactive simulation as a serious game in teaching a mathematical model based on a complex adaptive system concept (population growth) in the area of marine ecology to university students was experimentally evaluated. The second study demonstrated the effectiveness of developing and exploiting interactive simulation as a serious game in teaching a complex concept of marine ecology to 36 undergraduate and postgraduate students in the University of Stirling. A new interactive simulation tool was introduced and evaluated by comparing two methods of using the new interactive simulation; In the first method, the students used the active exploration-based method, where they used the white box interactive simulation teaching game without a teacher demonstration. The teaching game was then followed by a black box interactive simulation, or in the second method, the white box interactive simulation was demonstrated by the teacher with passive viewing (i.e. without the active exploration by the students). This is then followed by using the black box simulation (i.e. the testing game). The results

of the experiment and the evaluation for the learning effectiveness of the new interactive based simulation was done by using mixed evaluation tools in experimental design. The learning effectiveness survey showed no significant difference in the results but the mean of the students in the group who heard the teacher demonstration (DEMO) is higher than the mean of the group who actively explored the simulation without a lecturer demonstration (USE). However, results for the black box test showed statistically significant difference in performance of the DEMO group over the USE group. This shows the learning effectiveness of using the black box interactive simulation after a passive view of a teacher demonstration on the white box interactive simulation compared with the active exploration-based learning method without any teacher demonstration. The open-ended questionnaire showed that students preferred the use of the interactive simulation with teacher demonstration for teaching fishery management.

1.5 Publications

The following papers have been published or accepted for publication during the course of this research:

1. O. Ameerbakhsh, S. Maharaj, A. Hussain, T. Paine, and S. Taiksi, "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, pp. 1–7.

2. O. Ameerbakhsh, S. Maharaj, B. McAdam, A. Hussain, "A comparison of two methods of using a serious game for teaching marine ecology in a university setting," *The International Journal of Human-Computer Studies*, in the special issue on Strengthening Gamification Studies, 2018. (Accepted subject to corrections)

Chapter 2 - Literature Review

2.1 Overview

The aim of this chapter is to review the current state of the art with a view to find the answer to the research question, whether using interactive computer-based simulation in university classrooms as an e-learning tool is effective or not. This chapter covers general background material for the thesis and provides comprehensive reviews of related topics that are investigated in the thesis. A brief history of computer-based simulation in education its definition and associated terms are discussed, it also focuses on different uses of computer-based simulations, types of simulations, the use of computer-based simulations in schools and higher education in general, the use of computer-based simulations in medical health and business management training and the use of it in teaching ecology and marine ecology. The key aim of this literature review is to identify gaps in the recent literature where computer-based simulations were used to teach ecology and marine ecology concepts to university students. In light of the state of the art review a novel technique/approach of using interactive computer-based simulation has been proposed.

2.2 Research Scope of this Thesis

This research introduces the use of interactive computer simulation for effective e-learning in university classroom environments, and furthermore evaluates its effectiveness. Thus, this research encompasses multiple fields that are associated with computer science such as Human-computer interaction (HCI)

and E-Learning [1], [2]. In the following sections I will briefly explain in detail how this research is linked to these fields.

2.2.1 Human-Computer Interaction

HCI is an important field in designing e-learning environments as it combines both social behavioural sciences and information technology. This field focuses on the human: to recognise, respect and integrate a variety of human skills, capabilities, needs and preferences. HCI deals with usability, effectiveness and user performance. The theories and methodologies of HCI enable support in designing and building effective computer systems from the users' perspective. These theories and methodologies focus on the needs of the user and contribute in developing effective e-learning applications and supporting technology in education [3].

This research is related to the field of HCI because it is user-centred, and it investigates the effectiveness of the students' interaction with the interactive computer-based simulation.

The primary research in the HCI field is to investigate the development of computing products and processes that are used by people for different reasons such as work, education or pleasure. HCI has an associated discipline called Human Factors which is also a science falls in the field of engineering [4]. The discipline of Human factors is concerned with investigating the efficiency, effectiveness and satisfaction of using a system designed for human users. HCI is partly comprised of human factors, but also focuses on the interaction between human and computers. HCI has a broad scope as it engages with many different

disciplines e.g. cognitive psychology, experimental psychology, anthropology, sociology, computer science, cognitive science and linguistics [5].

Research ideas in HCI could be categorised by the following types [6]:

- Introducing an interaction device associated with new hardware, for example, an olfactory output, vibratory output or stylus input.
- Introducing a perception method using devices that are tailored for certain senses, for example, visualising data in different types of data charts, methods for colour coding.
- Introducing a system interaction method that is utilised in other software, for example, text scrolling direction such as vertical, horizontal, page turning; or a navigation method such as site map, hierarchy diagram or tabs.
- Introducing an interactive system which is designed for supporting a complex task such as a system that manages proposal, preference collection and allocation of projects done by students or a sketch-based system to draw charts for project management schedules.

HCI is defined in [7] as “is the study of the way in which computer technology influences human work and activities. The term “computer technology” now-a-days includes most technology from obvious computers with screens and keyboards to mobile phones, household appliances, in-car navigation systems and even embedded sensors and actuators such as automatic lighting.”

HCI research ideas could be tested in formal comparative experimental design or by exploratory usability evaluations. Experiments would be for comparative

reasons with the focus on generating data that shows the value of an HCI research idea. Evaluations are not for comparative reasons and the focus is on giving feedback for improvement of a system or to confirm that a system is ready for utilisation [6].

HCI is associated with a discipline which investigates the system design and is referred to as User-Centered Design or Interaction Design. This focuses on the ways of designing a computer technology that is potentially easy and pleasant for human usage. *Usability* is an important aspect in the design discipline. Usability is concerned with the effectiveness, efficiency and user satisfaction with the system. User experience is also part of usability evaluation process such as evaluating the user's experience after using a system that is developed for personal use e.g. when evaluating the experience of an online shopper who used an online business system [7].

One important rule of design is understanding the materials of the design. In HCI, people who use the system are as equally important elements as the other materials used e.g. computer hardware, programming software, tool kits, user-interface and the tools with which the interactive software was created. Every material used requires a certain design to achieve its purpose [8].

The hardware and software technology used are fundamentally important in developing the technology of e-Learning. However, the human computer interaction factor defines whether the ultimate learning efficiency is achieved or not from a user's perspective [9].

2.2.2 E-Learning

Any student who is studying via the utilisation of information and communication technology (ICT) is studying in an e-learning environment [10]. The interactive technologies that are found in e-learning may support numerous diverse types of abilities such as:

- interactive tutorials that are diagnostic or adaptive in feature
- interactive educational games
- simulations or models of scientific systems
- internet access for transactional services and to search
- internet access for providing digital versions of materials that are locally not available
- personalised information and guidance for learning support
- remote control access to local physical devices
- communications tools to collaborate with other students and teachers
- creativity and design tools
- virtual reality environments for the purpose of development and manipulation
- tools and applications for data analysis, modelling or organisation
- electronic devices for assisting disabled learners

All of the aforementioned capabilities could be applied in e-learning using a wide range of different types of interaction [10].

E-learning is defined as the utilisation of any of the new applications or technologies for the purpose of learning or to support the learner [10]. E-learning is important because it has the potential to make a substantial difference in how

learners may learn, how fast they grasp a skill, how easy it is to learn and how much students enjoy learning as it is an important element in learning. This kind of complex technologies will make different types of impact on the learning experience.

It is also suggested that the use of interactive computer in e-learning could be utilised by students to give them an alternative form of active participation in constructing their knowledge. For example, interactive computers can model or simulate real-world systems and transactions, enabling learners to create environments where they can explore, experiment and manipulate [10].

E-learning or the utilisation of technology in education, is to apply information and communication technologies for the improvement of the learning, teaching and assessment process. It has been widely accepted in the last decade [11], [12]. The direction of learning theories has progressed from “*a behavioural approach toward a learner-centred, constructivist epistemology grounded in concepts of situated learning and distributed cognition and social historical – cultural notions of the mind.*” [13].

E-learning has advanced significantly in the last era. Developments in ICT, as well as the requirement for incessant on-demand learning and training, makes e-learning an essential part of modern society. A well-built learning application lets users to practice with user-friendly systems that are capable in performing tasks, and lets students enjoy the process of learning and allows them to master the system. The more HCI is understood, improved usable and effective learning systems will be designed [1].

Research in the area of HCI has a vital effect on designing practical and effective e-learning systems. A poorly designed e-learning system will not motivate students use the e-learning product, nor will assist them to learn from it. A well-built e-learning system makes the process of learning more realistic, easy, usable engaging and challenging. Top-quality interfaces of e-learning systems should contain some features of games; they should also deliver the functional model of task, context and process, to users and encourage the process of exploration and enjoyment of learning. An effective e-learning interface design should also demonstrate interactivity, functionality, learner control, and cognition. These features are important in e-learning systems [1].

The term e-Learning has been used to describe any educational environment in which the process of teaching and learning is taken place in an Internet-based setting [14]. Some authors described e-learning as “the use of digital technologies and media to deliver, support and enhance teaching, learning, assessment and evaluation.” [15]. In this thesis the term e-learning is used in the context described earlier as “The use of digital technologies and media...”. Definitions of computer-based simulation, serious games and educational games will be discussed in depth in the following chapter.

The interactive computer simulation used in this thesis is built to teach concepts of ecology and marine ecology to university students with the specific aim of enhancing the e-learning experience of the students in classroom environment.

2.3 Interactive Simulation

The term “Interactivity” does not have one set meaning, and is a subject of substantial debate between authors [16]. The term interactivity is loosely defined and it seems to be better understood when closely examined [17].

It is argued that interactivity in its narrow meaning means when the learner is engaged with the task e.g., when the student is engaged with a system. This type of interactivity with a system has various forms and levels which are influenced by several aspects of the design of the interactive systems [16].

There are two different types of effects that can occur through interactivity:

1. Content learning – Yacci described content learning as learning that has purpose and focused on having an instructional goal [17].
2. Affective benefits – Yacci go on to describe affective benefits as sentiments and values toward the artefacts that are used for instructions, and which could be dampened or amplified [17].

Interactive computer-based simulation in this thesis refers to when the student is interacting with the content of the simulation, and with the ability to change and interrupt the simulation while it is running. This meaning of interactive computer-based simulation is close to the definition described in “Interactive simulation provides a flexible and user-friendly method to define the experiments performed on the model. During the interactive simulation run, the user can change the value of the model inputs, parameters and state variables, perceiving instantly how these changes affect the model dynamic.” [18]. A similar meaning is also

found in “Interactive simulation of social systems implies a human interaction with an open mathematical model during the model’s simulation run.” [19]. The software used in the case studies of this thesis to run the interactive simulation is NetLogo.

2.3.1 NetLogo

NetLogo is a modelling environment with a programming language for simulating complex multi-agent systems. It is aimed at research and education and is used in many fields and education levels. It is a tool for teaching and research at an undergraduate level and higher [20].

NetLogo is a modelling environment and multi-agent programming language for simulating complex natural and social phenomena, which is effective at modelling complex evolving systems. Models can instruct hundreds or thousands of “agents” to explore the macro-level patterns and micro-level behaviour of individuals that emerge. NetLogo allows people to amend simulations for the purpose of exploring their behaviour in various scenarios and is user-friendly environment for researchers and students who are not programmers to build their own models [21].

NetLogo is a standalone Java application which can run on all major computing platforms. The NetLogo language is a member of the LISP family that supports agents and parallelism (perform multiple tasks in the same time). Mobile agents termed “turtles” move around a grid of “patches”, which are also programmable agents. The agents interact with each other and perform multiple tasks simultaneously. Members of the NetLogo user community have turned these

“turtles” into molecules, wolves, bees, tribespeople, birds, worms, bacteria, voters, passengers, buyers, sellers, metals, cars, robots, neutrons, magnets, planets, shepherds, lovers, ants, muscles, networks, etc. “Patches” have been made into trees, walls, terrain, waterways, housing, cancer cells, plant cells, farmland, sky, desks, fur, sand, etc. Moreover, patches and turtles can be used to visualise and study mathematical concepts, or to play games and making art. Themes addressed include cellular automata, genetic algorithms, positive and negative feedback, evolution and genetic drift, population dynamics, path finding and optimisation, networks, markets, chaos, self-organisation, artificial societies and artificial life. The models all share the core themes of complex systems and emergence [22].

A review of five software platforms was conducted in [23] for their scientific agent-based models. NetLogo was deemed the best platform, having a powerful, easy-to-use programming language, user interface and extensive documentation. It is aimed mainly at creating Agent-based Modelling and Simulation (ABMS) of mobile agents with local interactions in a grid space. The authors even recommended NetLogo for prototyping complex models. This reflects its roots in education, as simplicity is its primary design objective. Its programming language is simplified by its primitives and high-level structures, and It contains many of the capabilities of a typical programming language. NetLogo was designed for models with mobile agents acting simultaneously in a grid space with local interactions over short times being the main behaviour. Although such models are easy to create, NetLogo is not limited to just that. It is also the most professional looking of the platforms [23].

NetLogo Web [24] is a version of the NetLogo modelling and simulation environment, it runs fully in the internet browser. As a replacement for the old NetLogo applet function. The purpose of this web version is to make it easy for NetLogo users to upload their models online so other users can try their model. The Web version works on platforms that Desktop NetLogo version may not work on. For example, tablets, smart phones, and Chromebooks. The developers of the Web version aim for it to have most of the Desktop NetLogo version features.

This version of NetLogo was used in the marine ecology case study as it made it easy for students to run the simulation from any class even from computers where NetLogo is not installed.

2.3.2 Agent-based Modelling and Simulation

Before explaining agent-based modelling and simulation (ABMS), a short insight about its importance and need is required, as well as why researchers are using it in their areas of computer science. ABMS is a recent modelling concept that has increasingly attracted interest over the past decade. The increasing number of articles in modelling and applications journals are evidence of this growth. It is because our world is increasingly complex [25]. Firstly, the systems that we need to analyse, and model are becoming more complex in terms of their interdependencies and conventional modelling may no longer be suitable. Some systems are too complex to model adequately: for example, economic market modelling previously relied upon the notions of perfect markets, agents similar to each other in nature, and long-term equilibrium because these assumptions made them analytically and programmatically easier to grasp. Using ABMS

allows more flexibility and realism. Another example is that data are being organised at lower levels of granularity, with micro-data now supporting individual-based simulations. A third important example is that computing power is increasing exponentially so we can now compute large-scale micro-simulation models that were not possible before [25].

To explain the term ABMS, when explaining the term agents, say there is no agreement on its definition in the context of ABMS. Academics have a difference of opinions in explaining the term “agent” when it is used in models that are “agent-based”. There are significant implications of the term “agent-based” when describing a model in terms of what it could achieve through relatively minor modification [25].

Some researchers say any type of *independent* component, whether within a model or software, is an agent [26]. The behaviour of an independent component ranges from being simple, e.g. simplistic if-then rules, to something more complex, e.g., described by complex behavioural models from cognitive science or artificial intelligence. Some academics [27] say the component’s behaviour should also be *adaptive* to be considered an agent. In this latter view, the term “agent” is limited to components that can learn from their environment and use their experiences to change their behaviour dynamically. Agents should have basic rules governing their behaviour as well as a higher-level set of “rules to change the rules.” The basic rules respond to the environment, whereas the “rules to change the rules” are adaptive [27]. A computer science view of “agent” emphasises the important characteristic of autonomous behaviour. This requires the agents to respond actively and plan rather than be passive [28].

The term “simulation” in agent-based simulation means one in which agent interaction is simulated repeatedly over time, as in system dynamics, discrete event and other types of simulation. However, in an agent-based model, agents interact repeatedly. For example, in ant-colony or particle-swarm optimisation, where agents optimise their collective behaviour when exchanging simple information, the purpose is to achieve a desired end-state, i.e., an optimised system, rather than just simulate a dynamic process without any goal [25].

ABMS is related to many fields including computer science, systems science, systems dynamics, branches of the social sciences, management science, complexity science and traditional modelling and simulation. It relates to Multi-Agent Systems (MAS) and robotics from the field of Artificial Intelligence (AI). However, ABMS is not only connected to artificial agents. It is commonly used in modelling human social and organisational behaviour and the decision-making of individuals [26].

ABMS has roots in Complex Adaptive Systems (CAS) and the idea that “systems are built from the ground-up”. CAS deals with how complex behaviours arise in nature among myopic, autonomous agents. Additionally, ABMS is usually descriptive rather than being normative, intending to model the behaviour of individuals, such as in traditional Operations Research (OR), which seeks to identify optimal behaviours [25].

Agent-based simulation is described as when agents interact with each other with incomplete information [29]. Agent-based simulations commonly model human behaviour or ethology, but can be used in many fields, such as physics

[30], geography [31], and biology [32]. An ABS may have groups of agents; each of which has local intelligence and the ability to assess and act upon the agents and environment around it. It also monitors the behaviour and conditions that emerge from the interactions. For example, a model of food distribution in an ant colony can have behaviours for individual roles such as worker or queen and generate hundreds of agents with corresponding behaviours. The simulation is run virtually in which each agent can interact by collecting, distributing and consuming food [33]. An example figure from a NetLogo simulation adapted from [29] can be seen in Figure 2.1.

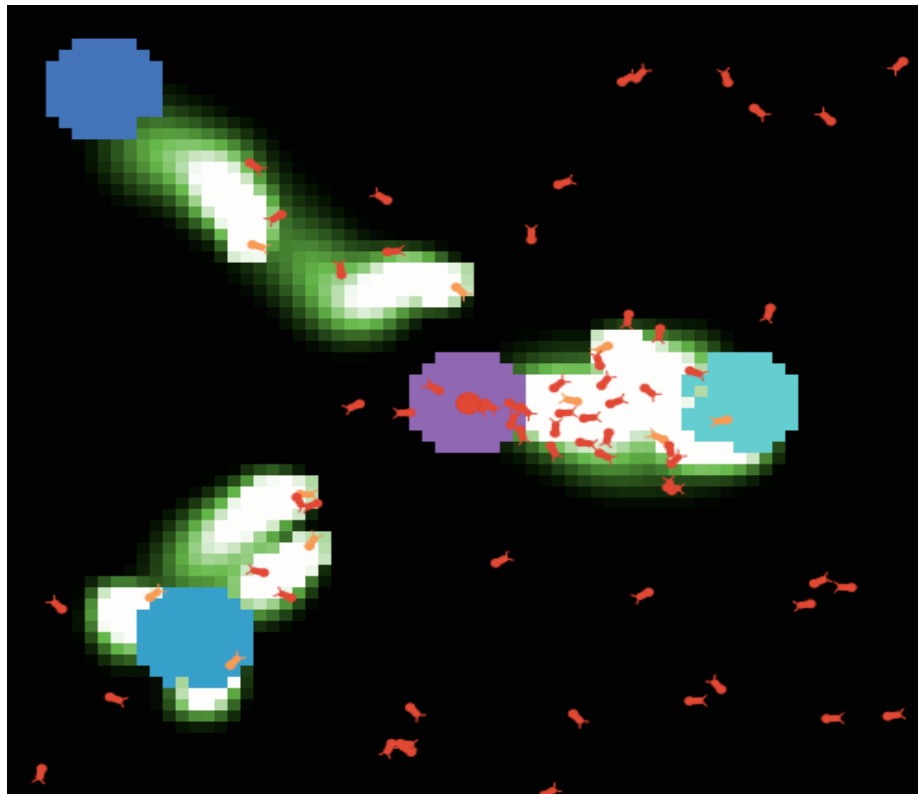


Figure 2.1: ABM of ant foraging [29].

ABS is a very powerful concept, not only for its metaphoric and algorithmic power, but because it is more comprehensible than other metaphors and approaches. This comprehensibility results from the similarity of the ontology of ABS with the

ontology of the real world. For example, contrast this with the ontology of a differential-equation-based model [34]. Differential equation model would be less comprehensible than using ABMS e.g., it needs an understanding of complex mathematical notation and experience with programming such equations.

Good academic science must be communicative, but little work has been done in optimising models for comprehensibility. This is an example of the power of ABS, showing it is much easier for a layperson to understand an ant colony in terms of ant behaviours than in terms of differential equations [35].

That is because of the nature of local simulation, it is not easy to create programs or agent rules to make a solution emerge. As in biological ecology, changing an ABS in a small way often results in larger, unexpected changes. For that reason, the ecology of the system can become unpredictable. Solving problems indirectly and designing intelligence for localised agents demonstrates the difficulties of general search problems, many local maxima, behaviours that cause negative or hard-to-predict side effects, and often the outcome is incomprehensible [36].

2.4 Complex Adaptive Systems

As previously mentioned, ABMS has roots in Complex Adaptive Systems (CAS): in this section the aim is to discuss CAS with some detail.

Complexity theory [37] began in the middle of the 1980s at the Santa Fe Institute in New Mexico, where the study of Complex Adaptive Systems (CAS) became a speciality. Proponents of CAS are largely based in the USA, whereas the European tradition is “natural sciences” in the area of cybernetics and systems.

CAS shares the subject of complex systems across many areas, similar to cybernetics and systems theory. However, the uniqueness of CAS is its use of computer simulations as a research tool, and a focus on systems, such as markets or ecologies, which are less integrated or “organised” than those studied by the older traditions (e.g. companies, organisms and machines).

Complexity arises from the inter-relationship, interaction and inter-connectivity of elements within a system and between a system and its environment [38]. Murray Gell-Mann, in “Complexity” Vol. 1, No. 5, 1995/96, traces complexity to the root of the word; *plexus* means entwined or braided, a derivative being *complexus* which means braided together. The English equivalent is “complex”, therefore complexity relates to the inter-twining of elements within a system and between a system and its environment.

Many systems in the natural world (e.g. ecologies, societies, the brain, the immune system) and many artificial systems (parallel and distributed computing, AI, neural networks and evolution simulators) are characterised by complex behaviours resulting from often non-linear spatio-temporal interactions among a large number of components at different levels of organisation [37].

These systems are known as Complex Adaptive Systems (CAS). The theoretical framework is based on work in the natural sciences, e.g. biology, chemistry and physics). CAS analysis is performed through theoretical, experimental and applied methods (e.g. mathematics and computer simulation).

CAS are dynamic systems which adapt and evolve when the environment changes. You cannot separate a system from its environment, in the sense that

a system always *adapts to* a changing environment. Rather, the focus is on a system *linked closely in an ecosystem* with all other related systems. In this context, change should be seen as *co-evolution with* all other related systems, and not as *adaptation to* a separate environment [37].

CAS deals with: (1) the comparison of real world and artificial examples of CAS to extract common attributes and processes and (2) simplified computer models of natural systems. CAS provides a framework for a class of complex systems and their phenomena, providing principles and computer tools. The field is interdisciplinary, taking information from systems theory, control theory, complexity science and network theory, and also from related fields such as statistical mechanics, artificial intelligence, game theory, and optimisation [39].

CAS studies high-level abstractions of real world and the artificial systems that cannot be examined through traditional techniques. High-level patterns emerge from the nonlinear and dynamic interactions of the low-level adaptive agents.

Generally, examples of CAS come from biology, sociology and economics. Examples include; embryo development, immune system, ecology, evolution, learning in the brain, weather, economy, trading, sociology, culture, politics, traffic, swarms, bird flocking, scientific theory testing, and antibiotic resistance.

As previously stated, computer models are important in investigating CAS where the system is reduced to its essential aspects. The characteristics of CAS are demonstrated by these models and provide a basis upon which to experiment. Modelling approaches created for this include agent-based models (ABM) [39].

Scholars of Complex Adaptive Systems agree diversity is a necessity for complexity. Complexity comes from interacting, adapting and accumulating differences [40]. Therefore, scholars of complex systems encourage diversity. They recognise they are also diverse agents, framing questions differently and bringing discipline-specific tools to understand diversity. Complexity is difficult to control but is possible to guide it in the direction desired.

Many difficult problems [41] centre on CAS - systems with many agents that interact, learn or adapt. A list of problems points to the usefulness of CAS:

- Encouraging innovation in dynamic economies.
- Sustainable human growth.
- Global trade.
- Market systems.
- Ecosystem preservation.
- Internet safety (e.g. controlling viruses and spam).
- Immune system strengthening.

Despite large differences, all CAS share the following features:

1. Parallelism.
2. Large numbers of agents sending and receiving signals.
3. Simultaneous agent interaction.

The aim of this thesis is to identify appropriate case studies for experimental evaluation of the proposed interactive simulation approaches, using complex adaptive system concepts from Natural Science subjects taught at a university level.

2.5 Effectiveness Evaluation of Computer-based Simulation

This research follows on from previous researchers who investigated the effectiveness of using computer-based simulations in teaching different concepts to students of various levels in a classroom environment.

For example, a study [42] reported on the effectiveness of computer based simulations as tools to support high school science students in understanding the complex concepts of chemistry. Investigating increasing the use of a series of computer-based simulations of complex concepts in chemistry.

Another study [43] explored the potential use of computer based simulation in the form of a serious game for sex education. This was carried out to investigate the following: (1) the influence of a newly designed computer-based simulation as a serious game on self-rated confidence for assessing sexual transmitted infections risk; (2) to study whether this differs by age, gender and scores on sexuality-related personality trait measures.

A study conducted in [44] investigating the effectiveness of computer-assisted instruction in comparison with traditional expository teaching also studied the differential effectiveness between male and female students. The aim of the study was to evaluate the effectiveness of computer-assisted instruction in teaching geography to school pupils using a computer-assisted instruction environment called "Micro-PROLOG".

The above studies show that evaluating effectiveness of computer-based simulations or computer-assisted instructions does exist in the current literature and is an important process to assess the effectiveness of the computer-based

simulations on the students learning. In this thesis the effectiveness of using interactive computer-based simulation in teaching ecology concepts to university students in a classroom environment is experimented and evaluated, comparing with the use of non-interactive computer-based simulation. Also, two methods of teaching are experimented, by comparing the use of interactive computer-based simulation in teaching and learning concepts of marine-ecology with or without an expert guidance. To evaluate the effectiveness of using interactive computer-based simulation, and also to identify which methods of using the interactive computer-based simulation are more effective.

2.6 Brief History of Computer-based Simulations

The use of games and simulations in an educational setting has begun since the late 1950s [45]. Games and simulations were not part of the instructional design effort up till 1970. Use of such exercises was first established by medical and business teaching faculties and researchers in the field of sociology who used instructional developments established military services. Due to the great power and flexibility of computer science and its contribution in redesigning games and simulations in a new distinctive and more effective way which created a great interest in the use of games and simulations for educational purposes. Games and simulations are being developed in a way that meets the requirement of modern methods of teaching where the use of effective teaching tool for profound learning is encouraged, where knowledge is constructed based on the student experiences. Games and simulations have the potential of creating an environment for the students to construct new knowledge based on their experience [46]. In the 1980s, due to the advancement in computer technology

capabilities, a variety of problem-based exercises were developed where a none evolving straightforward problem were presented by one or more dynamic diagrams or visuals. This type of exercises are sometimes referred to as simulation models or just simulations [46].

Utilising simulations in teaching transports the learners to another world, where they can apply their knowledge, abilities, and strategies to execute roles that were assigned to them. For example, children may play a game capturing a wicked wizard by searching vocabulary cues, or engineers may run simulations to diagnose problems in a faulty steam plant [47]. Simulations help students to understand the relations between concepts rather than just teaching them facts. This feature makes it a suitable tool to increase conceptual knowledge as it makes students learn based on inquiry approach where they learn in a way that is similar to how scientists do their research. This approach is called inquiry-based teaching which engages students in the process of learning [48]. Researchers have investigated the effectiveness of computer-based simulations in teaching and learning science more than four decades ago [49] for example, a study was conducted in 1972 [50] where the use of computer based simulation in teaching chemistry was investigated. These many years of researching the effectiveness of computer-based simulations in teaching and learning highlights the importance of using computer-based simulations in science education. The reason why researchers continue to explore the effectiveness of utilising computer-based simulations in teaching and learning is due to the enduring development software designers and researchers are making in the field of computer science. For example, the continuing improvements in features and

characteristics of software development. Also, due to the benefits of information and communication technology in general and computer-based simulations precisely. Moreover, due to the potential success of computerising or simulating scientific experimentations and natural phenomena in virtual laboratory environments [51].

2.7 Different ways of Simulations in Education

2.7.1 Definitions

This section provides a definition of Simulation and some of the key terms referenced in the literature review such as: computer simulations, games, simulation games, serious games, game-based learning, Interactive simulation.

There is no clear definition of simulation in teaching literature. The terms simulation and role play are often used interchangeably in the literature and the terms game and gaming in early literature are also found when referring to what is considered today as simulations and role-play exercises [52].

According to [53] The term “simulation” can broadly mean to represent a real system, an abstract system, an electronically generated environment or process. Simulation is viewed by [54] as a representation of real world systems focusing on a certain aspect of reality. A further definition of simulation is given in [55] who describes simulation as “a replicable representation of a process. The representation can be phenotypical or genotypical. If phenotypical, it is a reflection of the process; if genotypical, it is a subset. Thus, a phenotypical representation of employment would have participants employ fictitious persons; a genotypical representation would have them employ each other. Computer

animation might make the phenotypical representation realistic, but it cannot make it real. Genotypical representation, however, is real”.

According to [56] “Simulation” is a technique used in many diverse disciplines and trainings for learning and practice. This technique is used to replace real experiences with guided amplification, these simulations are often of an immersive type, that induce or emulates significant features of the real world in a wholly interactive manner. Immersive here signifies that participants of the simulation are immersed in a setting or task which looks like the real world.

The term “computer simulation” has various connotations. According to [57] there are twenty-one different definitions for “computer simulation” as mentioned in the compilations of definitions of simulations [57]. Computer simulation is defined in its narrowest sense by [58] as “the use of computers to model things”. A more broader definition of computer simulation is defined by [59] as “artefact that embodies some model of an aspect of the real world, allows the user to make inputs to the model, runs the model and displays the results”.

The terms “simulation” and “games” have a different and overlapping meaning associated to them and this overlap brought out the terms “simulation games” and “computer simulation games” as mentioned in [53].

The difference between game and simulation is described in [60] as follows: “a *game is an activity in which participants follow prescribed rules that differ from those of real life as they strive to attain a challenging goal. The distinction between play and reality is what makes games entertaining. A simulation is an abstraction or simplification of some real-life situation or process. In simulations,*

participants usually play a role that involves them in interactions with other people or with elements of the simulated environment.” In addition to the above distinction, a further distinction is given where the term game is described in detail and the contesting feature of gaming is explained as a reason for distinction between game and simulation as explained by [61] “ A game is a fictitious, whimsical or artificial situation in which players are put in a position of conflict. At times, players square off against one another; at other times, they are together and are pitted against other forces. Games are governed by rules which structure their actions in view of an objective or a purpose which is to win, to be victorious or to overcome an obstacle. They are integrated into an educational context when the learning objectives are associated formally to the content and the game enhances learning in the cognitive, affective and/or psychomotor domains. On the contrary, simulation is a simplified, dynamic and precise representation of reality defined as a system. A simulation is a dynamic and simplified model of reality and it is judged by its realism, by its correspondence to the system which it represents. A game is created without any reference to reality, what is never the case for a simulation or a simulation game. Simulation is not necessarily a conflict, a competition, and the person who uses it is not looking to win, what is the case in a game.”

According to [62], simulations, games, and role play exercises are active learning exercises that aim to develop students’ theoretical understanding of a specific phenomenon, collection of interactions, or using student interaction to imitate a socio-political process. They offer an imaginary or real environment to represent a certain condition or situation.

A distinction between simulations, games, and role play is explained in [62], the differentiation is given by describing each term separately. In simulations, the participant is rationally representing a real environment in which political or social interactions happen, with the purpose of enabling participants to immerse in the environment rather than just imagine it or hear about it. In games, they involve competing with instructions on how players succeed in the game exercise. Like in card games, board games, and other active learning exercises. In role play, the participants normally have less roles in preferences and objectives and they must take the effort of developing their character and think about how they would react to the given settings. Interactions in role playing exercises are more focused on interaction like when conducting interviews rather than focusing on goals as in negotiating a treaty. Role play exercises and simulations could be used in a classroom environment, or in a computer supported environment [52].

The term “Game Simulation” is defined in [63], as “*Simulation games represent dynamic models of real situations (a reconstruction of a situation or reality that is itself a social construction). Simulation games help to mimic processes, networks, and structures of specific existing systems. In addition to mirroring real-life systems, simulation games incorporate players who assume specific roles.*”

This definition demonstrates that the term Game Simulation is formed by combining features of games and simulations together. Another term which is associated to interactive simulation is “Serious Games” which is defined by [64] as “*a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives.*” to

distinguish between serious games and computer games some researchers argue that there is a pedagogical element in serious games and not just story, art and software [64]. Pedagogy makes it different from computer games and this pedagogy is a subordinate to story, the entertainment component comes before pedagogy. What is meant by pedagogy is that it involves educational and instructional activities that impart knowledge and skills. Serious games could be applied to various domains for example, healthcare, public policy, strategic communication, defence, training, and education [65].

Another term that is associated to interactive simulation is “Games-based learning” which is defined in [66] as *“games-based learning refers to the innovative learning approach derived from the use of computer games that possess educational value or different kinds of software applications that use games for learning and education purposes such as learning support, teaching enhancement, assessment and evaluation of learners.”*

Another distinction between simulations, games and serious games is given by [67] simulations use scenarios that are structured rigorously with a very advanced set of rules, tasks, and tactics which are designed carefully for developing certain capabilities that possible to transfer directly into the real world. Games are activities that are enjoyable and engaging, normally used for the sake of entertainment, but players could also experience a certain set of ideas, tools, or motions. Games are played in an artificial (virtual) environment controlled via certain rules, methods of feedback, and tools that are required for supporting them. Serious game is a mental competition, played using a computer following

certain rules, in an entertainment form to advance education, government or corporate training, public policy, health and tactical communication objectives.

The reason why each term was described with some detail in this section and the distinctions of each term were mentioned because some researchers view games, serious games, games-based learning and game simulations as they are all from the same range [68]. They hold this view because of the association found between computer-based simulation and the other terms.

According to Connolly et al [69] Computer-based simulations and computer games are built on the following educational theories:

- Constructivism is an educational approach that has its roots in philosophy, epistemology, and pedagogy, where the process of learning is seen as an active process where learners construct new concepts or ideas on the basis of their current or previous knowledge. The learner chooses the information and transforms it, constructs the hypotheses, and makes judgements, relying on a cognitive structure in doing so.
- Situated Learning, where the learning is done within the activity, context and culture where it occurs [70].
- Cognitive apprenticeship is an instructional learning theory where the processes of experts and how they handle complex tasks are modelled. Focusing on the cognitive and metacognitive skills involved, it also requires that the processes that are usually carried out internally to be externalized. Students will learn on their own by observing the processes of how experts think and carry out their skills [71].

- Problem-based learning is a learning theory with an instructional strategy in which real world situations are contextualised and significantly posed, and allows learners to be provided with resources, instructions and guidance as they develop problem-solving and content knowledge skills [72].

All of the above learning theories could be found in educational computer-based simulations and game-based e-learning environments.

2.7.2 Application Areas of Computer-based simulation

There are various areas where computer-based simulations are utilised. As explained in [73] Computer based simulations are utilised in research, design, analysis, training, education and entertainment.

- Research: Using simulations in research is important to explore the precision and usefulness of new analytic systems that could be useful in the design process and for analysis; it includes the creation and verification of systems models. Simulations could be used in research as tools establishing trends, demonstrating the relationship between system parameters or to predict the future.
- Design: Simulations are used by designers for characterisation or visualisation of a system that not yet established to attain an optimal solution. E.g. the use of simulation for manufacturing modelling to

investigate, by designing different facility machines and storage bins, times to prepare and transference of materials, for efficiency improvement.

- **Analysis:** The use of simulation in analysis is for determining a current operating system's capability or behaviour or for verifying the accuracy of the system. Furthermore, it might be used for testing real life systems in severe or even insufferable conditions. Behaviour modelling is done by collecting data from the system. For example, enhancing hospital management, through the simulation the schedules of staff, doctors, patients and equipment.
- **Training:** Simulations could be used in training for creation of situations that people face on their jobs and these simulations let trainees practice a series of actions or to train them how to respond to an event correctly. Training can allow trainees make possible fatal errors without real injury. A variety of training could be performed using simulations, from highly complex training using customised hardware for example, flight simulators, or replicas of nuclear power plants to easier training available on computers for example, IT or soft skills training.
- **Education:** Educational simulations, let's students learn how to do something and why. Simulations allow students to explore models and experiment, by creating and testing hypotheses and constructing their own understanding of the simulated system. Simulations could be tools for teachers they use for the demonstration and explanation of complex and dynamic systems behaviour. Any simulation can potentially be used in education at any level.

- Entertainment: Computer simulations used for entertainment for example, war games, arcade games and role-playing games need a model of an imaginary world that is consistent. Simulation techniques are used by many in training, design and analysis e.g. for control and optimisation. Strategy games sometimes have complex computer models.

This chapter focuses on the use of computer-based simulation in education and training in different fields to review how other researchers used compute-based simulation and in which areas and how they evaluated it.

2.7.3 Ways of using computer-based simulations in education

There are various forms of computer-based simulations available, from two or three-dimensional simple shape simulations to highly interactive simulations. These simulations could be experimented in laboratory experiments and research environments. Several types of computer-based simulations are mentioned in the literature, which allow instructional designers to utilise them for accomplishing either behavioural or cognitive instructional objectives [74].

Some authors describe computer-based simulations in educational context as an instructional tool that eliminate undesirable components of real world situations to allow learners to reach predetermined learning outcomes [75].

Computer-based simulations has a powerful technique that allow learners to study some aspects of the world by replicating it or imitating it. Computer-based simulations not only motivate learners but also, allow learners to interact with them in a way that is like how they would react in real life situations. They also,

simplify reality by allowing learners to omit or change details. Which let students learn procedures such as, how to solve problems, understand characteristics of phenomena and ways to control them, or learn tactics of how to react in various situations [76].

The simplification feature in simulations allow students to focus on important information or skills which makes learning easier and makes simulations appropriate tools for accomplishing simplified cognitive and behaviour tasks [77].

On the contrary to the opinion above, some constructivist pedagogy authors describe educational computer-based simulations as a simulated real-life scenario that is displayed on the computer, where the learner plays a real role carrying out complex tasks. This viewpoint, state that simulations should imitate the complexity of the real-world situation so that learners can struggle in learning to reach higher order of cognitive skills such as inquiry, which is considered as an essential skill in scientific education and learning. These simulations take learners through an environment in which they conduct several integrated tasks to learn complex skills in actual problems or inquiries [78] [79].

2.7.4 Types of Simulations

Different authors have categorised simulation into several types and each type is related to a pedagogy either an instructive or constructive pedagogy. According to [80] educational computer based simulations have been categorised into four types:

1. Experiencing Simulations: used to set the affective or cognitive stage for future learning, and these programs are used to lead the formal presentation of the material to be studied.
2. Informing Simulations: used to transfer knowledge to learners. According to [80] it is more appropriate to incorporate informing simulations in an environment that is supported with tutors like in classrooms or labs.
3. Reinforced simulations: used to strengthen certain learning objectives, it is commonly used in repetitive practice. A series of stored or generated exercises are presented to the student to complete. These simulations are designed to adjust to the student's knowledge level and to track progress.
4. Integrating Simulations: used by students for applying and relating the skills gained from the actual information and principals they learned. This type of simulation seems to be predominant for gaining problem-solving skills.

According to [46] educational computer-based simulations could be categorised into two types:

1. Symbolic Simulation: when the student is not actively participating in the simulation environment. Though students could be executing some of the tasks, but they will not be part of the evolving event. For example, to predict the population trends in a simulation of demography.
2. Experiential Simulation: when the student is actively participating and immersing in the complex and changing environment. This type of simulation allows students to perform complex problem-solving tactics when participating in the simulation. This simulation also, develops the

students' skills of how to organise and manage their own learning and thinking, and in increases their cognitive strategies.

According to [81] educational computer-based simulations are divided into two main types:

1. Conceptual Models: when the simulation hold concepts, principals and fact that are related to the system.
2. Operational Models: when the simulation events include series of cognitive and non-cognitive operations. Operational models are normally used in experiential learning; in a discovery learning environment mainly, to find conceptual simulations.

According to [74] Computer-based simulations reflect either instructive or constructive pedagogies. The following table will show which type of simulation belongs to which pedagogy.

Authors	Instructive	Constructive
Thomas & Hooper [80]	Informing Simulations Reinforcing Simulations Experiencing Simulations	Integrating Simulations
Gredler [47]	Symbolic Simulations	Experiential Simulations

De Jong & Van Jooling [81]	Operational Simulations	Conceptual Simulations
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Table 2.1: Types of simulations and related pedagogies [26]

There are different types of computer-based simulations that have been used in various studies depending on the pedagogy of the computer-based simulation. The case studies in this thesis reflected on both types of pedagogies. E.g. the case study presented in Chapter 4 based on the use of interactive agent-based simulation for constructive learning, whereas the second case study presented in chapter five is based on the use of white box simulation game for instructive learning and a black box simulation game for constructive learning.

2.8 Use of Computer-based Simulation in Education

This section focuses on reviewing the literature for use of computer-based simulations or games in school and university education in general and in teaching ecology and marine-ecology in specific.

Different databases were used to conduct the search e.g. Google scholar, Science direct, Taylor and Francis Online and IEEE Xplore Digital Library and thousands of literatures were found.

The terms used during the search for this review “simulations in education”, “computer simulations in education”, “games in education”, thousands of papers were found. Then the search was narrowed down, by using the terms “simulations in ecology”, “computer simulations in ecology”, “games in ecology”

and “simulations in marine-ecology or aquaculture or fishery management”, Also, the following terms were used “computer simulations in marine-ecology or aquaculture or fishery management”, and “games in marine- ecology or aquaculture or fishery management”. Relevant empirical studies were included in this review based on investigating the effectiveness of computer-based simulations in science education and other fields such as, business training, medical training, and teaching of ecology and marine ecology concepts.

In the next sections literature review encompassing computer-based simulations and games were (utilised in school or university education) will be brought to light. Computer-based simulations in general and specific research pertinent to teaching ecology and marine-ecology concepts will be discussed.

2.9 Computer-based simulation in School Education

This section presents various examples of using computer-based simulation in school education where they were used to teach different subjects to various age groups and the impact and effectiveness of its use was investigated. Computer-based simulations were used by students in their classes, because they play a significant part in building their skills of inquiry and in creating virtual experiments for students [82].

There are several cases in the literature where computer-based simulation has been used in school education. E.g. The study conducted with primary school students by [40] in which they describe a software called NetTango which was developed with the NetLogo Agent-based Modelling and Simulation software,

designed specifically for primary school students to use on a multi-touch table-top touch screens called “Surface” developed by Microsoft.

In the aforementioned study, they reviewed literature on using interactive table-tops multi-touch screens for learning and they presented examples from the exploratory study they conducted with 28 children (ages 6-10) they stand around an interactive table-top multi-touch screen, with their eyes fixed on the screen and with their bodies leaning over the table-top screen. Watching little wolves and sheep roaming across the screen. One of the children shouts, “Save yourself, little guy!” Another child asks, “Why are our wolves dying out?” One child responds, “Old age!” while another says, “No, they are not getting enough energy from food!” So, the children explored a simulation of a predator-prey ecosystem using an application called NetTango, on a multi-touch table-top screen that was designed for engaging primary school children in a collaborative exploration of agent-based models and simulations. The study introduced a new table-top simulation application for children to play with and explore, and evaluated children’s playful explorations within its discovery spaces, the study concluded with the following: use of computer-based simulations (in this case, table-top learning environments) is receiving increased attention of researchers in software designing communities, The novelty of this medium at the time of conducting the study made designing effective simulation educational applications challenging and overcoming these challenges is possible through research.

While conducting the study, the researchers encountered some challenges during observing the children’s playful exploration and found two challenges: 1)

children got distracted and lost while exploring the inquiry space, 2) interference of children with one another when working together on the multi-touch screen.

The researchers suggested solutions to those challenges:

1. for the children's lack of systematic by suggesting some improvements to the simulation where adding a restriction that limits children to only be able to change one parameter at a time. Once they have tried all the variables, and understood their effect on the system, a teacher could remove the restriction, which will help the children to develop a greater understanding of exploring the space.
2. for the interference because of excessive interactivity, they suggested a tweak to the design of the interactive simulation model by limiting the interactivity of the graph and the world window which will stop children from playing with the window screen, as well as retain them from getting in the way of other children who would like to watch the simulation.
3. Providing different views of the entire Modelling and Simulation environment, to show the salient features of both the experiment and exploration spaces in the simulation. Thus, explorers would need to toggle between views to explore them, and that will solve the problem of equal-saliency. As it is important to view the numerical values of the variables to visualise the simulation.

Another example of using computer-based simulation in teaching children is a study which was conducted on high school students by [83], where they used a computer-based simulation game called "BioWorld" developed for high school students learning biology. BioWorlds simulate a hospital environment where

students can exercise the knowledge they have learned about body systems and practice it to solve problems which will assist them in knowing the reason of diseases. the software is a complementary software to the biology curriculum where students work collaboratively to collect evidence for confirmation or refutation of their hypotheses. By attempting to solve simulated cases in BioWorld.

A total of 40 Biology students from grade 9 studying at an all-girls private school in a metropolitan city participated in this study. The study examined students' use of computer-based simulation game BioWorld in solving problems associated to the digestive system. Analyses of student actions and verbal dialogue were carried out to identify the types of features within the BioWorld system that were very encouraging to scientific reasoning and learning. An exploratory analysis of the types of help provided to students by their teacher, researcher, and use of the computer-based simulation BioWorld on its own was conducted to evaluate how scaffolding influenced actions of students. The teacher designed the study by allowing students to choose their own partners for collaborative work, resulting in 20 groups in total. The sample was then reduced due to limitation of instructors. Data were consequently examined from 6 groups; three groups from each classroom, which led to 2 teacher-guided groups, 2 graduate student investigator-guided groups, and 2 BioWorld-only groups.

The teacher selected these 6 groups as being suitable for comparison in terms of their previous grades and ability to articulate their understanding. Because of the small sample size, it was impracticable to include the class variable together with the other independent variables of interest in a single analysis. Thus, a one-

way MANOVA with class as the between-subjects factor was performed to examine whether there was a main effect of class on the dependent measures. An alpha level of .10 was adopted to compensate for the small sample size. Multivariate or univariate differences were not found for the class variable, consequently the data were collapsed across class for all subsequent analyses.

They performed a Pearson correlational analysis to examine the effect of the features of BioWorld from the perspective of relationship between group and expert actions. This analysis showed a significant correlation between proportion of expert symptoms gathered during problem representation and overall evidence gathered that was expert-like ($r= 0.59$, $p= 0.002$). The declarative knowledge gained in the library was positively correlated with the proportion of expert-like diagnostic tests ordered ($r= 0.42$, $p= 0.04$). Therefore, declarative and procedural knowledge as defined in this study were correlated. Furthermore, those students who scored high on collecting expert evidence also scored highly on expert-like diagnostic tests ordered ($r= .49$, $p= 0.02$).

The study findings suggested that (1) initial problem representation, as identified by symptoms that students select as relevant to their current hypothesis, is related to the amount of expert-like evidence gathered overall, (2) information gathered in the library is related to whether or not appropriate diagnostic tests are taken, (3) the ability to select relevant from irrelevant information is indicated by the proportion of expert-like evidence collected as it relates to total number of symptoms entered, and (4) final arguments were examined in terms of expert-like evidence selected.

they summarise their study with the following comments, the exploratory information gathered from their study on human tutoring conditions compared to use of computer-based simulation game BioWorld alone were preliminary; nevertheless, this exploratory information provided a direction for more empirical studies of the effects of tutoring on learning in this type of problem-based computer-based learning environment. In addition, the study recommended an investigation of better ways for students to learn, with human scaffolding or without. Highlighting the need for more future follow up studies using BioWorld with larger samples [83].

This study is an example of the difficulty of conducting empirical research to study effective use of computer-based simulations. Especially, when running class experiments or interventions because of unpredictability in controlling the sample size. Also, the data collected in this study was quantitative only involving same level student from different classes and a comparison of three different method of learning the concepts which gave each groups advantages and disadvantages in the learning process which could rise concerns on the strength of the study for example, in this study, the instructors were of different expertise level and the students who had human tutors got the advantage of getting recommendations that were not possible for the students who used the computer-based simulation as a scaffolding tool which could affect the performance of the students.

Another example of using computer-based simulation in school classrooms is the study conducted by [84] to investigate the impact of computer-based simulation on the students' science process skills, their academic achievement and the students' cognitive developmental stage was also measured in the investigation.

The study sample size involved 181 students from five different Fourth-Year classes (aged 15 years) of a secondary school in the country of Israel. Students were distributed into two groups, an experimental group (two classes; N=82: 68 girls and 14 boys) and a control group (three classes; N=99: 80 girls and 19 boys).

The experimental group studied using the computer-based simulation environment and using a blended learning method where they used laboratory experiments and computer simulated experiments. The control group used the traditional classroom/laboratory method only.

The computer-based simulation used in this study is called 'The Growth Curve of Microorganisms' (TGCM) it was designed by some of the team members of the project. A laboratory assistant and a technician were available with each group for technical assistance. The duration of the study was the same for both groups. Although, both groups used different learning methods, the experimental group and control group studied the same learning material. However, the control group did not practise working with the computer-based simulation and instead did their experiments without computers as shown in their textbook.

Three biology tests were performed, and results were gathered from all tests: (1) students' knowledge on the topic of microorganisms was measured using an academic achievement test by means of a pre-test and post-test, (2) students' cognitive stages (concrete, transitional, and formal) was measured with a videotaped group test (VTGT), and (3) students' science process skills on the

topic of microorganisms was measured using a biology test of science processes (BTSP).

The results of the study showed that computer-simulated experiments could enhance cognitive learning. Students who used a computer-based simulation environment showed integrative and complex reasoning, which is normally very difficult for students in Fourth-Year who are doing laboratory work. The results for the cognitive stages of students, showed that students in the concrete and transitional operational stages from the experimental groups have achieved significantly higher scores than students from the control group, with effect sizes of 2.66 and 2.83, individually. There were no significant differences found in the mean scores between the experimental group and control group in the formal operational stage. Therefore, the study proved that computer-based simulation is more effective for the lower cognitive groups only.

Teachers who taught in the experimental groups said that students who used computer-based simulation showed confidence and a positive attitude towards it, but the study did not systematically investigate the attitudes and self-esteem of students.

This study used a performance-based assessment of learning using tests as a quantitative data collection tool to evaluate the performance of students who used computer-based simulation software in a blended learning environment, against those who used a traditional learning environment. The comparison was done in a within-year (two groups) comparison using five different classes from the same year level (Fourth-Year) and dividing them into two groups an

experimental and control group. This type of experimental design evaluation is not always possible if the sample size is small, for example when conducting similar study with university students in a smaller group which results in some studies using different evaluation methods.

One more example of a study investigating the effectiveness of using computer-based simulation, comparing it to traditional teaching methods is a study conducted by [85], where they investigated the achievement of 248 secondary-school students in Fifth and Sixth-Year, studying the subject of molecular genetics. Students were divided into three groups and were taught the same science content but with different methods. The first group were the control group containing 116 students taught in a traditional lecture format. The second group was the experimental group containing 61 students and used a computer-based simulation. The third group had 71 students and used static illustration activities with models and pictures without computers. Three instruments were used for evaluation; a multiple-choice questionnaire; an open-ended questionnaire; and interviews. Five questions from the multiple-choice questionnaire were used as a pre-test and were given to the students before learning the molecular genetics topic. The rest of the multiple-choice questionnaire and open-ended questions were given to the students after the teaching of molecular genetics. The questions in both instruments were categorised under three groups of subtopics and the results showed that students who participated in the experimental groups and used computer-based simulation enhanced their knowledge in the subject of molecular genetics in comparison to the control group who were taught in the traditional lecture format. Nevertheless, data from the open-ended questions

showed that the computer-based simulation activity was significantly more effective than the picture-and-model illustration activity. Based on these findings, their study concluded that it is advisable to use computer-based simulations in teaching molecular genetics, specifically when teaching the concepts of dynamic processes. Nevertheless, students who were engaged in using picture-and-model illustration activities can still improve their achievement compared to the traditional lecture format group.

This study used a mixed-method approach to evaluate the use of computer-based simulation, using three instruments for evaluation; a multiple-choice questionnaire, an open-ended questionnaire and interviews. The comparison was done between three groups from different levels of school education; Fifth and Sixth-Year students. They were divided into three groups: a control group taught in a traditional way, an experimental group taught using computer-based simulation and a third group taught using static illustration activities with models and pictures without computers. This experimental study was conducted in school-level education and with a large sample group, where students were at different levels in the same subject, because some were from different school years, which could affect their level of background in the subject and suitability for comparison.

Another study conducted in [86] investigating the effectiveness of NetLogo simulation as a tool for introducing Greek secondary-school students to (eco)systematic thinking. In this study it was used to assist students from different levels of achievement to understand the way some simple ecosystems are designed, Also, to conceptualise the complexity features of ecosystems and how

to model the systematic behaviour of such ecosystems. Their study was part of a broader study investigating the effectiveness of the teaching of ecosystem complexity to secondary-school students using computer-based simulation and technologies.

Ten students (aged between 16 and 17) participated voluntarily in the study from different secondary schools and they were studying the second class of the Greek Lyceum. According to the researcher both groups had similar socioeconomic status, gender mix and school-grade achievement, which made them suitable for comparison. Each one of the groups was taught separately by the first of the study authors, for 16 hours of teaching, and he gave each student four worksheets - one for each quartet of teaching hours, which they finished during the instruction process. The students who worked using computer-based simulation were divided into groups of two or three, based on availability of computers. There was no case of a student sitting alone at a computer screen without a partner. Moreover to the printed worksheets, the answers of the students and the classroom discussion were audio-recorded by the researcher.

Students used specific models from NetLogo models' library with instructions from their teacher. They were instructed to run the NetLogo simulation doing certain things with the models. While running the simulation students were also answering questions on worksheets given to them by the teacher. Evaluation of the worksheets' responses and the post-teaching evaluation of the students was done by the researcher. Both oral (recoded) and written responses were evaluated using an evaluation sheet. The findings of the research were encouraging and proved that the NetLogo simulation helped the students develop

a better understanding of ecosystems' complex/systematic behaviour, and to some extent it gave students the capability to analyse the systematic relations within simple ecosystems and to build analogous relations in other simple ecosystems.

This study used a two-group, within-year evaluation to evaluate the learning effectiveness of using computer-based simulation and qualitative data was collected by use of tape recorders. The study was limited because of the small sample size, which did not allow the study to draw general conclusions and made it more of a case study. This research showed that the use of NetLogo computer-based simulation as a teaching environment can possibly help secondary-school students to understand structures of simple ecosystems, and can potentially help them in acquiring or slightly improving their skills on representing and even constructing models. The results were triangulated with the results of using other modelling tools other than the NetLogo System Dynamics Modeller, for example the Stagecast Creator (SC) [87], which was utilised for students in primary school level. The oral answers of the students were used in the survey as an encouraging feedback with respect to the use of the software as a tool in understanding the model.

The studies presented in this section were conducted with primary and secondary-school level students to evaluate the use of computer-based simulation in comparison to traditional ways of teaching i.e. without a computer.

The studies used different methods of evaluation to investigate the effectiveness of computer-based simulation, based on students' performance where

quantitative data was used to measure the students' performance using tests as a measurement. Interviews were used in some of the data to measure the students attitude towards the use of computer-based simulation and one study audio-recorded the students' answers to evaluate their performance.

2.10 Computer-based simulation in higher education

In this section, a review of some examples from the literature will be presented where computer-based simulations were used in higher education to teach various science subjects in classroom environments.

One example is a study conducted by [88] in which they used a new computer-based simulation program called "Connected Chemistry" and investigated the impact of its utilisation on the students' understanding and application of chemistry concepts. The study was done with a group of six undergraduate students (two third-year students and four fourth-year students). The simulation gave the students a chance to discover and observe the simulated interactions by enabling them to acquire a good understanding of chemistry processes and concepts in the classroom and laboratory environment. The simulation showed the chemical equilibrium concepts. The methods used by researchers in the study to collect data were the observation of the students and interviewing them.

It was a small study that explored the potential benefits of computer-based simulation in teaching chemistry concepts to students in higher education. A 90-minute interview was conducted with six undergraduate students studying for a science degree. The interview had three parts and it was about the concept of chemical equilibrium. Some of the common misunderstandings about the

concept of chemical equilibrium came up during the interview. The evaluation was done to examine their knowledge before introducing the computer-based simulation program when the students were relying on memorising facts to explain chemical equilibrium concepts and strict procedures for solving chemical equilibrium problems, and then after using the computer-based simulation “Connected Chemistry”.

The results showed that by using computer-based simulation, students employed problem-solving techniques. Students also showed improvements in defining chemical equilibrium, and characterising reasons that affect equilibrium. Overall, the study indicated that using computer-based simulation in teaching chemistry concepts is a helpful tool in promoting conceptual reasoning.

Another example of using computer-based simulation in higher education is the study conducted in [89] where a NetLogo multi agent-based simulation program was used to allow students training to become teachers to interact with the simulation model in a more interactive way. Students played the role of an agent when they were running the simulation. The purpose of the simulation was to investigate the depth to which learners can understand basic concepts of ecosystems, through the slight effect and/or interaction with simple models of NetLogo, and to assist the learners to act like agents to be able to build an ecosystem of their own. Participants were not required to write any code when running the simulation, they just interacted with the interface and applied some choices, then were interviewed by the researchers for data collection.

The study was carried out with a sample of 17 higher-education students in Athens studying to become primary school teachers. This study was part of a larger research, with data collected through semi structured interviews. During the interviews, users were given worksheets and access to computers, where three NetLogo models were installed. Students gave oral answers to the interview questions, which were recorded by the researcher using a digital recorder. Students also provided answers on the worksheet and there were PowerPoint slides with menus on the screen from which choices were made. This decided what the behaviour of the agent(s) should be in the next execution of the model.

The results of the study were encouraging and showed that students understood the concepts of natural and environmental system models by understanding the behaviour of agents and they were capable of building models of ecosystems. Also, by using simple NetLogo simulation models and their variations, and by navigating through interfaces which were created for specific circumstances, students possibly learn how to act and think like members of ecosystems and therefore understand the functions and behaviour in a better way.

One more example of using computer-based simulation in higher education, is a study conducted by [90], in which they investigate the learning of undergraduate students of theoretical content in materials science by using a simulation developed in NetLogo, called "MaterialSim", where students design their own models of scientific phenomena. The purpose of the simulation was to assist students in building models using the simulation software and investigate

common university-level subjects of material science such as solidification, crystallisation, crystal growth and annealing.

The study involved design research and empirical evaluation. The researchers conducted an empirical investigation over three years (2004, 2005 and 2006) with 21 undergraduate-level students, who enrolled in a material science course of sophomore level. The purpose of the study was to explore an engineering course at undergraduate level using the simulation software “MaterialSim”, in which they explored; (1) the students’ learning outcomes when engaged in scientific investigation when interacting with the simulation software MaterialSim, (2) the effects of students coding their own models instead of only interacting with the simulation program, (3) the advantages, characteristics and trajectories of the knowledge of scientific content that is articulated in epistemic forms and representational infrastructure unique to the sciences of complexity, and (4) design principals of the simulation software: What principals administer the designing of an agent-based simulation learning environment generally, and specifically for material science?

Data was collected via survey, pre-interview, interaction with the pre-built computer models, students’ construction of new models, and a post-interview. The results of the study suggested that agent-based simulation approaches in representing knowledge offered a fundamentally different way for students to engage in scientific investigation. Also, exploring and learning about just a few simple fundamental rules of natural phenomena, and having access to a computerised simulation to manipulate, represent, combine, and analyse them, appears to be a more procreative method for students than the existing teaching

approaches in materials science and engineering that employ numerous aggregate, equation-based representations in use at the time when the study was conducted.

This study chose a quasi-experimental design by comparing students' learning before and after the use of computer-based simulation to evaluate its effectiveness. They investigated undergraduate students' learning of theoretical content in materials science through programming their own computer models of scientific phenomena. The evaluation was done using the qualitative data collection method.

One more example of using computer-based simulation in higher education is the study conducted in [91] where they used a program called "Netlogo Investigations In Electromagnetism" (NIELS), a computer-based simulation of emergent multi-agents-based computational models. The models of the simulation are related to phenomena such as; 1) electric current, 2) resistance as emergent from simple, 3) body-syntonic interactions between electrons, and 4) other charges in circuit.

The study involved using NIELS in a university physics course, in which the ability of an emergent levels-based approach was highlighted as a simulation system that provides students with a profound, professional understanding of the relevant phenomena by relying on what they have learned. The purpose of the simulation is to make students familiar with the concept of electric potential energy and Coulomb's Law. Students used the simulation model for interaction with the test charge of variable magnitude to act or virtually become as a nucleus

that is infinitely heavy, and positively charged. The position of the nucleus is controlled by the students via the computer mouse. Both of the charges (i.e., the test charge and the positively charged nucleus) interact by the use of Coulomb's Law, which says that the product of the magnitude of the charges is directly proportional to the force between the two charges and inversely proportional to the square of the distance between the centres of the two charges. Permittivity is a constant of proportionality and is contingent on the medium between the two charges and their electrical properties. Learners have the option of selecting the medium in which both charges are set, which will help them identifying the role of permittivity. When they run the models, they will see three plotting windows instantaneously plot the possible energy of the test charge against time, Coulomb's force between both charges against time, and the distance between the charges against time. Learners in this simulation model interacted with the model using the "electron's trajectory" to guess how the distance between two charges is proportional to the force between them; Also, they conduct trials testing how the Coulomb force hinges upon features of the test particle for example; (1) mass of the particles, (2) magnitude and sign charge of the particles and (3) the distance between the two charges.

The study was conducted during the first three weeks of a class of physics with 46 students at Midwestern University. Data collection was done via mixed method tools including interviews, which was done in a quasi-experimental design. Results of the study showed that students who used the simulation model NIELS showed better understanding of the concepts in terms of being able to

explain the relevant phenomena than those who did not use the simulation model.

A study conducted in [92] investigating the use of computer-based simulation to improve students' abilities in foreign languages, the study involved 30 higher-education students, studying at the faculty of Technological Equipment and Building Equipment (TUCE) in the Technical University of Civil Engineering, which is located in Bucharest. The aim of the study was to investigate the advantages of using computer-based simulation to improve students' abilities in foreign languages such as English, German and Spanish. The goals were to help students to learn faster and more easier, and also to investigate the efficiency of the (computer-based simulation) pedagogical approach and whether is it effective time-wise (i.e. whether their learning improved faster or whether this method was more time consuming). Data collection was done in three stages; (a) a pre-learning lever was assessed to determine the level of the student in the language for new vocabulary acquisition, (b) a simulation of the new context was presented for vocabulary acquisition in for of active learning and language awareness, (c) the obtained language skills were assessed. The students were assigned to two groups randomly; a control group and an experimental group. Students in the control group were taught a vocabulary from foreign language in a traditional teaching method whereas the experimental group were taught using a computer-based simulation method. The results of the study showed that students' abilities in foreign languages were enhanced in both groups but the experimental group who used a computer-based simulation learned faster and more easily than the control group.

One more study conducted in [93] where the effectiveness of utilising computer-based simulation to teach students in higher education was evaluated. They investigated the effectiveness of computer-based instructional simulation by comparing between students learning in traditional learning environments, also blended and fully online learning environments. They chose a casual-comparative design for their study to establish whether students who used a computer-based instructional simulation in blended and fully online environments learned better or students who learned in a traditional classroom environment learned better. They ran the study for a six-year period between late 2008 and early 2014. The study was conducted with 281 undergraduate business students who self-enrolled on a 200-level microcomputer application module. The overall results of their study supported previous studies performed by other researchers ([94], [95], [96]) which showed that computer-based simulations are very effective when used in combination with traditional lectures and in blended learning environments.

One more study conducted in [97] investigated the use of computer-based simulation in the form of a serious game simulation as a teaching method in pharmacology. They conducted a pilot study exploring the learning of students using the simulation to be introduced to major pharmacological principles. Seventy-nine undergraduate students participated in the study, who were enrolled in a pharmacology theory course. A pre-post-test design was used to evaluate the knowledge of the students before and after using the simulation, and a 13-item 5-point Likert scale questionnaire was used to evaluate the students' satisfaction and self-confidence. There was a significant difference between the

pre and post test results as students scored high scores after the simulation. Students were also satisfied with the design element and were confidently engaging in the activity. They concluded their study stating that serious game simulation can be an effective teaching tool and a promising emerging educational method.

This section presented six different examples of investigating the effectiveness of using computer-based simulation in higher education;: the connected chemistry study, the future teachers study of agent-based simulation in ecosystems, the MaterialSim study, the electromagnetism study, the foreign languages teaching case study, the comparative study between students who used computer-based instructional simulation in hybrid and fully online environments, students who learned in a traditional classroom environment to investigate who learned better, and the use of computer-based simulation in pharmacology.

2.11 Use of Computer-based simulation as a tool for training

This section focuses on providing examples from the literature of using computer-based simulation in different fields where it was used for training. Computer-based simulations have great potential as a tool for creating highly-relevant training contexts for training programs, where trainees are actively participating in the learning process [98].

One of the fields of training where computer-based simulation could be applied is medical training as mentioned in the research conducted in [56], where they state that computer-based simulation trainings has created a new educational

and training application in the field of medicine. Practises based on evidence can be set in action by using algorithms and protocols, and they can practise it using computer-based simulation applications. For successful computer-based simulation training, it should be integrated into traditional educational programmes. Clinical faculties should be involved in the early stages of the development process of the simulation program. As there is potential in virtual reality learning and computer-based simulation environments, it will help in creating the curriculum and it will assist in engaging the wider medical community. Teamwork training performed in a computer simulation environment can also provide an extra benefit to traditional training instruction, enhance their performance, and may also reduce the chance of error [56].

Another study was conducted in [99] where they investigated the use of computer-based clinical simulation in teaching patient safety in a critical-care nursing training course. They used a high-fidelity computerised simulation using a mannequin (human model) that simulates an example of a real-life situation to teach medical and aviation students. Five students participated in the study who joined a course called “Adult Acute Care - The Interface Between Theory and Practice”, which ran for 15 weeks. The students participated in three simulation experiences over three separate weeks. In each simulation experience, key concepts were integrated which were taught in class in the weeks prior to the simulation training. Simulation scenarios covered the case of a patient who had a car accident and developed a chest pains, a case of a patient with asthma exacerbation, and a patient diagnosed with pneumonia and experiencing an anaphylactic reaction from the prescribed antibiotics. It was evaluated using a

mixed-method approach using a questionnaire designed by the researcher with four five-point Likert-scale items and two open-ended questions, to allow students to evaluate the simulation after each experience. The simulation process was also informally evaluated by the group of instructors and their assistants who also experienced the simulation. They concluded their study by stating that integrating computer-based simulation into an existing nursing course is an effective method for training. It is necessary before introducing and organising the computer-based simulation and organising the simulation experience, to have a vision, guiding principles, and a framework. Although, the researchers felt that computer-based simulations can never replace real clinical experiences, they offer students opportunities that are unparalleled in practising several skills in a controlled and safe environment.

Another study conducted in [100] investigated the use of human-patient simulation using a highly sophisticated computer-based mannequin in different sizes (adult, child or infant), integrated with a software that helps in developing pre-planned situations that can simulate variable clinical scenarios. They implemented the study at Dartmouth-Hitchcock Medical Centre (DHMC), in Lebanon. The simulation was used for developing the clinicians' skills and capabilities in paediatric and moderate sedation. The study suggested that experiencing computer-based simulation training assisted team members in learning the importance of clear and direct communication in an emergency situation, and clinicians have used and delivered these new learned skills in real health care situations.

One more study investigating the effectiveness of human-patient computer simulation in classrooms as a training strategy was conducted in [101], where they used human-patient computer-based simulation as a training strategy in a classroom with 45 nursing students in an associate degree programme. They used a pre-post-test design to investigate if significant learning occurred after using the computer-based simulation in the classroom. Students were given a questionnaire to establish whether they were satisfied with the training strategy. The results of the study showed that students did learn from the simulation in the classroom and there was a significant difference in the t-test results between the pre and post test results. Also, that the students rated the classroom simulation positively.

Another field where computer-based simulation could be effective is using simulation in human-resource training. Computer-based simulation and serious games were used in the 1950s when the use of information technology was introduced in some American business schools and since that time, computer-based simulations have been an effective learning experiences in comparison to traditional classroom training.

One of the first simulations designed to train managers was The Looking Glass, Inc. which focused on leadership behaviour by providing feedback about self-leadership perceptions and others' leadership perceptions. It was developed by behavioural scientists at The Centre for Creative Leadership, an unconventional method to look at managers with the purpose of observing them "online" to study the context and the content of a managerial job. It is a complex in-basket business exercise and provides a realistic context for studying a diverse array of

variables during the working life of the top 20 managers of a medium sized manufacturing business. The simulation included a diversity of problems in finance, production, personnel, sales, research and safety functions and which are expected to be resolved at managerial level, which includes presidents, vice presidents, directors and plant managers. Participants in the simulation had the option of calling meetings, writing memos and making or deferring decisions [102]. Also, there are other computer-based simulations in decision support systems which have been used commonly for the purpose of training managers, to help the managing staff in making their short and long-term decisions [103].

An example of using agent-based computer simulations in business management is to emphasise the role of prototypes to support in organisational decision making. The emphasis is on the use of agent-based models as a powerful instrument for business analysis and transformation. The simulation model was built based on the Freddie's Newsstand exercise, a business learning exercise which was founded based on the famous "newsvendor problem that investigates optimal order rates in the case of uncertain demand for perishable products" and they concluded their study stating that agent-based modelling and simulation (ABMS) is an emerging field in which models simulate real-life environments in a way which looks natural, whereas the complex system is made from basic units in the form of agents. This makes using agent-base modelling and simulation particularly interesting in analysing emergent phenomena i.e. the large-scale behaviour of a complex system which does not have any clear explanation in terms of the system's constituent parts but in their interaction, Also, due to the flexibility of agent-based modelling and simulation, it makes it easy to

integrate it into a system with a broader scope or could be simply adapted to any additional restrictions and behaviours. This helps in training managers exploring new scenarios as per their choices [104].

One more example of using computer-based simulation in business training is the research conducted in [105] where a simulation experiment was developed on the NetLogo simulation platform for the purpose of observing the risk of a credit card system operation in various circumstances and enabling immediate adjustment. The purpose of the study is that the simulation will assist in providing a reference to commercial banks on credit risk management when making rules on issuing credit cards. They concluded their study by stating that using a computer-based simulation is an effective technique for experimental economics. This technique could assist in providing a decision-making reference and is suitable for further similar studies.

In this section three different examples of using computer-based simulations in medical health care were cited; the teaching of patient safety in a critical care nursing course, the use of human-patient simulation using a computerised mannequin, and the effectiveness of human-patient computer simulation in classrooms as a training strategy.

Three more examples of using computer-based simulation in business management training were also cited; The Looking Glass simulation, the agent-based computer simulations for business management for emphasising the role of prototypes to support in organisational decision making, and the credit risk

management case study to help bank managers when making rules on issuing credit cards.

2.12 Computer-based Simulation in Teaching Ecology

The study of ecology, especially population dynamics theory, is thought to be one of the most complex topics for students in the areas of biology and ecology studies [106]. It is considered complex because describing and interpreting population dynamics is developed based on a rich conceptual background, and the mathematical concepts are especially rich in this area, including many abstract and complex mathematical models. Therefore, instructors in the field of ecology have to teach the necessary concepts and then transfer them through understanding of the ecological modelling process [107]. Also, according to [106] most biologists are not sufficiently qualified to interpret mathematical equations. Because of these difficulties, some teachers believe that the traditional teaching method (oral lectures) is not enough for dealing with complex subjects like ecological modelling [108]. Other authors believe that computer technology is an appropriate alternative tool for teaching biology at all education levels [109]. Some claimed that the use of computers can potentially present the teaching of biological material in a manner that is engaging and exciting [110]. The interfacing systems of computers are also considered to deliver advantages that enhance the quality of teaching science and increase the level of learning excitement [111]. According to [112] concepts of biology can be communicated more effectively and clearly via the use of computer technology rather than the use of more traditional tools, e.g. lectures, discussions or conventional laboratory practicals. The use of computer-based simulations in ecology, can improve the

students' knowledge and understanding, and can also enhance skills involving the analysis and application of ecological models [113].

One example of using computer-based simulation in teaching ecological concepts is the study conducted in [34], they described a computation-based approach that enables students at secondary-school level to investigate the connections between different biological levels. They introduced the use of agent-based, embodied modelling tools, where students are able to model the micro rules underlying a biological phenomenon and then observe the results of the aggregate dynamics. In their study, they describe two cases in which the computation-based method was used. In both cases, students framed hypotheses, constructed multi-agent models that uses these hypotheses, and tested these by running their models and then observed the outcomes. They then compared these cases against the traditionally used, classical equation-based methods. They argued that the embodied computation-based method connects more directly to the experience of students, provides in-depth investigations as well as a deeper understanding, and allows advanced topics to be productively introduced into the learning course.

Another example of using computer-based simulation in teaching ecology is the study conducted in [107] where a computer simulation program called "STELLA" was used to simulate the "logistic" equation of population growth in teaching ecology to students from the School of Biology, University of Thessaloniki, Greece.

The concept of logistic equation of population growth is believed to be the basic background model for constructing the mathematical theoretical framework of ecology. The model explains how population density changes under environmental restrictions and is the principal tool for the study of the phenomena of density-dependent population growth and intraspecific competition.

The study evaluated the effectiveness of utilising computer-based simulation in teaching by comparing the traditional teaching procedure (oral lecturing) with a new teaching method (computer-based simulation), using data showing the performance of students in exams.

The traditional teaching method involved mainly classroom lectures without the use of any special visual media. Instructure were supported with simple laboratory experiments to illustrate phenomena such as the density dependence of population growth and intraspecific competition. The idea behind these experiments was to learn the concepts of the growth of a population for example a population of *Drosophila Melanogaster* under situations of limited food supply. The students recorded the size of the population at specific time intervals. At the end of the experiment they were asked to plot changing population size against time and then to interpret and discuss the graphs produced.

They compared the traditional way of teaching with the new way of teaching which was introduced by module instructors to exchange laboratory exercises, as well as replacing a good part of the classroom lectures with an interactive teaching method based on model simulations using the STELLA computer program.

STELLA is a graphical computer program that requires elementary knowledge of mathematics, where constructing a model is readily available by the use of symbolic icons. It allows users to construct models and to examine further the effects of modifying parameters, as well as testing other hypotheses by changing the actual models. Using the logistic equation as a reference model, the students explored the behaviour of the population system for different values of parameters R and K. More precisely, students were asked to explore the effect of periodically and randomly fluctuating parameters R and K on growth of population. The students also tested discrete population growth as well as growth of population in the scenarios of delaying feedback regulation.

In order to measure the learning effectiveness of each one of the above teaching methods, they evaluated 400 written caseworks from the period 1990-97 when the traditional method of teaching was used. Another 37 written coursework from the period of February 1998 when the new method of teaching was introduced, along with essays written by students after completing their training with STELLA, were also evaluated.

The study reached to the general conclusion that those students who were taught via the traditional method of teaching (oral lectures) achieved relatively good results with respect to the biological explanation of logistic growth and the description of relevant theories, although significant difficulties were associated with it. Whereas the results of students, who used STELLA computer simulation, were examined, and their exam questions were related to constructing computer simulation models of population growth, students got higher average marks than their colleagues in previous academic years. The improvement is even more

outstanding if the comparison is related to performance on questions about the concept of population fluctuations only with mathematical modelling.

They also conducted focus group interviews to conduct a more detailed evaluation of the effectiveness of the STELLA computer-based simulation program. Three groups of 16 students in total participated in the study. The study concluded by stating that the utilisation of STELLA for teaching ecology had a significant impact on students and helped in advancing their level of comprehension of the role of mathematical models in ecological theory. It provided the possibility for teachers to emphasise important areas of ecological modelling that were only superficially mentioned within the classical teaching environment. Their reaction of the first attempt of using the STELLA program is that it helped students to understand the dynamic nature of ecological phenomena and how a mathematical model relate to these phenomena.

Students found it helpful to learn how a model is built, how its parameters work and how these parameters affect the growth of population. In summary, the students were found to appreciate what an ecological process really is a point that caused students major difficulties in the past. With the use of STELLA, the teaching and learning procedure became more interactive. The students were able to build models by themselves, and this is something they found both very effective and interesting, as demonstrated by their feedback, also by their results in the exams.

One more example of using computer-based simulation for teaching ecological experiments is the study conducted in [114] where they investigated the

effectiveness of using computer-based simulation at a university in the UK between 2008 and 2009 using first and second-year students registered on a bioscience degree programme. They used a computer-based simulation called “The Virtual Rocky Shore (VRS)”. The aim of this simulation is to enable a precipitous, student-centred learning environment of experimental design. They conducted a series of tests to evaluate the undergraduate biology students’ learning, to determine the effectiveness of the simulation in helping students understand the concepts of experimental design and data analysis. The study had three tests; 1) before any teaching sessions on this topic (CTR), 2) after theory sessions on experimental design (EXP), and 3) after an extra practical session using the VRS.

The study had a small sample size, a total of 12 students participated in all of the three sessions. Because of bad weather, the rest of the students could not attend on one of the teaching days, therefore only 6 of the level-two students (from a total group of 20) finished all taught sessions and tests. For the reason of keeping the statistical analysis balanced, the score marks of 6 tests were selected randomly from each of the other 5 treatment combinations (student level (1 or 2) and teaching sessions (CTR, EXP, or VRS), giving a total sample size of 36). Results of the tests were analysed using a series of two-way ANOVAs. Results showed a significant increase in students’ marks between the first and third tests. The change in score marks during the second test was also significantly greater than for the other two tests. Hence, some students learned experimental design in an effective way than theory sessions alone, whereas other students simply understood the process after using the experiential learning component of the

computer-based simulation VRS. Feedback on the process was taken from students via end-of-course evaluations, which was overall positive, although some students found the VRS computer-based simulation too abstract, indicating that the utilisation of computer-based simulations may require to be supported by real experience in the laboratory or field.

The three examples of using computer-based simulation in teaching ecological concepts to students of secondary-school level or university-level showed that using computer simulations is an effective tool to teach ecological concepts. The first study compared two cases where computer-based simulation was used against other cases where there was no use of computer-based simulation in teaching biological phenomena. The second study, compared the use of computer-based simulation STELLA to the traditional way of teaching (oral lectures). In the third study, a comparison was carried out between the use of computer-based simulation to teach the concepts of experimental design and data analysis, and traditional way of learning without computers.

2.13 Computer-based Simulation in Teaching Marine Ecology

There are a few examples of using computer-based simulation in teaching marine ecology. One of the examples where applying computer-based simulation models was introduced as a learning tool in fishery management, is the study conducted in [115] where the case study of the yellow perch fishery in Green Bay, Lake Michigan was used. In this experiment a combination of modelling techniques of sensitivity analysis and policy were compared to develop conclusions that were appropriate under a variety of uncertainties. The study was

used as a learning tool for fishery managers. In [115], they proposed computer-based simulation models as effective learning tools to teach academic students about fishery management based on the success of computer-based simulation in the study conducted by other researchers in [116].

Another example is the study conducted in [117] where they used a computer-based simulation game called “FishBanks” [118], it is a famous fisheries management simulation game that has been used by many researchers over the years to teach the sustainability of fisheries. The study [117] used “FishBanks” to evaluate the effect of institutional environment on the economic and biological performance of fisheries.

The computer-based simulation was used as a practical activity in a Natural Resource Management course for students of undergraduate level registered for a course in the area of Environmental Science at the Autonomous University of Madrid, Spain. The study investigated three options of playing the computer simulation game; open access with two different time frames, and regulated access under the administration of an institution.

The computer-based simulation game was used by 48 different groups of between 20 and 25 undergraduate students in the area of environmental science, approximately 1100 students played the simulation game between the years 2001 and 2009.

The study evaluated the effectiveness of the computer simulation game by comparing the time scales of actors involved in fisheries management, i.e. two different time lengths; short versus long-term (10-year iteration versus 15-year

iteration), and by comparing the presence or absence of management institutions to guide fishing management decisions (open access versus regulated access through a resource management regime).

The results showed no significant difference when comparing shorter periods against longer periods of expected resource exploitation. However, results showed that sessions run under an institutional administration for resource management performed better than those under open access in terms of income distribution among competing companies, fish population, and aggregate asset value. Fleet size, a proxy for human pressure on the resource, had a more intense effect than the existence or not of an institutional environment. The findings also indicated that once a critical threshold is reached in stock deterioration, institutions may be insufficient to reverse the changes, suggesting ultimate environmental limits to the effectiveness of institutions.

One more example of using computer-based simulations in marine ecology is the study conducted by [119] where they analysed the complexity of Marine Spatial Planning (MSP) and explored the role that simulation gaming (SG) could play in addressing it. They used the simulation game in a quasi-experimental design and policy intervention where MSP was involved. The simulation game was played in Lisbon, Portugal, in November 2001 by 68 international MSP professionals (scientists, policy advisers and marine spatial planners) from 16 different countries. The study evaluated the effectiveness of the policy intervention by utilising pre-game, in-game and post-game questionnaires to collect data, together with analysing the MSP processes and outcomes using observations and a digital map tool. The analysis showed that MSP offers a comparative

assessment in real environments and simulations of real environments. Observed variety and changes in the computer game-based simulation intervention and provided evidence that the participants were engaged in experimentation using different strategies, policy change and policy-oriented learning. The computer game-based simulation intervention proved an effective and promising tool for national and international experimentation and exchange among professional MSP planners.

These three examples show that the use of computer-based simulations is an effective tool in teaching the concept of fish sustainability in marine ecology for educational reasons or as a training tool for policymakers. The evaluation was done by comparing the performance of students in different settings of computer-based simulation or quasi-experimental design.

2.14 Conclusion

In this chapter, an attempt to justify the linkage between this thesis and the fields of HCI and E-Learning was made. Both fields are associated to Computer Science because the case studies in this thesis involved the use of interactive computer-based simulation in the teaching and learning of complex concepts in ecology and marine ecology to university students in a classroom environment.

The effectiveness of the interactive computer-based simulation was evaluated by the students who used the system. Examples from previous research were presented, where the effectiveness evaluation of computer-based simulations in teaching different subject to students of different levels in education were investigated.

The term interactivity and interactive simulation were explained, and a section on the NetLogo modelling and simulation platform with a review of its features were followed, with the concept of Agent Based Modelling and Simulation (ABMS) and Complex Adaptive Systems (CAS) mentioned in different sections. The purpose of these sections was to explain why this thesis investigated the use of interactive computer-based simulation and why it was designed on the NetLogo platform for the case studies in chapters 4 and 5.

This chapter also highlighted the importance and advantages of using computer-based simulation in educational settings. Also, it discussed different definitions of simulation and different ways of using simulations (educational simulations, games and serious games), and their implications in a variety of areas like research, design, analysis, training, education and entertainment. Computer-based simulation could be used in laboratory experiments and in research environments in different modes, such as two or three-dimensional mode or very-interactive. It could be used in a behavioural or cognitive instructional objective. Computer-based simulations have been categorised into four types; experimental simulation, informing simulation, reinforced simulation and integrating simulation. Some researchers say there are two types of distinguished simulations; symbolic simulation and experiential simulation. Some other researchers divide computer-based simulations into two main types; conceptual models and operational models. The pedagogies used in computer-based simulations are either instructive or constructive depending on the type of the simulation.

All the examples in this chapter showed that using computer-based simulation is an effective tool in students teaching and staff training. The literature review also

demonstrated that some of the studies used quantitative data only to evaluate the effectiveness of computer-based simulation and some used mixed methods to evaluate the effectiveness of computer-based simulation.

The state-of-the-art review, showed that computer-based simulation was used in teaching ecology or marine ecology, but the comparison was done either to compare the use of computer-based simulation to the traditional way of teaching without computers, or in a quasi-experimental way where the performance of students was evaluated before and after introducing the computer-based simulation. The review identified a gap in studies and lack of interactive computer-based simulation uptake in higher education to teach concepts of ecology and marine ecology. Also, the effectiveness evaluation was analysed by comparing traditional learning methods (oral lectures) and the use of computer-based simulation, or by comparing two different settings of using the simulation in terms of duration (short-term versus long-term), or in term of comparing the use of the simulation in a restricted setting versus open access setting.

In this thesis, a new way of experimenting with interactive computer-based simulation in teaching ecology and marine ecology concepts will be presented. In the forthcoming chapters, details of experimental case studies involving use of interactive computer-based simulations in teaching scientific subjects such as ecology and marine ecology will be discussed. The experimental case studies focus on the use of interactive computer-based simulation in teaching ecology and then evaluate its use by comparing interactive computer-based simulation to non-interactive computer-based simulation. Also, the use of interactive computer-based simulation in teaching marine ecology as a serious game will be

discussed, and then evaluate it by comparing two different methods of using the interactive computer-based simulation within the classroom; active exploration-based learning from the interactive simulation without teacher demonstration compared with learning from an expert demonstration of the interactive simulation will be discussed.

Chapter 3 - Methods for the evaluation of learning interventions

3.1 Overview

This chapter is about the research methods which are utilised to evaluate learning interventions/experiments. Science could be described as the procedure of conducting an inquiry. This could be demonstrated using three techniques; resolving problems, answering questions, and/or producing further effective processes for the first two. Science both informs (answers questions that begin with words such as who, what, when, where, and how many), and instructs (answers how-to questions) [120]. In order to answer questions, the researcher requires methods, techniques and tools which are believed to be scientific. Mixed research methodology is a study that associates or combines both quantitative and qualitative methods. Mixed methodology designs offer researchers across interdisciplinary research areas with a rigorous approach to answering research inquiries [121].

Many educational researchers [122] no longer have the traditional research approach of conducting research studies strictly through either a quantitative or qualitative approach. Alternatively, they adopt a mix of both research methods in their studies. Educational researchers combine aspects of both at different levels of their observational work, such as in the preparation of research questions or hypotheses, the design of research methods, information analysis, and discussion of research findings. Such integration is said to harness the strengths of both traditions and underpins a methodologically sound research plan [122].

This thesis is about evaluating the effectiveness of using interactive computer-based simulations in university classroom environments to teach science subjects.

This chapter aims to explore different types of research paradigm and to identify the suitable research paradigm for this thesis. Also, it presents different types of case studies and the procedure for conducting an evaluative case study. Different types of evaluation methods will be explored and discussed.

3.2 Research Paradigm

This section talks about research paradigms in general, and the different types of paradigms available in the research world, then will narrow the discussion to the use of the *pragmatic* research (mixed) paradigm which will be used in this thesis.

The research paradigm is defined as “the set of common beliefs and agreements shared between scientists about how problems should be understood and addressed” [123]. Some researchers use the term worldview instead of paradigms [124]. Paradigms or worldviews act as a general philosophical position about the world and the nature of research that a researcher could bring to a study. Paradigms are raised based on discipline orientations, researcher inclinations, and previous research experiences.

The type of research approach is chosen based on some factors [124]:

- Philosophical assumptions that the research will bring to the study.
- Processes of inquiry (research designs).

- Research methods of collecting data, analysis, and interpretation of data.

Furthermore, the research approach is selected based upon the nature of the issue being addressed or research problem. Also, it depends on the researcher's personal experiences, and the type of audiences selected for the study. All of this will help the researcher to determine which research approach (qualitative, quantitative, or mixed methods) to be used for the study. Although, it is claimed [124] there is an ongoing debate about what beliefs or worldviews researchers bring to inquiry, four paradigms are highlighted here that are commonly discussed in the literature; post-positivism, constructivism, transformative, and pragmatism. The key fundamentals of each paradigm are highlighted in Table 3.1.

Post-positivism	Constructivism
<ul style="list-style-type: none"> • Determination • Reductionism • Empirical evidence • Verifying theory 	<ul style="list-style-type: none"> • Understanding • Meanings of multiple participant • Constructing social and historical • Generating theory
Transformative	Pragmatism
<ul style="list-style-type: none"> • Political • Focused on power and justice • Collaborative • Focused on change 	<ul style="list-style-type: none"> • Consequences of actions • Focused on problem • Pluralistic • Focused on real-world practice

Table 3.1: four paradigms extracted from [6]

Pragmatic paradigm: Pragmatism as a paradigm rises out of consequences, circumstances and actions rather than pre-existing situations like in post-

positivism research. Pragmatic researchers focus on the research question rather than the method. They utilise all approaches available to understand the problem and it supports mixed-methods studies. Pragmatic research is not bound to a single paradigm and reality. Mixed-method research uses pragmatism, because researchers draw profusely from both qualitative and quantitative data when they conduct their research. Researchers have the freedom of selecting the methodologies and techniques of research that best meet their requirements and purposes [124].

These paradigms could be categorised by the way researchers reply to three basic questions, which can be categorised as the ontological, the epistemological, and the methodological questions [125].

The questions will be something like the following:

1. Ontological Question: What is the nature of “reality”? Or, what is the nature of the “knowable”?
2. Epistemological Question: What is the nature of the relation between the researcher (the knower) and the knowable (or known)?
3. Methodological Question: How may the researcher carry out discovery knowledge? [125].

As mentioned at the beginning of the section, this thesis will focus on the use of the pragmatic research method, therefore the next section will discuss the use of mixed methods in evaluating human-computer interaction research areas.

3.3 Pragmatic Paradigm (Mixed Methods) in evaluating HCI research

This thesis is a multidisciplinary research study. It is about investigating the use of interactive simulation in university classrooms and covers the area of technology and human behaviour. The field of Human Computer Interaction (HCI) and e-learning covers areas across technology and human behaviour. HCI adopts various fields such as psychology, cognitive science, computer science, areas of organisational and social sciences to investigate and understand how human users experience and utilise interactive technology. The contributions made in these disciplines tend to fall into engineering or social science studies. The purpose of practical research contributions in these areas is to reveal unknown insights about human behaviour and its relationship to technology, and mixed research methods are adopted in these areas [126], [127].

HCI technologies and tools are evaluated to support humans and their social activities. There is a variety of research methods that could be adopted in HCI research. As mentioned earlier HCI is a multidisciplinary area and researchers can use most of the research methods that are used in social sciences, along with some engineering and medical research methods. The most used research methods in this area are; field studies, focus groups, user interviews, surveys, user requirements, usability evaluation, task analysis, iterative design, formal heuristics evaluation, prototyping without user testing, card sorting, informal expert review, and participatory design [126].

As mentioned earlier, the pragmatic paradigm uses mixed methods. Mixed method paradigms are generally regarded as vital for their holistic investigation

[95]. The topic of the mixed-methods paradigm is defined by the Journal of Mixed Method Research as *“research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or program of inquiry”* [128].

Evaluation of systems using mixed-methods approaches can allow the combination of seeking to quantify what the computer simulation or the system is doing, and the impacts that result from it (quantitative data), and seeking to increase the understanding about how the programme is working (qualitative data). Mixed methods also allow the organisation of the project into a controlled method, for example first exploring whether something works using a quantitative method and then examining why it worked [129].

3.4 The use of case study for evaluations

Case studies are an important tool in educational research. It is a research method used by researchers because of their concern about the limitation of quantitative methods in providing thorough and complete explanations of the social or behavioural problem that is being studied. The use of case-study methods, will enable the researcher to go beyond the statistical results of the quantitative data and will assist in understanding the behavioural conditions from the participant’s perspective. This could be done by way of using mixed methods (quantitative and qualitative data) [130].

Here we discuss what is meant by a case study, and the different types of case study that can be conducted. There is no single definition for case study as

mentioned in [131], [132], who stated many definitions by different authors. Some of them are mentioned below:

'Case study' is a generic word that involves investigating an individual, group or phenomenon. Whereas variable methods may be used during the investigation and may comprise mixed methods (qualitative and quantitative) approaches, the distinctive characteristic of case study research is the idea that human systems develop a characteristic integrity or wholeness and are not basically a loose collection of behaviours. Because of this idea, case study researchers say that to explain why things happen as they do, to understand a case, and to generalise or predict from a single example involves a detailed inquiry of the interdependencies of parts and of the patterns that occur [133]. This definition focuses on cases' holistic nature and the need for the study to explore the relationships between their constituent parts.

Another definition for case study in [134] states that case study is not a method in itself. Rather, it is focusing on one thing and looking at it in detail from different angles. Then [134] defines case study as: Case study is not a methodology but the choice of what to study, and whatever methods we use to study the case. The case could be studied completely or could be analysed hermeneutically (joining intuition to intellectual precision), or could be studied entirely by repeated measures. Also, it could be studied based on culture or origin using mixed methods, but the focus is always on the case, using whatever methods are suitable for investigating the subject [134].

According to [135], all research at some point is a case study and the reason for that is normally that data is collected and/or analysed for some unit, or set of units. This description of case study suggests that the main difference between case study and other types of research is the number of cases inquired and the amount of thorough data which can then be collected about each one. In a case study you find more data than in social surveys. As in social surveys you find a set of questionnaire responses from each of the people who participated, but with case study you are finding a lot more data about a limited number of participants [132].

The word “case” in English has many meanings as noted in the Oxford dictionary [136], which says it could mean an ‘event’ or ‘situation’. Some authors [132] explain the meaning of ‘case’ as a particular instance, an event, and a set of circumstances that surround this event. They also say that a case study is about a set of conditions or state of affairs in their wholeness and the case will be described by those circumstances.

Next are the circumstances of the situation that are being studied. It could be investigating the place where it happened, when it happened, what happened before it, how all of this affected what was going on and how events turned out. There can be no assumption that the case is in any way representative of a wider whole instead it is a special one-off, distinct by the individual circumstances that the researcher describes.

After mentioning many definitions for case study, one last definition will be quoted which was adopted in [132], in which case study was defined as “*case studies*

are analyses of persons, events, decisions, periods, projects, institutions or other systems which are studied holistically by one or more methods. The case that is the subject of the inquiry will illuminate and explicate some analytical theme or object”.

It is argued that case studies are useful and could help the researcher obtain a rich picture and analytical insights from the cases. Each study has a subject of interest which could be a place, event, person or a phenomenon. Also, a study has an analytical frame in which it is investigated [132].

3.4.1 Types of case studies

There could be different purposes for carrying out a case study. According to [132], there are five types of case studies depending on the purpose and object of the research; intrinsic, instrumental, evaluative, explanatory, and exploratory.

- **Intrinsic case study:** An interest in the subject. This kind of research is sometimes called ‘blue sky’ research or ‘curiosity-driven’ research. The reason for calling it ‘blue sky’ is because the researcher can think openly and freely; there are no barriers because there are no presumptions or ulterior motives. The inquiry is just for the sake of finding something out.
- **Instrumental case study:** Carried out with a specific purpose in the mind of the researcher. It is done to offer an insight into an issue or to review a generalisation. The case study plays a supportive role. In summary the investigation is serving a specific purpose and is acting as an instrument and tool.

- **Evaluative case study:** The inquiry is framed to evaluate and investigate how well an event, or object is working or has worked, whether something has been changed, or an idea is being newly introduced. In an evaluative research the researcher is looking for what the change has led to. Whether it improved things or made things worse or did not change things at all. An evaluative case study is about introducing an innovation then investigating the effect of that innovation through a mixture of evaluation tools and measures.
- **Explanatory case study:** The purpose of the inquiry, is to investigate a case thoroughly with detailed understanding and potential explanation of what a case study does best. The explanations could be context-specific or tentative. The multidimensional feature of the case study is that it gives the researcher the chance to relate one thing to another and give explanations based on the connections between these things and look at these connections. A case study is a strong possible tool for explanations but limited to the background and circumstances of the case.
- **Exploratory case study:** The inquiry is done to investigate a problem or an issue that the researcher may have little knowledge of, or has some familiarity with but is unsure about the reason behind it. Information could be one-dimensional as the researcher may be looking at it from one perspective. An exploratory case study is carried out when little is known, and the purpose is to explore as many explanations the researcher can find and to establish the 'shape' of the issue or problem.

This thesis will use evaluative case studies to evaluate the use of interactive computer-based simulation for teaching science subjects in a university classroom environment.

3.4.2 Case Study Approaches

In this section, different case study approaches are presented. A case study could be done to test a theory, build a theory, draw a picture, whether experimental or interpretative [132].

- **Testing a theory:** some researchers think of testing a theory in a narrow sense; a specified and near-conclusive procedure to negate or affirm something. A more inclusive definition is that theory testing aims “to test explanatory theory by evaluating it in different contexts”. Some have argued that theory testing is about external validity and could be the replication of case studies for the purpose of knowing whether previous results extend to new cases [137].
- **Building a theory:** is a research strategy that includes using one or more cases to develop theoretical ideas and propositions. Case studies are observations about a phenomenon that are based on a variation of sources of data. The main aim is using case studies as the basis from which theories could be developed inductively. The theory is emergent in that it is situated in and developed by recognising relationships and patterns among constructs within and across cases and their basic logical arguments [138].

- **Drawing a picture or illustrative demonstrative:** is used to describe what is happening with a phenomenon or situation, and why it is happening. This is sometimes helpful when the study is aimed at a target audience that is completely unaware of the topic. It describes every element involved in a case (the people, location involved, their goals, what they do, etc.) in a way that remains entirely accurate while still focusing on a language that will be understandable by the target audience [139]. An illustrative case study makes a topic more real for the reader [132].
- **Interpretative:** is a case study investigation using a specific approach that answers questions. This approach involves having a detailed grasp and deep immersion in the environment of the subject. A deep understanding of the multifaceted nature of social situations in this type of approach is often called “ethnography” [132].
- **Experimental:** is a specific type of research design where ideas are tested in a controlled environment and in case studies the systematicity of the experiment is taken and grafted on to the expectations of a case study. In social science an experiment is to establish ‘whether or not something causes something else to happen. For example, does X cause Y? Does the introduction of a new science curriculum cause an improvement in students’ understanding of science? Doing an experiment is the only way for finding out with any sort of validity in social science [132].

This thesis uses the experimental case study approach to experiment the use of interactive computer-based simulation for teaching science subjects in a university classroom environment.

3.4.3 Experimental Case Studies

Experimental case study is discussed in detail because this is the approach used in this thesis to experiment and evaluate the use of interactive computer-based simulations in classroom environments which are using case studies for teaching ecology and marine-ecology concepts to university students.

Experimental case study is one of the approaches used in social science case studies [132], and it involves treating two or more groups in the exact same way, but with a change in one variable. The way to set up the experiment is to bring an extra group, as similar as possible to the first group. The second group will receive the same treatment as the first group, to remove all sources of variation between the groups, except the one deliberate variable. Any difference in the results of the groups after introducing the deliberate change is the aim of the experiment.

There is another type of experiment which is more appropriate for case studies, because the change introduced in this type of experiment is within one situation, for example, the students in the classroom. This type is called the *repeated measure design*. In the classic experimental type, the comparison is between the experiment group and the control group. In the repeated measure (or crossover) design there is only one group and the control is from the group itself, with the change being imposed by the difference in one of the variables. In a crossover experiment both the control and alternative treatments are administered to all participants. Each participant serves as his or her own control by being tested during different phases. The advantage of using repeated measures (or crossover) is the use of only one group, thus effectively doubling the number of

participants in the treatment, compare to the classic experimental design which uses a two-group design. It also ensures that the ability level of subjects receiving the two treatments will be the same. More scenarios and types for designing experiments and interventions are mentioned in [140], [141].

To make such experiments more thorough, the case study should be done with the aim of obtaining a multifaceted view on the case study and looking a thing from all sides, from the top and bottom and by adding other sources of information to gain a solid understanding of the case study in all dimensions [132]. In the case studies carried out in this thesis both designs (classic experimental design and crossover design) were used to evaluate the use of computer-based interactive simulation.

3.4.4 Different process for conducting case studies

This section discusses the structure of the case study. What is meant by structure is the style and manner of the case study. A case study could be studying one individual or several individuals. If it is studying several individuals then it could be done one after another or all at once. Also, whether it separates nested elements of the single case for specific examination or looks back at past events or collect as time proceeds or both. There are two different kind of processes for conducting a case study. This include Single case study and Multiple case study. The brief description of each type is provided below:

- 1. Single case study design:** A single case study focuses on a single thing and studying the lineaments of its structure, and the characteristics, with the emphasis on understanding what is going on.

2. **Multiple case study design:** A multiple case study could be called different names such as; collective, comparative or cross-case analysis. As described in [134], when there is less interest in one individual case, then multiple cases could be investigated together to research a phenomenon, population or general condition. This is called a multiple case study or collective case study. There are several subjects in a multiple case study. Each specific subject is not as important in itself, as when compared with other subjects and what each subject offers collectively. It is also called 'cross-case analysis' because the emphasis is on the comparison between the cases. Other types of multiple studies are cited in [132]:

- **Multiple case studies:** emphasis is on the comparison of different examples, finding the contrast between and among the cases, then identify an important theoretical feature. So, each unit is a case and will be compared with others.
- **Nested case studies:** a nested case study gets its integrity and its completeness from the broader case by contrasting the units as part of the broader case. So, the case is broken down into subunits. These subunits are part of a larger unit which makes the case. Rather than focusing on the subunit on its own, the case is made from all the subunits together for example, classrooms within a school or individuals within a group of a class.
- **Parallel and sequential case studies:** one of the types of multiple case study. In a parallel case study, all the cases are investigated

at the same time. Whereas, in a sequential case study the cases are studied in sequence, one after the other, assuming that what took place in one case or intervention will probably affect the next [142].

This thesis will be using a multiple case study where the use of interactive computer-based simulation will be experimented with a group of students and then evaluated by the data gathered from the groups.

3.4.5 Sample Size in Case Study Research

Sampling means “*the selection of a subset of population for inclusion in a study*” [143]. Sample size in case study research is not necessarily relevant [132] 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 [144]. According to [6] it is rare in HCI research to conduct studies where all members of the population can take part in the experiments.

The author in [144] suggests considering the use of various practices to make case study research stronger. Among those practices, the author suggests a typical sample size of three to five participants is recommended for case study

research, and a sample size of 15 to 30 participants is recommended in an experimental research.

3.4.6 Generalisation in Case Study Research

Generalisation is an important factor in natural science research, because from generalisation comes induction which means that if X happens regularly in certain conditions, we can assume that X will happen again in those conditions. But in social science research, this type of generalisation is not possible [132]. This type of generalisation is also not possible in case study research. The method of generalisation in case study research is 'analytic generalisation' whereas previously developed theories or observations are used as a template with which the empirical findings of the case study will be compared. This is because the nature of case study research is to focus on one aspect of a research problem. Conclusions drawn from the case study will not be generalised but rather will be related to one specific event [142].

3.5 Mixed Methods and Data Collection Tools

Mixed research methods are combined quantitative and qualitative research paradigms. Utilising more than one approach; this can capitalise on the strengths of each approach and offset their respective weaknesses. It might also offer further comprehensive responses to the research questions, moving beyond the restrictions of a single approach. Another relevant concept in mixed methods is multi-method research studies; they use various methods of gathering data and analysing them within one research paradigm. For instance, conducting a qualitative case study in which the researcher may observe as a participant and

also conduct interviews with people. Otherwise in a quantitative subject area a researcher might pick out a study attitude of the students and then collect information from computer records about for example the frequency of 'hits' in the usage of web-based course materials. In other words, a researcher may use methods that are broadly compatible within a prototype or a circle of values and beliefs. In mixed-methods research, a researcher can use semi-structured interviews with a small number of teachers or students and in the same time may carry out a large-scale survey. This kind of integration of qualitative with quantitative methods is also sometimes referred to as multi-strategy research [145].

Multi-method designs broadly add one source of information on to another source, or used to 'triangulate' the issue by utilising various data sources to tackle a research problem from different points of view. There are two types:

A1) Multi-method quantitative research studies remain within a quantitative paradigm but utilise more than one quantitative method of gathering data. For example the utilisation of a questionnaire posted or emailed to distance-learning students in combination with other data accumulated on the same students sourced elsewhere – e.g. student record data. This type of research design might sanction you to validate between, for example, students' views of the assessment process and their actual assessments, or the dates they returned coursework.

A2) Multi-method qualitative methods could combine observations; student interviews consisting of staff interviews and email discussions.

Furthermore, the key idea for this design is to crosscheck between sources and enhance one type of data with data obtained from the other method.

Mixed-methods research designs are theoretically more intricate. They may offer a substructure for triangulation, but more often they become the basis of various ways for understanding the research problem. They might set out to explore the same things from divergent perspectives, but it often turns out that the viewpoint implies such different ways of observing that the lines of observation do not converge.

B1) Mixed-methods research might comprise a questionnaire followed up by in depth observations, or individual interviews which are utilised as the substructure for constructing a survey.

B2) The final type of mixed-methods research, is 'mixed-model research', which needs some explaining. It is not just about utilising different methods it about mixing methodologies. Tashakkori and Teddlie in their book [146] explained mixed-model research with detail. They argue that the issue is not just about method, but additionally involves commixing of methodology (i.e. the 'logic of methods'). This might sound abstract, but it has many implications. It signifies looking beyond stitching together methods from different paradigms and instead considering other characteristics of research design [147].

A mixed-methodology research was adopted by different researchers. For example in [148], which is a project about "learning and teaching as

communicative actions; A Mixed-Methods Twitter Study”. The study used mixed methods and observed that convergent data-validation designs made the combination of hypothesis testing (quantitative data) and hypothesis generation (qualitative data) possible to employ in one study with a small sample of participants. Utilising this design, gave them the ability of synthesising complementary results and offer a complete picture of the perception of students from the use of Twitter social networking platform in an e-learning online course, as a tool to support learning communities and to encourage student discourse regarding academic topics [148].

A similar mixed methodology was also used in a PhD thesis; “Evaluating the Effectiveness of the E-learning Experience in Some Universities in Saudi Arabia from Male Students' Perceptions”, by Algahtani [149]. The methodology used was to allow the learners to rate each item of four dimensions; autonomy in e-learning, interaction with the content, interaction with the instructor and interaction between learners.

Algahtani [149], discussed these four dimensions in detail in his thesis. He compared these four dimensions and then the findings were amplified by mixed methodology techniques, the open-ended responses and the interviews conducted with the focus group. These two qualitative data collection tools provided a broader grasp of the positive sides and negative sides of e-learning, and explained its requirements and obstacles. For quantitative findings, Algahtani used questionnaires for those participants who preferred writing their answers instead of giving an oral interview. Furthermore, both research methods made triangulation of the phenomenon possible in more than one way, and also

enhanced the validity of the research and increased the understanding that this research provided by obtaining in- depth opinions and ideas, which were hard to express in the statistical responses or quantitative data only.

3.6 Tools for data collection

There are many tools for mixed-methods data collection, for use in case study field work. These methods are the tools that the researcher will use to seek information on what is being investigated. The common used tools for collecting data are mentioned in Table 3.2 [132]:

Tool	Description
Interview (structured)	Quantitative
Interview (unstructured, semi-structured)	Qualitative
Accounts	Qualitative
Diaries	Qualitative
Group interviews	Qualitative
Focus groups	Qualitative
Interrogating documents	Qualitative
Questionnaires	Quantitative and qualitative
Observations (structured, unstructured, participant observation).	Quantitative and qualitative
Image-based methods	image
Measurements and tests	Quantitative
Official statistics	Quantitative

Other numerical data	Quantitative
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Table 3.2: Types of data collection tools

This chapter will not discuss all of the above mentioned tools, as they have been discussed and explained by many authors like [132], [150]. In [151] they also compared different evaluation tools and developed a framework for evaluating game-based learning environments as a starting point for researchers. The problem with these tools is that they are not suitable for the case studies chosen in this thesis. A more specifically customised evaluation model is more suitable to measure the learning effectiveness of the participants in the case studies of this thesis.

The focus in this chapter will be on tools that have been found to be useful for evaluative case studies, such as the studies in this thesis, The chosen evaluation model Learning Effectiveness Survey (LES) has been used by other researchers to carry out such evaluative case studies as mentioned in [107], [152], [153].

3.6.1 Interviews

Interviews are good tools for evaluating the effectiveness of interventions. Interviews give participants the opportunity to say what they think about the system freely without being bound to the categorised questions that have been defined for them by the researchers. There are three types of interviews as mentioned in table 3.2.

Structured interviews are designed in a way that the researcher will meet the participant and ask a set of prepared questions exactly as structured, with very specific questions and mostly with a set range of responses. This type of question

is also known as a closed-ended, fixed-choice or pre-coded question [154]. This type of interview has limited strengths, for example managing such interviews is easier and quicker than other types of interviews, and is also easier in terms of coding the interviewees' responses. There is no other great advantage in this type of interview as questions could have been forwarded to the interviewee instead of meeting face-to-face as it happens in open-ended questionnaires [132].

Unstructured interviews are used when there is no set way for conducting the interview. It is just like a conversation and there is no set list of questions presented by the researcher and in fact, the interviewee will set the agenda. This type of interview is used in an interpretative case study.

Semi-structured interviews are used when interviews are structured with a list of issues for which answers are found through specific questions, and the researcher is free to follow up on points as required. This type of interview is commonly used in small-scale social research experiments and this interview approach is utilised in this thesis. This type of interview has many advantages, such as if the main research ideas are open-ended, and it focuses on the interviewees' perspective specifically. The interest is focused around the interviewees' opinion. The interviewees have the freedom to drift from the question and it is sometimes encouraged, as it gives insights on what is important and relevant according to the interviewees. The researcher has the freedom to depart from the interview guide and ask follow-up questions based on the interviewee's answers. This makes semi-structured interviews to be more flexible, and rich in terms of content because of the more detailed answers [154].

In this thesis, semi-structured interviews were conducted through teachers of ecology and marine ecology modules, to get their opinion on the use of interactive computer-based simulation in teaching.

3.6.2 Questionnaires

Questionnaires are a written type of questioning, and the questions may be closed i.e. a Yes or No answer, or open questions when assessing participants' attitudes on a topic. Questionnaires can be structured in a tight way and can allow more open responses if the researcher requires it. It can be handled in different ways; read out to participants either face-to-face or over the telephone, handed to participants, sent by post or posted online [132]. According to [153], questionnaires are one of the most commonly used tools for collecting data in effectiveness evaluation as highlighted in previous sections in this chapter.

The Learning Effectiveness Survey (LES) model [152] was used in this thesis as it is more relevant to the contained case studies than other evaluation models or frameworks available. For example, the Kirkpatrick's classic evaluation model [155], which is designed for training evaluation rather than evaluation of specific educational interventions as done in the LES model.

3.6.3 Measurements and tests

Tests are used to assess the level of something, for example testing someone's reading ability. The results are almost always given in numbers. There are many different types of test questions, for example true-or-false, short answer, essay, simple multiple-choice or complex multiple-choice. Each test has its advantages

and disadvantages in terms of reliability, validity, feasibility and acceptability [153].

Tests could be criterion-referenced or norm-referenced [156]:

- Criterion-referenced tests are to assess whether the subject being tested meets the criterion or not, regardless of how good other participants perform in the test.
- Norm-referenced tests are to compare the participant who is being tested with a sample of similar participants.

Driving tests are a typical example of a criterion-referenced test, because the person being tested is not compared to other people doing the test. If the person being tested can do a three-point turn then a box will be ticked. How others perform their three-point turn does not matter. Ability and achievement tests are example of norm-referenced tests because the performance of those being tested is compared to with other people's performance [132]. Choosing the type of test depends on what you are looking for in the effectiveness evaluation [153].

The tests used in this thesis were designed specifically for each case study by the teachers as will explained in the following chapters.

3.7 Evaluation

There are two types of evaluation that are applied in the educational system; formative and summative [157]. Formative evaluation is also called progress or process evaluation, which discusses the type of evaluation activity that aims to obtain feedback and comments throughout the procedure of developing and

implementing the system, in order to propose improvements and assist in the change, innovation or intervention.

Alternatively, summative evaluation is also called impact or outcome evaluation, and is the type of evaluation that is done after the procedure of developing and implementing a computer system. Summative evaluation aims to collect feedback and information to evaluate the impacts, effectiveness, effects and outcomes of the developed system [158].

Thomas Reeves in [159] identified six major functions of evaluation for any type of interactive system, such as interactive computer-based simulation or any system that is used for learning and has a feature of interactivity.

The six major functions are as follows; “review, needs assessment, formative evaluation, effectiveness evaluation, impact evaluation and maintenance evaluation” [159].

1. Review is performed during the early development and consideration for an interactive system. Two main review activities were discussed by Reeves in his book; the review of existing interactive systems and the review of professional literature connected to the project.
2. Needs assessment is performed during the process of developing interactive systems. The main activities that are carried out in needs assessment are task analysis, job analysis, learner analysis, and to answer why the system is needed [160], [161].
3. Formative evaluation is performed before the interactive system is finalised, to gather information for system developers for creating,

debugging and improving the interactive system at different stages of its development. Several activities are performed during formative evaluation e.g. user observations, expert review, and usability assessment [162], [163].

4. Effectiveness evaluation is to establish whether the interactive system achieves its goals and objectives after the implementation of the system. Some of the main activities involved in effectiveness evaluation are field tests, observations, interviews and performance evaluation [164].
5. Impact evaluation is performed to establish whether the learning goals e.g. knowledge, skills, and attitudes obtained during the learning process are transferred to the aimed context of use, i.e. real-life practice. This is done to find out if the interactive program has any impact on actual students' performance. Some of the main activities performed during the impact evaluation process include interviews, document analysis, and observations.
6. Maintenance evaluation is performed to assess the sustainability of an interactive system over a period of time. Several activities are performed during maintenance evaluation including observations, interviews, document analysis, and electronic data collection.

3.7.1 Effectiveness evaluation

This section focuses on effectiveness evaluation because this thesis is about investigating the effectiveness of interactive computer simulations as a learning system for use in university classroom. Effectiveness evaluation is part of usability evaluation in HCI research [3], [165], [166].

In theory, the ideal way of evaluating learning effectiveness is to measure performance improvements in achievement tests [167]. The complications of carrying out performance-based assessments are discussed in [152], who argue that a comparison of performance on final examination is the apparent way to measure improvement of performance in a university environment. Nevertheless, there are practical and theoretical issues in using examinations to measure the effectiveness of a particular intervention. There are two alternative approaches to measure whether there has been any effect on learning by a change in teaching a specific lesson:

- **Longitudinal (between-years) comparisons:** comparing students' achievements between first year and the next year.
- **Two-group (within-year) comparison:** comparing students' achievements between randomly selected two groups studying within the same year.

The longitudinal approach is a quasi-experimental design, and there are two major internal validity problems with this approach.

- **Selection bias:** there is a possibility of difference in students' characteristics from year to year which can provide an alternative explanation for any differences found.
- **Instrumentation:** using the same exam from year to year is usually not practicable, so differences in the exam itself can give an alternative explanation for any differences found.

The two-group approach is a true experimental design. It represents the only scientific way of demonstrating whether an intervention has had an effect on learning or not. However, there are a couple of theoretical and practical problems mentioned in [168], by applying such a research design in university environments:

- A possibility of internal validity complications due to *diffusion of treatments*, because of the difficulty in isolating groups from each other.
- There is a risk of *internal validity* in the *selection bias*, as per the difficulty of randomly assigning students to groups.
- The potential of confounding variables, if groups are run in different locations, using different instructors or at different times.
- Concerns of ethical issues with equity in teaching and fairness in assessment, as students in one group may perform better in the assessment compare to the other group due to an unfair advantage they may have had.

Lastly, running two parallel classes with different teachers doubles the teaching resources required, raising practical issues because of the increase in cost and teaching load.

Perception-based assessment of learning is identified in [152], as a substitute for performance-based assessment of learning, which is done by asking students to evaluate the effectiveness of their own learning.

End-of-semester course evaluation surveys are typically used for perception-based assessment evaluations. They have become prevalent and increasingly

encouraged in higher education. Also, they have become the principal tools for collecting information to assess university instructors' teaching effectiveness [169]. Studies show that end-of-semester course evaluation surveys are the most commonly used source of information to evaluate teaching effectiveness [170].

However, conventional course evaluation instruments have been critiqued as being inadequate measures of teaching effectiveness, e.g. [169], [171], [172]. Instructors are repeatedly frustrated as there is very little, if any, connection between changes in teaching and the subsequent ratings [169]. Reasons for such frustration are mentioned in [152]:

- Conventional course evaluation tools are intended to provide a variety of objectives and are not explicitly focused on measuring learning effectiveness.
- They have a tendency to evaluate the instructor rather than the methods used. Students' ratings are mainly based on the instructor who is teaching the course rather than the course that is taught [167]. Some studies show that teachers may increase their points by engaging in trifling manners and actions, pleasing the political preferences of students, persuading students by cancelling some of their lessons, teaching unchallenging courses, or sometimes just by dressing casually [173]. For these reasons, scores on these evaluation instruments are often dismissed.
- Conventional course evaluation tools are established on a "student-as-consumer" model. The focus is on students' preferences and aversions regarding the course, instead of how well the learning goals were attained.

- They take the approach of “one size fits all”. Usually an evaluation form is used to compare two different teachers or courses. This feature may make the evaluation tool bureaucratically suitable but not much help for improving the course or diagnosing a problem. An effective evaluation tool must be adaptable to the learning goals of individual courses, as teaching methods may differ based on different learning objectives [167], [174].
- Many of the course evaluation tools lack an explicit theoretical base [175]. Many are not based on theoretical models of the learning process as they contain specific items developed in an *ad hoc* manner. Interpreting results becomes difficult because different items in the evaluation tool measure different underlying constructs, except at the level of individual items. Ideally, items should be generated after developing the theoretical model [176], [177].
- Many institutions develop their individual course evaluation tools to suit their specific purposes as there are few standard tools for course evaluation.

3.7.2 Learning Effectiveness

Defining explicit *learning goals* is an important element while developing any educational programme. They help in selecting the most appropriate teaching methods and learning activities to achieve goals of learning [178], [179]. The Learning effectiveness of any educational course may only be reasonably evaluated in the context of the learning goals of the course. Learning effectiveness is defined as “*the extent to which the learning goals of the course were achieved*” [152].

3.7.3 Learning Goals

According to [152], learning goals are defined as “*particular knowledge, skills or attitudes that participants should have at the end of the learning episode*”. They further differentiate between these three types of learning goals.

- Knowledge: “the facts and concepts students should understand”. Knowledge goals include comprehension abilities and memorisation [178].
- Skills: “the tasks students should be able to perform”. Skill goals involve the comprehension of how knowledge might be used to solve problems and includes applying knowledge, analysing , synthesis and evaluation abilities [178].
- Attitude:” the attitudes, motivations and beliefs students should possess” [178].

3.7.4 Short-term and long-term learning

Learning is a continual procedure. University courses are generally not taught separately as standalone modules, but as part of a larger educational programme for example a diploma or degree to prepare students for practical life. Therefore [152] differentiate between the following concepts:

- **Short-term learning:** whether the course successfully achieve its stated goals. This is to evaluate the effectiveness of the course on its own as an educational unit and not as part of the whole degree or diploma.
- **Long-term learning:** whether the course contributed positively to the students’ general learning experience. This is to evaluate whether the

course was relevant to practical life. For example, a course can be effective by helping students achieve the learning goals, but the learning goals of the course might be not relative to practice, e.g. if it is using some discredited or outdated techniques.

3.7.5 Improvement and Evaluation

To understand the difference between improvement and evaluation, [152] explains the difference by saying that improvement is one of the anticipated objectives of the evaluation process. When performing an education evaluation, the aim is to evaluate the effectiveness of the educational course and to improve it as well. A distinction is defined in [152] between both terms:

- Improvement: to modify the learning intervention to improve its effectiveness.
- Evaluation: to measure the effectiveness of the learning intervention.

Generally, numerical scale-based questionnaires (quantitative data) are most useful for evaluation purposes, while open-ended questionnaires (qualitative data) are very useful for the improvement of educational courses [167], [170].

3.8 The Learning Effectiveness Survey (LES)

The evaluation instrument proposed in [152] is known as the Learning Effectiveness Survey (LES). This instrument was used in both case studies in Chapter 4 and Chapter 5. The following sections will define the instrument in its general form and will explain how the instrument will be used in the context of particular learning goals and intervention.

3.8.1 Theoretical Model of the Learning Effectiveness Survey (LES)

The LES instrument is founded on an explicit theoretical model of the learning process, unlike instruments proposed in previous literature. This theoretical model is summarised in Figure 3.1:

- The circles denote the theoretical constructs.
- The arrows denote causal relationships between the theoretical constructs.
- Process improvement is presented in the figure as a cloud to imply that it is a qualitative construct.

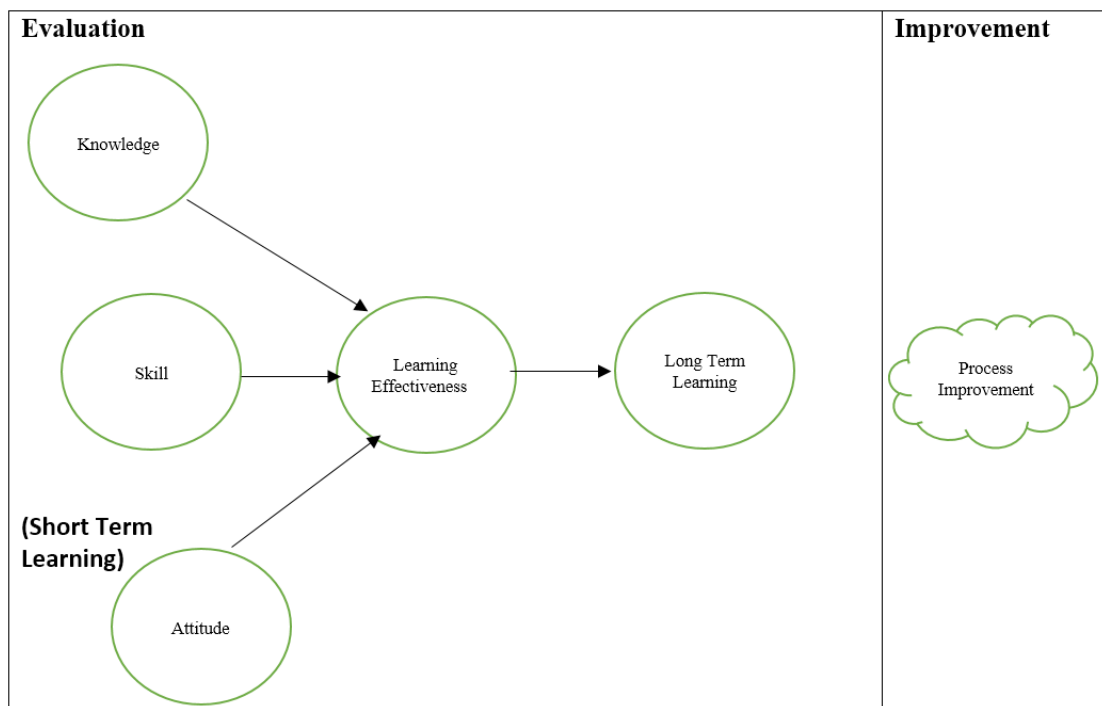


Figure 3.1: Theoretical Model of LES extracted from [39]

The definitions of the constructs are [152]:

- Knowledge: measuring the effectiveness of the educational intervention in increasing the knowledge of students.

- Skills: measuring the effectiveness of the educational intervention in improving students' skills
- Attitude: measuring the effectiveness of the educational intervention in changing students' attitudes
- Learning Effectiveness or (Short-term learning): measuring the effectiveness of the intervention overall in improving student learning in the course
- Long-term Learning: measuring the value of the educational intervention in terms of preparing participating students for future courses or modules and for future practical life.
- Process Improvement (suggestions): ideas to improve the educational intervention for effective achievement of learning outcomes.

It is argued in [152] that:

- Improvements in learning goals (knowledge, skills and attitude) will determine the learning effectiveness of the intervention within the course.
- Learning effectiveness will determine the long-term learning of the intervention because effective learning determines the learner's perceptions of the practicality of the learning gained for practical life beyond the course.

3.8.2 Using the LES instrument for evaluation

The LES was developed to evaluate the learning effectiveness of educational interventions. The survey items (questions) were established to measure each of the theoretical constructs shown in Figure 3.1. Items in the survey cover learning

goals, learning effectiveness, long term learning and process improvement. A detailed explanation of theoretical construct of the questions is presented in the following sections [152].

3.8.2.1 Learning Goals Questions

Questions on learning goals are used to evaluate course-specific knowledge, skill, and attitude. They are established based on the precise learning goals of the learning intervention under study. Typically, a single question is designed to address each learning goal.

3.8.2.2 Learning Effectiveness Questions

Learning effectiveness in the survey instrument is evaluated by combining standard questions and intervention-specific questions. There are two typical questions:

- How much did the learning intervention contribute to the overall learning of the students in their course or module (Contribution to Learning).
- How effective was the learning intervention compared to other learning activities in the course or module (Relative Effectiveness).

3.8.2.3 Long-Term Learning Questions

Long-term learning is evaluated by questions which evaluate the contribution to learning outside the scope of the studied course. For example, the students' perception on how the intervention can help in future courses, or in practical work and future working life.

3.8.2.4 Process Improvement Questions

Process improvement questions are established based on the precise intervention being evaluated and would gather information about how the effectiveness of the intervention could be improved. This can be done by combining closed and open questions.

3.8.3 The LES Instrument

The LES survey instrument which was used in the case studies of this thesis, contains of different parts, each question resembles one of the constructs mentioned in the theoretical model. The survey was used differently in both case studies of this thesis. In the first case study the first part of the survey that relates to evaluation of the intervention by collecting quantitative data using Likert scales for each construct and then results were in numeric scores. The final part of the survey instrument which relates to improvement and other open-ended questions for qualitative data collection about the class intervention was given separately at the end of the class intervention. While, in the case study both part of the survey (quantitative and qualitative) were given together. The second part of the instrument is called opinion/feedback questionnaire. This part of the survey gives it an evaluation power as well as diagnostic power. The quantitative replies in the first part of the survey instrument provide the basis for evaluating the effectiveness of the learning intervention, while the qualitative responses provide the basis for evaluating and determination of why the educational intervention was effective and successful and how it could be better and improved in the future. The theoretical model of the LES instrument is designed to work in the context of particular interventions and for specific learning goals [152].

3.9 Conclusion

In this chapter, different types of research paradigms were identified, and a detailed explanation of pragmatic research paradigms was given. Pragmatic research is one of the paradigms used in evaluative research. This thesis will be using a pragmatic paradigm in evaluating the use of interactive computer-based simulation as an intervention in case studies of teaching ecology and marine ecology in a university classroom environment. Different types of case studies were also presented in this chapter. This thesis will be utilising multiple evaluative and experimental case studies to investigate the use of interactive computer-based simulation in teaching ecology and marine ecology to university students in a classroom environment. Mixed data collection tools were used to measure the learning effectiveness of the participants.

Also, different types of evaluations were presented, and formative and summative evaluations were explained. The type of evaluation performed in this thesis is a summative evaluation for the final version of the interactive computer-based simulation used in the case studies. Moreover, six major functions were identified for evaluating any type of interactive learning system. Learning effectiveness evaluation is a type of evaluation performed to measure the usability of a system in HCI research. The learning effectiveness evaluation of participants who used interactive computer-based simulation in learning ecology and marine ecology concepts was undertaken. This was done using the Learning Effectiveness Survey (LES), to measure the learning effectiveness of the interventions in each case study. Open-ended questionnaires were also used to gather qualitative data from the participants, a performance test was also done

in one of the studies to measure students' performance and semi-structured interviews were conducted to gather data from the module teachers.

Chapter 4 - Experimental evaluation of the effectiveness of using Interactive Agent-based Simulation: A case study from teaching ecology.

4.1 Overview

This chapter presents the details and the outcome obtained from the case study experimentation performed to evaluate the effectiveness of interactive agent-based simulation for teaching and learning purposes. For this purpose, a complex concept of complex adaptive systems in areas such as ecology is selected as a target subject, whereas the university classroom is the target e-learning environment. More specifically, two lab interventions were carried to teach, the undergraduate students of an advanced module: BIOU9CE (Community Ecology & Conservation Applications) at the University of Stirling, the concept of spatially-explicit predator prey interaction. The objective of the experimentation was to compare and evaluate the effectiveness of interactive agent-based simulation versus non-interactive simulation.

It has learned that the use of interactive simulation significantly enhance the teaching-learning process [180], and therefore its used can be seen in many fields of science education including but not limited to physics [181], chemistry [182], biology [85], mathematics [183] and other sciences [181]. Moreover, it has been reported in the context of ecology that the use of computer-based simulations can improve skills related to the analysis and application of ecological models [107]. In this case study, the effectiveness of utilising interactive agent-based computer simulation (implemented in NetLogo [20]) is investigated and compared to a non-interactive version of the simulation (implemented in R [184])

both versions of the simulation were developed in Stirling University. The purpose of the simulations is to assist students learning complex ecology concepts at higher education level.

This chapter presents the case study of experimenting the use of the interactive simulation and comparing interactive simulation with non-interactive simulation, using a total of 38 students from the BIOU9CE module. These were undergraduate students from third and fourth year. Amongst them 20 were from the academic year of 2015, whereas the remaining 18 were from the academic year of 2016. These students were registered for the BIOU9CE module at the University of Stirling. Results of the study indicate that the students found that the interactive computer-based simulation to be more engaging and an effective way to learn the subject.

The remaining chapter is organized as follows: Section 4.2, the underlying subject used for the experiment, i.e. spatially-explicit predator prey model is explained. Section 4.3, describe the proposed interactive agent-based simulation tool (NetLogo), whereas the research methodology used to run the interventions is presented in section 4.4, and the design of the intervention is explained in section 4.5. Section 4.6, explained the data analysis, whereas the quantitative and qualitative results are explained, and the summary of findings obtained from the experiment is explained in Section 4.7. In section 4.8, results are discussed and compared with other studies. Finally, some concluding remarks are given in section 4.9.

4.2 Community ecology

All living things on earth live in natural groups called communities. Community ecology is the study of patterns and progressions involving these groups of two or more species. Communities are typically studied using a variety of techniques, including observing natural history, statistical descriptions of natural patterns, field and laboratory experiments, and mathematical modelling. Community patterns come from a complex collection of processes including predation, mutualism, competition, indirect effects and selection of habitat, which result in the most complex biological entities on earth [185]. The BIOU9CE module is about the study of interactions among organisms and between organisms and their environment. Students of the module are expected to gain a broad overview of the structure and dynamics of ecological populations and communities, and their conservation, understand the key drivers of population dynamics, gain hands-on experience in determining sustainable rates of hunting under realistic scenarios of uncertainty and variability, and gain experience of the effects of space and spatial heterogeneity on population dynamics [186]. The following model is a practical for the students to learn about space and coexistence in ecological interactions. The practical runs a simulation model of predator–prey interactions, which is an integral part of ecological theory since they are the basic modular building blocks for understanding the complexity and dynamics of ecological communities [187].

4.2.1 Spatially-explicit predator prey Model

The model considers how space affects the interaction between individuals and their environment. The predator functional response is an important part of this

theory because it describes the rate at which individual predators consume prey for their own production and, reciprocally, describes the level of mortality that predators cause on their prey populations [187]. Populations have spatial structure because individuals are located at specific locations in space. This has several effects on their ecology. First, an individual's spatial location restricts the set of organisms that it can interact with to be those in its local neighbourhood [188]. Second, space (together with the sensory organs of the organism in question) affects the detectability of predators and prey. Third, heterogeneity in the spatial distribution of resource availability, refuges, mates and abiotic conditions, etc., can strongly influence ecological processes. Finally, the viscosity of the environment, together with the dispersal abilities of the organism, affects how quickly they can move through space. All four of these factors influence ecological interactions among organisms [185].

The purpose of the simulation model is for the students to learn about predator-prey interaction by using a realistic predator-prey model. In so doing, the students will:

1. explore the linkages between ecological processes and their representations in models
2. explore how explicitly accounting for space affects the outcome of models
3. explore ways to use models to predict the outcome of predator-prey interactions
4. design and execute a modelling study of predator-prey dynamics.

4.2.2 Modelling platforms

During the lab experiment, the predator-prey model was simulated on R and NetLogo as 2 different modelling platforms. The primary motivation is to provide a user-friendly and effective way to interact with a relatively detailed model. This feeds into the secondary motivation, which is to evaluate the educational potential of R and NetLogo. This will help improve teaching provision in future years. NetLogo is a popular multi-agent programmable modelling environment used by tens of thousands of students, teachers and researchers worldwide [22]. NetLogo provides a graphical user interface to write models.

4.2.3 Description of model

This section provides details of the main features of the spatially explicit predator-prey model and will explain the different variables in the simulation. It will comparatively explain the differences in the context of implementation using the R and NetLogo model.

1. **Arena:** Predator-prey dynamics are simulated within a homogeneous, two-dimensional closed habitat. The habitat is rectangular, with dimensions specified by the student. The model is spatially explicit where each individual having a set location in the habitat. In R, space is continuous, and individuals occupy X-Y coordinates. In contrast, the individuals occupy grid cells NetLogo. However, the grid is so fine that the space is effectively continuous. In both R and NetLogo, either a vertical (or horizontal) cylinder could be created by joining the top and bottom edges of the arena, or the left and right edges. Similarly, the torus (a donut)

can be created by joining both the top/bottom and the left/right edges. These manipulations make the spatial area of simulation essentially endless.

2. **Time:** Time is discrete, with a small step size.
3. **Movement:** Prey move throughout the habitat at a speed determined by the student (N_{speed}). They move in randomly-chosen directions, unless there is a predator within a 'dodge_radius', in which case they move away from the nearest predator (with a certain degree of error). Predators, likewise, move at a speed determined by the students (P_{speed}). Again, they move randomly unless they are within a 'search_radius' of prey, in which case they move towards the nearest prey (again, with a certain degree of error). When a prey is located within a certain 'catch_dist' of a predator it means caught and eaten by that predator. If several predators catch a prey simultaneously, they share it. We assume that all prey contain the same level of resources, as far as the predator is concerned.
4. **Growth:** Prey grow by acquiring resources from the environment. There is density dependent competition among prey, however. We assess how many other prey are present in the neighbourhood around each individual. Elevated local density reduces the resource gain for each affected prey. This effect is modulated by the parameter 'dd' (density dependence). The effect of local crowding is particularly severe when dd is high. Predators, on the other hand, grow by consuming prey.
5. **Reproduction:** Prey and predators must obtain a threshold level of resources from the environment to reproduce. Reproduction is by asexual budding whereas each new individual is generated at the same location as the parent, with a minimal level of resources. The threshold levels of

resources necessary for reproduction by prey and predators ('Nb' and 'Pb') can be set by the users.

6. **Death:** Mortality for the prey occurs only when they are consumed by the predator. Predators face a user-defined per-capita probability of death (d) in every time-step.

INITIAL CONDITIONS: These consist of the initial quantity of predators and prey present in the arena at the start of the simulation. They are located randomly, with a random energy level. The aforementioned names presented in brackets represents variables that are used in the implementation of the model using both simulations i.e. R and NetLogo.

4.3 Interactive Agent-based Simulation (NetLogo version)

The focus of this case study is the use of interactive agent-based simulation to demonstrate its effectiveness for teaching and learning purposes of complex concepts from complex adaptive systems such as ecology. Interactive simulation is the representation of an event or procedure where the outcome is changeable by the user [88], and this is done while the simulation is running [18]. In this study NetLogo is used as an interactive agent-based simulation environment. NetLogo is a multi-agent programming language (or modelling environment). It's been used for modelling complex evolving systems such as the simulation of complex natural and social phenomena. Models can instruct thousands of "agents" to explore the micro-level behaviour of individuals and macro-level patterns that emerge. NetLogo allows users to modify simulations to explore their behaviour in different scenarios. NetLogo is simple enough for students and researchers

who are not programmers to create their own models. NetLogo is a standalone Java application which can run on all major computing platforms [21].

The term simulation is described as an artificial environment that is carefully built to manage individuals' experience of reality [189]. It works as an exercise implicating reality of function but in a simulated environment [190] A detailed overview of the term interactive simulation is provided in Section 1.4 of Chapter 1.

Interactive computer-based simulations provide many benefits to support calls for inquiry-based, learner and knowledge-centered teaching and instruction [191] as explained in chapter two of this thesis. For example, simulations offer the benefit of flexibility, supporting students to actively engage in problem-solving, higher-order thinking and in reinforced practice[192]. Therefore, interactive computer simulations have the potential to make teaching more interactive and make learning abstract concepts more real. Interactive computer simulation let students challenge their own theories by working with and receiving immediate feedback about original and/or real data and making tailored problem-solving decisions [49].

The Interactive version of the simulation implemented in NetLogo lets the user interact with the simulation while running the simulation to input parameter values, using slide bars and buttons. Also, the view of the simulation is in animation. While, the non-interactive version of the simulation implemented in R does not allow the user to interact with the simulation when the simulation is in running stage. In fact, the users have to provide codes at a command line using

R to input parameter values after the simulation is finished and run another simulation again after making changes to the parameter values. Also, the view of the simulation is in static snapshots.

4.3.1 Model outputs

The main model output is stability, measured as the persistence of the two species to the 'max.time' (a variable that you can adjust). We also obtain from the model the mean population size of the prey and predators, as well as their ranges, which gives an indication of the amplitude of variation in population sizes. Greater oscillations, and oscillations that intensify through time, are indicators of instability, whereas small and damped oscillations indicate relative stability. In addition to population dynamics, students can observe the spatial patterning of predators and prey in the arena – are they all spread out? do predators hunt as a group? do prey disperse from one another and from predators?

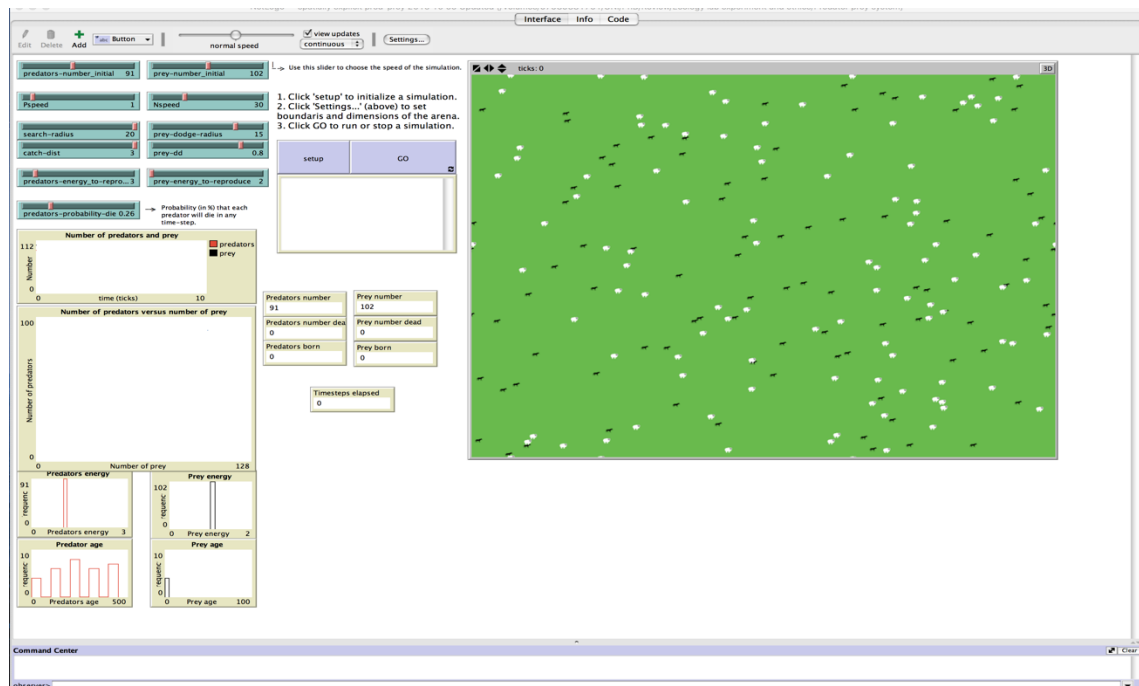


Figure 4.1: Interactive simulation model (NetLogo)

In NetLogo (Figure 4.1), the prey are shown as white sheep and predators as black wolves, whereas in R (Figure 4.2), prey are black circles and predators are red stars. In both, their size indicates their current level of resources. In R, the heavy black bar on the right indicates the 'catch distance' of the predator. Any prey within this distance of a predator dies. The thin red line indicates the dodge radius of the prey. If there are predators within this distance, prey will try to avoid them. The tall thin bar at the bottom right indicates the progress of the simulation up to the maximum number of time-steps specified by the user. This simulation run just ended, with 102 prey and 91 predators alive at the end. Similar information is provided in NetLogo's graphical user interface.

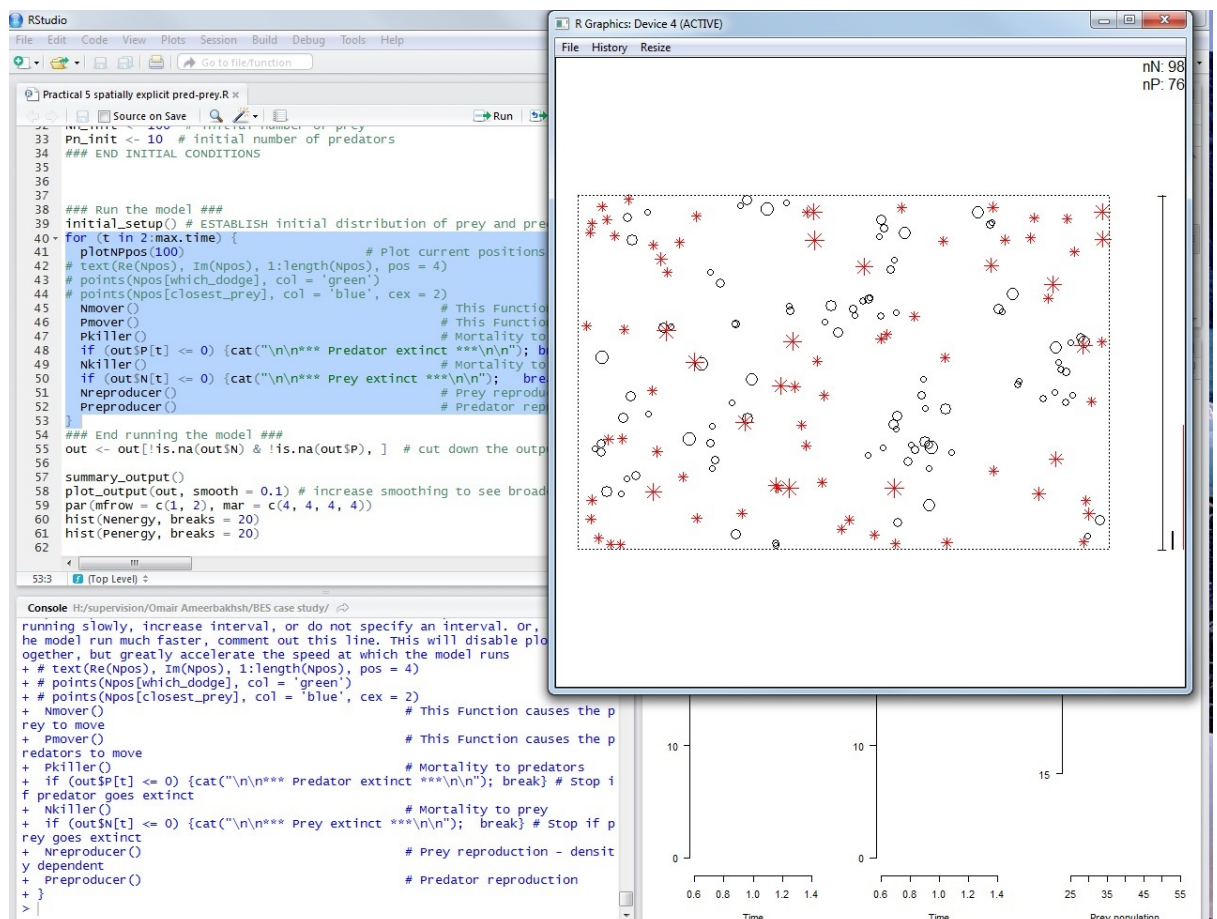


Figure 4.2: Non-Interactive simulation model (R)

4.3.2 Manipulations

Students used the system to investigate a wide variety of ecological hypotheses.

For example, they might hypothesize that:

- the probability of prey survival decreases as their speed decreases and the predator speed increases;
- increasing the predator's search radius decreases the probability of stable coexistence, whereas decreasing the search radius increases it. Changes in the dodge radius would have the contrary effect;
- changing the resources needed for reproduction for predator and prey would affect their population sizes and stability;
- changing the surface area-perimeter ratio would affect the stability of coexistence.

Many additional manipulations are possible. We settled on the above manipulations due to lab time constraints.

4.4 Methodology

4.4.1 Ethical approval

Ethical approval for the study was granted to by the Psychology Ethics Committee in the faculty of natural sciences at the University of Stirling (see Appendix 1). The consent form and information sheet used in this study are in (see Appendix 2 and 3).

4.4.2 Research Methods

The research methods used for this case study is mixed methods, as there are no existing frameworks for studying the effectiveness of interactive computer-based simulation for teaching ecology in higher education. The approach used is a mixed method (quantitative + qualitative) strategy [121]. The quantitative part uses *the learning effectiveness surveys* (LES) developed by Moody and Sindre [152] to evaluate the effectiveness of interventions in educational settings. Learning effectiveness is assessed from the perspective of evaluating the learning goals of the whole course or module. The learning goals of an educational intervention are defined as specific knowledge, skills or attitudes that participants should gain at the end of the educational intervention [152][193]. (LES) was used to ask students to measure the effectiveness of their own learning from the two simulation tools. A *self-efficacy scale* [194] was also used to measure the students' perception of their capability to run and manipulate each simulation. These were applied in a crossover randomized controlled trial in a lab intervention setup [195] where study participants intentionally "crossover" to the other treatment group.

A crossover randomized controlled trial begins the same as a traditional randomized controlled trial, however, after the end of the first treatment phase, each participant is reallocated to the other treatment group [195].

This design demonstrates several scientific strengths such as the possibility of reversibility (ethical approach, in this case it means to allow students to use the other version of the simulation), it compensate for lack of randomisation, and it improves the efficiency of a study by not waiting time in looking for subjects to

recruit [140]. This design was chosen for ethical reasons, to give all students the chance to use both interactive and non-interactive versions of the simulation models. This was required by the university to give all students the chance to use both versions as it would be unfair to expose some of the students to the interactive model only as other students could argue that they did not get the chance to learn using the interactive model which they might argue affected their overall score in the end of the course.

The questions of the questionnaire were validated by the main-stream teacher and supervisory team and researchers from the school of education in Glasgow University were also consulted. Also, pre-testing of the questions of the questionnaire was done by performing a pilot study with a small group of computer science students who participated voluntarily to ensure that the questions were unambiguous and answerable before running the actual study. The purpose of this was to ensure that the questions in the questionnaire are clear and understandable [196].

4.5 Design of Interventions

The intervention took place in four stages. The students were divided into two groups A and B. In the first stage, group A carried out an exercise using a non-interactive R simulation and group B did the same exercise using an interactive NetLogo simulation. In the second stage, group A did the exercise using NetLogo and group B used R as shown in (figure 4.3). Learning effectiveness survey were applied after each stage. At the third stage of the intervention, students were given opinion questionnaires for feedback on the two simulation tools to collect

qualitative data. The questionnaires include questions about preferences, reasons for preferences, effectiveness, power, advantages and disadvantages of both tools.

The duration of the intervention was four hours for both studies. The fourth stage of the intervention, at the end of the lab for performance assessment, students were given an assignment to do at their own time with deadline time for submission to the lecturer. The assignment was for the students to choose one or more ecological hypotheses to test using the modelling platform of their choice. There are many hypotheses that they can examine. Each student was advised to test hypotheses that are different from colleagues. They were also advised to consider what parameters of the model they will manipulate, and what response variables they will measure to evaluate their hypotheses. Also, to consider how they will replicate their study to obtain confidence in their results. They were asked to consult with the instructor about their study design prior to testing their hypotheses. Finally, a semi-structured interview was conducted with the lecturer to get his feedback on the NetLogo simulation model.

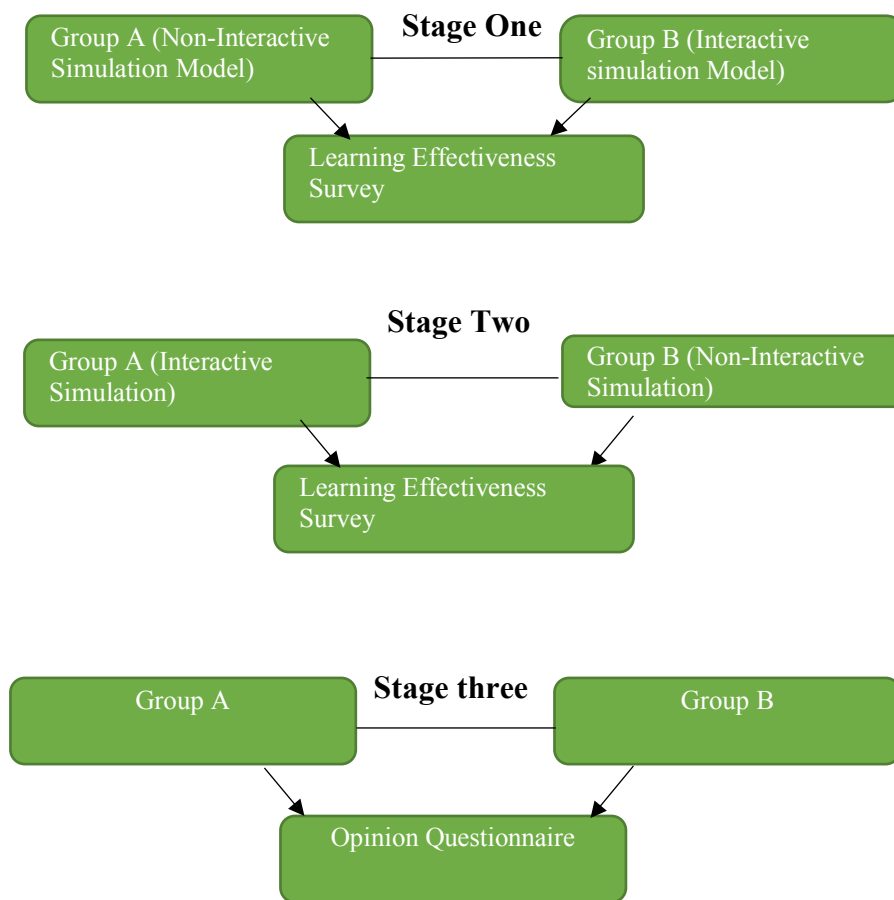


Figure 4.3: Design of class intervention

The learning effectiveness survey used a Likert scale of 6 scores for each question, where 1 means “not at all” and 6 means “very much”. The survey contains 16 questions covering all the 5 factors of LES including Knowledge, Skill, Attitude, Learning effectiveness and Long-term learning. The survey responses were collected online via the university’s online learning platform “succeed” (see Appendix 4 and 5). The details of the survey questions and their associated construct can be seen from Table 4.1.

Q. No	Learning Effectiveness Survey Questions	Construct
1.	To what extent do you feel that you have learned from this version of the model in today's lab practical?	Learning Effectiveness
2.	To what extent do you feel that the model could help you more to explore the linkages between ecological processes and their representations in models?	Knowledge
3.	To what extent do you feel that the model could help you to better explore how explicitly accounting for space affects ecological interactions?	Knowledge
4.	To what extent do you feel that the model could help you more to explore ways to predict the outcome of predator-prey interactions?	Learning Effectiveness
5.	To what extent do you feel that the model could help you more to design and execute a modelling study of predator-prey dynamics?	Learning Effectiveness
6.	How effective was this version of the model at helping you learn the key concepts?	Learning Effectiveness
7.	How easy was this version of the model to use?	Skill
8.	How engaging did you find the exercise using this version of the model?	Attitude
9.	How visually attractive did you find the user interface in this version of the model?	Attitude
10.	How much did this version of the model help you understand the spatially-explicit predator prey concept?	Knowledge
11.	How able were you to manipulate this version of the model, as requested in the lab handout?	Skill
12.	How capable were you to evaluate the first suggested hypothesis: "the probability of prey survival decreases as their speed decreases and the predator speed increases"?	Skill
13.	How capable were you to evaluate the second suggested hypothesis: "increasing the predator's search radius decreases the probability of stable	Skill

	coexistence, whereas decreasing the search radius increases it...”?	
14.	How capable were you to investigate the third suggested hypothesis: “changing the resources needed for reproduction for predator and prey would affect their population sizes and stability”?	Skill
15.	How enthusiastic were you about using this version of the model?	Attitude
16.	How much do you feel that this version of the model will help you in completing your assignment?	Long-term learning

Table 4.1: Learning Effectiveness Survey Questions

4.6 Data analysis

There were fewer than 50 participants; it is therefore appropriate to use nonparametric tests such as the Mann-Whitney-Wilcoxon U Test to analyse the data [197], [198]. The responses gathered from the survey were pooled from groups of both interventions to obtain the adequate sample size for statistical analysis [199], [200].

4.6.1 Reliability of learning effectiveness survey (LES)

Cronbach's alpha is a measurement commonly used to test the internal consistency ("reliability"), It is used to measure the reliability of multiple Likert questions in a questionnaire or survey that uses a scale. This test is performed to determine the reliability of the scale. It is also often used in conjunction with a data reduction technique such as principal components analysis (PCA) or factor analysis. It is recommended that the values of Cronbach's alpha are 0.7 or higher [201].

A reliability analysis was conducted on the survey items used to measure each question in the learning effectiveness survey (LES). The Cronbach's Alpha result was of high levels of reliability (> 0.9).

4.6.2 Validity

The questions of the opinion questionnaire and teacher interview were created based on the same pattern of the learning effectiveness survey, but the aim of the opinion questionnaire was to look for more open-ended answers to verify and validate data gathered from quantitative data in the LES. Triangulation is a procedure used for verification to increase the validity of data gathered and to remove the intrinsic biases or weakness and to overcome the problems that occur from using single method. This procedure is utilised for confirmatory and for completeness purposes. Triangulation means the combination more than one method in one study investigating a single phenomenon for convergence on a single construct, it can utilise both data collection techniques (quantitative and qualitative) for validation and inquiry [202]. Thus, both (Quantitative and Qualitative) datasets in this case study were compatible [203].

4.7 Results

4.7.1 Quantitative Data from the Learning Effectiveness Survey

Table 4.2 show the differences in the first stage between Group A (R Model) and Group B (NetLogo Model). A comparison was done. There was significant difference in all questions between both models. NetLogo showed higher score more than the R model. However, Question 12 How capable were you to evaluate the first suggested hypothesis: "the probability of prey survival decreases as their

speed decreases and the predator speed increases”? (1 = not capable at all, 6 = very capable) there was no significant difference between the R model and NetLogo model.

Q. No	Median		P Value
	Group A (R)	Group B (NetLogo)	
1.	3	5	< 0.05
2.	4	5	< 0.05
3.	3	5	< 0.05
4.	4	5	< 0.05
5.	4	5	< 0.05
6.	4	5	< 0.05
7.	4	5.5	< 0.05
8.	3	5	< 0.05
9.	3	5	< 0.05
10.	4	5	< 0.05
11.	5	6	< 0.05
12.	5	5	> 0.05
13.	4.5	5	< 0.05
14.	4.5	5	< 0.05
15.	3	5	< 0.05
16.	4	5	< 0.05

Table 4.2: LES results from stage 1

Table 4.3 show the differences in the second stage between Group A (NetLogo Model) and Group B (R Model). A comparison was performed and found significant difference in questions 7, 8, 9, 11 and 15. However, there were no significant differences in other questions.

Q. No	Median		P Value
	Group A (NetLogo)	Group B (R)	
1.	4	4	> 0.05
2.	4	4	> 0.05
3.	4	4	> 0.05
4.	4	4	> 0.05
5.	4	4	> 0.05
6.	4	4	> 0.05
7.	6	4	< 0.05
8.	5	3	< 0.05
9.	5	3	< 0.05
10.	4	4	> 0.05
11.	5	4	< 0.05
12.	5	4	> 0.05
13.	5	4	> 0.05
14.	4.5	4	> 0.05
15.	4.5	3	< 0.05
16.	4	4	> 0.05

Table 4.3: LES results from stage 2

Table 4.4 shows the differences in the first stage between Group A (R Model) and Group B (NetLogo Model) for the self-efficacy scale. There was significant difference between both groups. NetLogo showed higher score.

Self-Efficacy Scale Question	Median		P Value
	Group A (R)	Group B (NetLogo)	
Please rate how confident you feel about your ability to run and manipulate the simulation. Rate your degree of confidence by recording a number from 0 to 100 using the scale given below select one: (0 10 20 30 40 50 60 70 80 90 100) Cannot do at all Moderately can do Highly confident	70	80	< 0.05

Table 4.4: Self-efficacy scale from stage 1

Table 4.5 shows the differences in the second stage between Group A (NetLogo Model) and Group B (R Model) for the self-efficacy scale. There was no significant difference between both groups.

Self-Efficacy Scale Question	Median		P Value
	Group A (NetLogo)	Group B (R)	
Please rate how confident you feel about your ability to run and manipulate the simulation. Rate your degree of confidence by recording a number from 0 to 100 using the scale given below select one: (0 10 20 30 40 50 60 70 80 90 100) Cannot do at all Moderately can do Highly confident	70	60	> 0.05

Table 4.5: Self-efficacy scale from stage 2

4.7.2 Qualitative Data

The stage 3 is based on the opinion questionnaires (see Appendix 6), where qualitative data were gathered from the participants. Furthermore, a lecturer interview (see Appendix 7), was also performed. All the obtained qualitative data were analysed using framework based thematic analysis [9][10] to code the data where the theme of the questioned was following the same pattern in the qualitative data but looking for open-ended responses. The NVivo software [204], [205] was used to analyse the students' responses to the open-ended questions. The questions asked from students consist of ten different themes. These themes can be seen from Figure 4.4 and their details are individually described below:

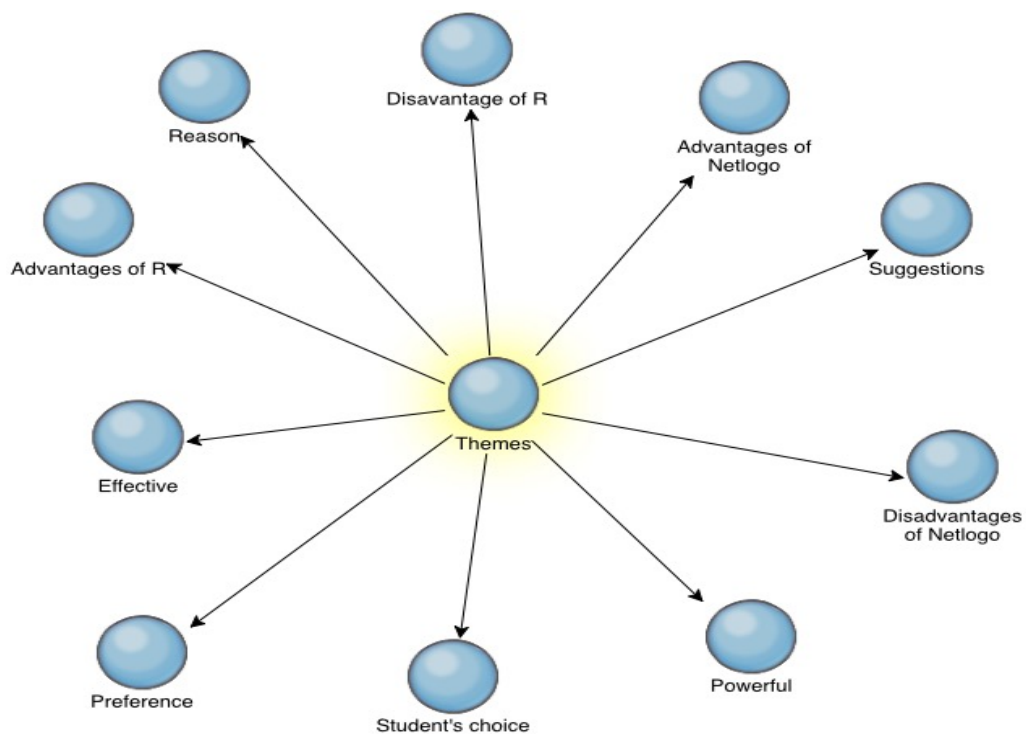


Figure 4.4: Themes of qualitative data

4.7.2.1 Advantages of NetLogo Model

Almost all of the participated students, i.e. 34 out of 38 responded to the Advantages of NetLogo question. Their responses include the following advantages: Attractive, better user interface, better visualisation, easier to visualise, easy to learn, good for investigating dynamics, interactive because of the ability to change variables mid-run, easy to change parameters, real-time simulation, simpler to manipulate, it has slider bars interaction, constant graphical output, no coding is required and user friendly. One student explains some advantages of NetLogo by saying:

“Easy to use easy to manipulate the models visually attractive leading to a better understanding of the model” (Student B09)

4.7.2.2 Disadvantages of NetLogo

Amongst 36 participants, 29 students responded to the disadvantages of NetLogo question and mentioned disadvantages such as: Lack of numeric output, new to students as they have never used it before, doesn't run multiple replicates, not showing written outputs of statistics, unable to enter exact numbers and unable to save output of variables to record. One student explains some of the disadvantages of NetLogo by saying:

“NetLogo does not seem to be as accurate, the sliding bars could easily not be at the correct number. This can be fixed however by slowly changing the bar and looking at the number at the side” (Student B06)

4.7.2.3 Advantages of R Model

Amongst 38 participants, 34 students responded to the advantages of R question and have mentioned the following advantages: Ability to customise graphical output, adequate to answer the hypothesis, control variables, easier to use, greater manipulation, numeric output, powerful, precise, run replicates of scenario, statistical data, freedom in setting minimum and maximum value for parameters, more complicated results, which can be helpful, furthermore R allows more customization if one is confident with coding and it runs faster. One student explains some advantages of R by saying:

“R provided graphs that better showed how predators and prey were influenced, i.e. I could see if they were reaching stability or not. Also, was easy to print exact population sizes” (Student A11)

4.7.2.4 Disadvantages of R Model

Amongst 38 participants, 32 students responded to the question (disadvantages of R) some of their responses include the following disadvantages: Complex, difficult to learn, difficult to interpret data, hard to visualise because of bad graphical interface and because its text only there is no interaction, less user friendly, not easy to manipulate, requires coding experience, time consuming, unattractive, it can be very difficult to use, it will take you a lot longer to fix any errors and take longer to set up a model. It isn't as interesting to use and it's not as visually stimulating as NetLogo, more intricate and complicated which I don't think is necessary for this model, hard to understand and manipulate code, cannot see all the script and output on one screen so must keep going back and finding code and its output, does not give a good visual aid and can be confusing

to manipulate, very dry, boring visual surface, changing parameters can sometimes be a bit complicated. Furthermore, running the code takes more effort than just pressing setup and start in NetLogo, it is very difficult to see the species interacting whereas in NetLogo this is very clear. One student explains some of the disadvantages of R by saying:

“The R language takes time to understand, I have been using R a lot during this semester so know how it works however if I had never used R before I would have found using this version of the model difficult. I had never used NetLogo but managed to use the model with ease.” (Student 18)

4.7.2.5 Preference

Majority of the students, i.e. 27 of 38 participants gave preference for NetLogo simulation over the R simulation. The remaining 11 participants preferred the R simulation over NetLogo.

4.7.2.6 Reasons mentioned by students for preference of NetLogo or R

Amongst 38 participants, 27 students preferred NetLogo over R. They mentioned the following reasons for their preference: Better interaction, better output to understand, better visualisation of the model, control of parameters, easy manipulation, easy to use for new users, easy visualisation, good interface, interactive, more comfortable, no need to code, real time simulation, user friendly, more interesting to use. It was fun to use and easier to read compared to R, and changing the parameters was a lot clearer and easier, better presented and more suitable for the comparisons. Easier to express ecology understanding without being hindered by being able to code information, NetLogo's simplicity makes

working with it easier because the user surface is cleaner and simpler, the constant graphical output is nice to look at to view predator/prey numbers, provides visual representation of the model, allowing you to discern exactly what is the cause of either predator/prey extinction, e.g. predator efficiency too high, there were fewer errors, simulation was very visually appealing, changes to parameters were very clear to carry out. One of the students said:

“Visually, it was much more appealing, and you could watch exactly how the species interacted with each other much more clearly. Manipulations could be done during the run to see how this impacted the species. I liked that you could see how much energy value each organism was through their size.” (Student 11)

The remaining 11 students preferred R over NetLogo and the reason for their preference are the following: Allows you to enter exact values, displays numeric data with output, easier to change the simulation back through coding, easier to customise, easier to trace progress because of separate display sections of the simulation, easier to track, less experience with NetLogo and more experience with R. One of the students said:

“I find it easier to interpret results when there is numeric data alongside graphic output. I prefer the way the window in R is separated into different sections and I like being able to trace my progress and changes back through the code in the console.” (Student A2)

4.7.2.7 Effective

NetLogo simulation was considered as more effective than R by 29 students out of the 38 participants, whereas the remaining 9 students termed R as more effective than NetLogo.

4.7.2.8 Powerful

Amongst 38 participants, 29 students believed that R was more powerful than NetLogo. The remaining 9 students said that Netlogo was more powerful than R. No reasons were asked for their response as they were asked for general reasons in a different question in the opinion questionnaire.

4.7.2.9 Student's Choice

Amongst 38 participants, 23 students said that they would choose NetLogo over R if they were given the option of choosing only one simulation program. The remaining 15 students said that they will choose R over NetLogo. No reasons were asked for their response as they were asked general reasons in a different question in the opinion questionnaire.

4.7.2.10 Suggestions

Amongst 38 participants, 7 students had some suggestions for NetLogo. This include the following: Ability to learn to code in NetLogo, get more variables, option for iteration, option to plot output under different variables, replace slider with textbox. One of the students said the following:

“Combination of both the visuals from NetLogo and output manipulation from R would create a great programme!” (Student 4)

Amongst 38 participants, 8 students provided some suggestions for R that include the following: develop R to be more interactive, make R more visual, could use more attractive/clearer looking models, could have a better user interface which would make this programme much better to use, correct the code in R for the area from circular-rectangle, could not change spatial factors.

One student said:

“Another program could be developed to make RStudio more user-friendly, having buttons and sliders to manipulate models and parameters, and graph things more easily” (Student B1)

The remaining 23 students had no suggestions for both, i.e. NetLogo and R.

4.7.3 Qualitative analysis of lecturer’s interview:

A semi structured interview was conducted with the teacher to get his opinion on the use of NetLogo interactive simulation in teaching the ecology model. The questions of the interview were formed to answer the question of whether interactive simulation is an effective tool for teaching and the questions covered the teacher’s perception on the NetLogo simulation. The interview was conducted in the teacher office a digital recorder was used to record the interview. Then the interview was transcribed by the researcher and emailed to the teacher to be verified and confirmed the transcribed version of the interview has all his answers. A framework approach was used to analyse the themes coded from the interview. The teacher found that the NetLogo model was useful, approachable, attractive and effective for teaching complex ecological models to his students. He thought that R was more powerful but stated that his response was based on

regular use of R and unfamiliarity with NetLogo. He also thought that students responded very positively to NetLogo and found it very effective.

Theme	Implication	Supporting quotation from the teacher's interview
Game	NetLogo is a toy program. Looks like a game.	<i>"it kind of looks like a game. With little wolves and a little sheep"</i>
Approachable	Not intimidating to for students who did not have a lot of experience in using NetLogo before.	<i>"I think that as a teaching tool that could be very useful. It's good to have something that's approachable and not intimidating for students who to be honest have not had a lot of experience in doing these things before"</i>
Interactive	NetLogo parameter can be adjusted during the running of the simulation.	<i>"NetLogo for example you can adjust the parameters for the model during the run, which can be good but if you are interested in seeing how does changing something affect the outcome"</i>
Dynamic	Ability to make multiple graphs during run of the simulation.	<i>"the ability to change parameters values during a model run that is something you can't do in R also the ability to make multiple graphs during run of the simulation you can do that in NetLogo but it's not easy to do that in R. The graphing capabilities of "R" are good but they are not that good. So that type of dynamic figure that type of dynamic graphic something it can be done in NetLogo"</i>
Abstraction	Students will never have to the code and they can deal with the graphical user interface not like in the R model.	<i>"abstraction is probably the key thing. What I mean by that is in NetLogo the students never will have to see the code they never even have to see anything that looks like code they can deal with a graphical user interface, they can deal with the entire model using their mouse, they never have use the keyboard, so I think for a lot of students that is attractive"</i>

Effective	Students were very engaged with it and managed to complete all manipulations and enjoyed using it as a game-based learning tool.	<i>“for this particular week an agent-based model is perfect. It is exactly what I want as a teaching tool but other weeks they are not agent-based and not individual-based. I think that agent-based modelling wouldn’t be helpful for other topics in the course. And so, I have thought, would’ve be useful to change over entirely to use NetLogo but I don’t think that would be effectible for this particular model.”</i>
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Table 4.6: Thematic analysis of teacher interview

4.8 Discussion

The study conducted in this chapter assist the main goal of this thesis, which is to investigate the effectiveness of interactive simulation as an e-learning tool in higher education considering the regular students in classroom environment. The case study was conducted in a comparative setting to identify the effective tool between interactive and non-interactive based simulation for learning the same concepts. For this purpose, a difficult concept known as (Spatially-explicit predator prey interaction model) from Ecology domain was selected. The study utilised an R based non-interactive and a NetLogo based interactive models. The findings obtained from this study illustrate that both the students and teacher preferred the interactive based version of simulation for learning and teaching purpose of the selected concept, i.e. (Spatially-explicit predator prey interaction model). The main reasons for their preference summarised from qualitative data include some of the following aspects facilitated by the interactive version of the

model: the capability of the interactivity and engagement with the model during the simulation time, ease and enjoyable procedure, feel like playing as a game.

The case study interventions were performed in three stages, where students were divided into two groups. Each of the group was given the chance to experiment using both version of the simulations. The results obtained from first two stages were of quantitative nature, whereas, qualitative data were gathered in the last stage from all participants as well as the course teacher. The analysis of quantitative data indicates statistically significant difference at stage 1 in 15 out of 16 survey questions. However, at the stage 2, statistically significant difference was observed in 5 amongst 16 questions. The key reason behind the difference between stage 1 and stage 2 results was the improved knowledge of the students for the underlying concept, i.e. (Spatially-explicit predator prey interaction model) during stage 1. The obtained qualitative data are further analysed to validate the results and findings of the quantitative data. The qualitative data was analysed using NVivo software [204], [205] based on students' responses to the different open-ended questions belonged to ten different themes. The analysis of the participant responses hinted that the use of interactive simulation was the favourite choice and concluded as more effective due to the interactivity and engagement features during simulation time in comparison with the non-interactive version of the same model.

The overall analysis of both kind of results demonstrate that the use of interactive simulation can improve the e-learning experience in classroom environment. The findings of this study adhere some of the existing studies in this domain. E.g. the findings of the studies conducted in [107], [114], [206] informs the effectiveness

of computer simulation programs as tutorial tool for teaching biology to students of different levels. In their study, they utilised various computer-based simulation programs to teach various concepts from the biology (and ecology) domains. Their findings conclude that the use computer simulation programs helped students to understand the dynamic nature of biological (and ecological) phenomena and how these can be resembled using mathematical models. Analogously, the study conducted in this chapter approached at similar findings. However, the study focused in this chapter was to demonstrate the effectiveness of interactive against non-interactive simulation, whereas, the studies conducted in [107], [114], [206] were focused on the computer based simulations in general against traditional method of teaching. The closely related work to this chapter is the study conducted in [207], where they have studied the effectiveness of interactive simulation versus non-interactive simulation for emergency preparedness scenario. Their study found that the use of interactive simulation had larger impact on participants' appraisal of threats. The findings reported in this chapter has similar conclusion that the use of interactive simulation for learning and training purposes is more effective in contrast to non-interactive simulation.

4.9 Conclusion

This chapter study the use of an interactive agent-based simulation model to determine its effectiveness against the non-interactive version for learning and teaching purposes. The study was carried out with the help of a case study based on teaching complex concepts of complex adaptive systems such as ecology. The case study was conducted in e-learning classroom environment. The chapter

explains the design of the study, the associated ethical aspects, the adapted methodology, demonstrates the obtained results and the quantitative and qualitative analysis. The key findings of the study were reported. The study suggest that the use of interactive agent-based simulation is more effective in teaching and learning of complex concepts against the non-interactive simulation counterpart. The responses obtained from the study participants were found to be more favoured towards interactive agent-based simulation because of their interactivity and easy to use features.

Chapter 5 - Experimental evaluation of the effectiveness of using Interactive Simulation Game: A case study from teaching marine ecology.

5.1 Overview

This chapter aims to analyse the effectiveness of using interactive agent-based simulation as a serious game for teaching and learning of a mathematical model based on a complex adaptive system concept (population growth) in the field of marine ecology. For this purpose, it evaluates two ways of using interactive simulation, i.e. an active exploration-based use of interactive simulation compared with passive viewing of an expert demonstration of the interactive simulation. In this case study the interactive agent-based simulation was designed as a serious game. The interactive simulation game was developed in Stirling University. The term “serious games” has no fixed definition but it refers to the type of games that has “a specific purpose” to deliver engaging interactive media to support learning in its broadest sense beyond the usual motive of entertainment alone [208]. The use of serious games and interactive simulation in formal education, with sufficient support has been identified as motivational and to helpful to students in high level learning of complex skills [67], [209]. Serious games and interactive simulations have been increasingly integrated into science education as part of the teaching-learning process [180]. They have been used in teaching physics, chemistry, biology, mathematics and other sciences [181]. The case study in chapter four 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 such as for optimal management

of aquaculture and mariculture systems [210], [211]. There are also several simulation-based games on the theme of marine ecology. However, most of these games aimed at younger audiences [212], [213], whereas little has been done on the use of such games for teaching advanced concepts at the university level. This is evident from chapter two where the example of the Fishbank simulation to teach concepts of sustainable fisheries was presented [117].

Proponents of serious games for science education argue that these games deliver many benefits including, the increased concentrated engagement in learners, inspiring active learning, improving understanding of complex subject matter, and fostering collaboration among learners [214]. However, more research is needed, both to test these claims, and to discover the most effective methods that can integrate serious games into the educational process so as to realize their benefits. Some evidence is gathered in a meta-analysis [215] which found significant learning benefits for games compared to non-game approaches. Another meta-analysis [216] found that the use of game 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.

This case study makes a twofold contribution. First, the experimentation of a new interactive computer-based simulation as a serious game, developed for use in undergraduate and postgraduate courses in marine ecology and aquaculture. The interactive computer-based simulation game is designed to help learners to explore a mathematical model of fishery population growth and understand the

principles of managing a fishery sustainably. Secondly, the evaluation was done by comparing the following two different methods of using the simulation within the classroom:

1. In the first method, the students used the active exploration-based method, where they used the white box interactive simulation teaching game without a teacher demonstration. The teaching game was then followed by a black box interactive simulation.
2. In the second method, the white box interactive simulation was demonstrated by the teacher with passive viewing (i.e. without the active exploration by the students). This is then followed by using the black box simulation (i.e. the testing game).

The white box interactive simulation shows all the parameters and variables used in the simulation, whereas, the black box is a testing game that only shows the parameters and variables accessible in the real world. A mixed methods study design was used, using both quantitative and qualitative methods to compare the learning effectiveness of the two approaches, and the students' preferences.

The aim of this case study is to investigate the effectiveness of interactive simulation in teaching Marine Ecology at higher education level. The investigation was carried out by running interventions with a mixture of undergraduate and postgraduate students from the University of Stirling in a classroom environment. Also, compared active and exploration-based learning with passive viewing of an expert demonstration.

The underlying research questions this case study is focusing on are to investigate the following: (1) Is it effective to use interactive simulation as a serious game to learn complex mathematical model from the field of marine ecology in a university classroom environment? (2) Which way of using the interactive simulation game is more effective, passive viewing with an expert demonstration or active use without expert demonstration?

In section 5.2, the game and the target concepts that the game intends to teach are described. The methodology of the study is explained in section 5.3, whereas section 5.4 explains the design of the study. In section 5.5, the study participants were described. Section 5.6, explains the data analysis part of the study. The quantitative results and the qualitative of the study are presented in section 5.7. The chapter ends with a discussion in Section 5.8, and conclusion in section 5.9.

5.2 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 the following two main difficulties to be addressed in teaching this topic:

1. 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. 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.

2. 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 above-mentioned problems can be addressed using 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, engaging, allows students to explore the model and understand how to use it without engaging with the mathematical details. In this section, we first give some more detail about the concept that is being taught and then describe the games that was developed to teach this concept.

The interactive simulation is based on a mathematical model adapted from [217]. 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. Figure 5.1 illustrates this system, where it presents 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).

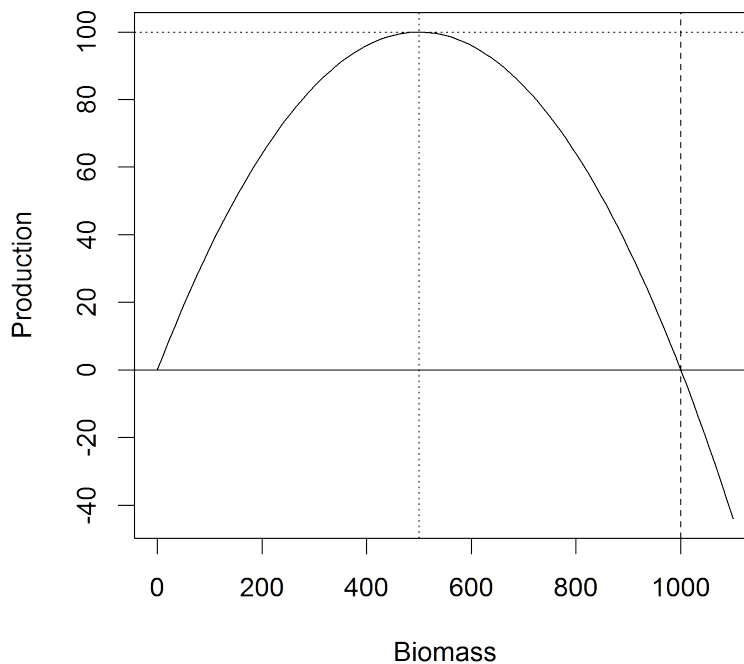


Figure 5.1: the relationship between production rate and biomass

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. 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 Figure 5.2. Here, the horizontal axis again represents the biomass, as in Figure 5.1, but the vertical axis now also represents the TAC. Table 5.1 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} .

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

D	Biomass > K/2 and TAC > production. Biomass is decreasing slowly	Gradual decrease in CPUE	Reduce TAC to achieve Pmax
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Table 5.1: Using CPUE to infer conditions in the fishery and estimate Pmax

Figure 5.2 estimate Pmax by tracking catch per unit effort (CPUE). As in Fig 5.1, 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.

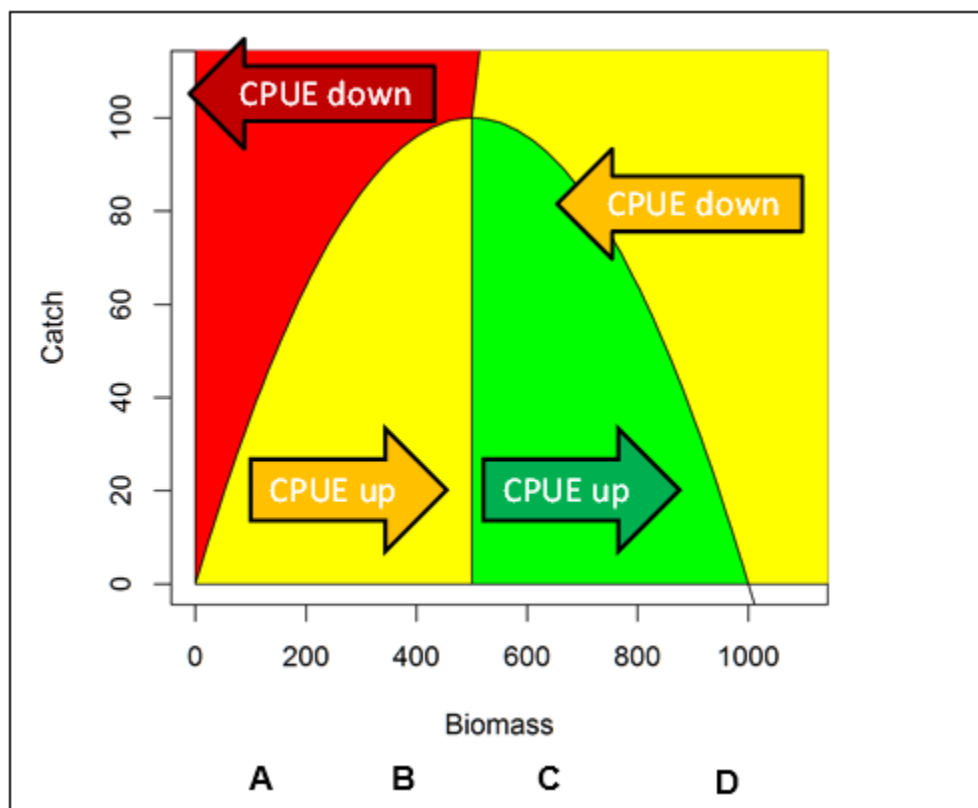


Figure 5.2: Estimating Pmax by tracking catch per unit effort (CPUE)

The mathematical model described above was encoded within the NetLogo agent-based simulation tool [218] as an interactive game, and exported the model 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 Figure 5.3. The first version is “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 second version is “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. Figure 5.3 shows the Good Time Fishing game, which is called white box or teaching game that shows all parameters and variables used in the model. Figure 5.4 shows the black box simulation or testing game that shows only the parameters and variables accessible in the real world.

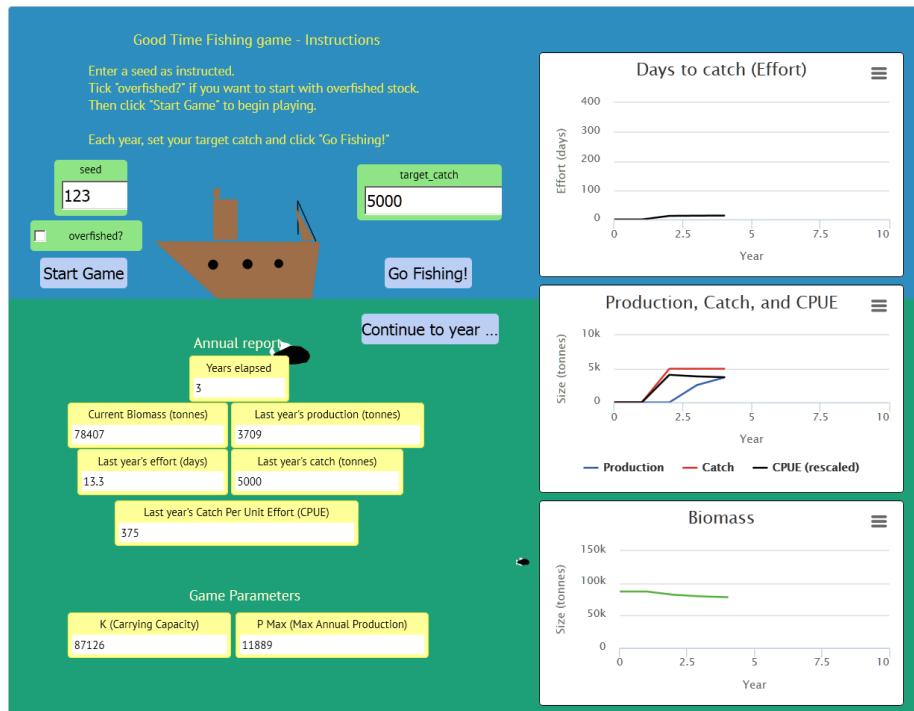


Figure 5.3: White box simulation game

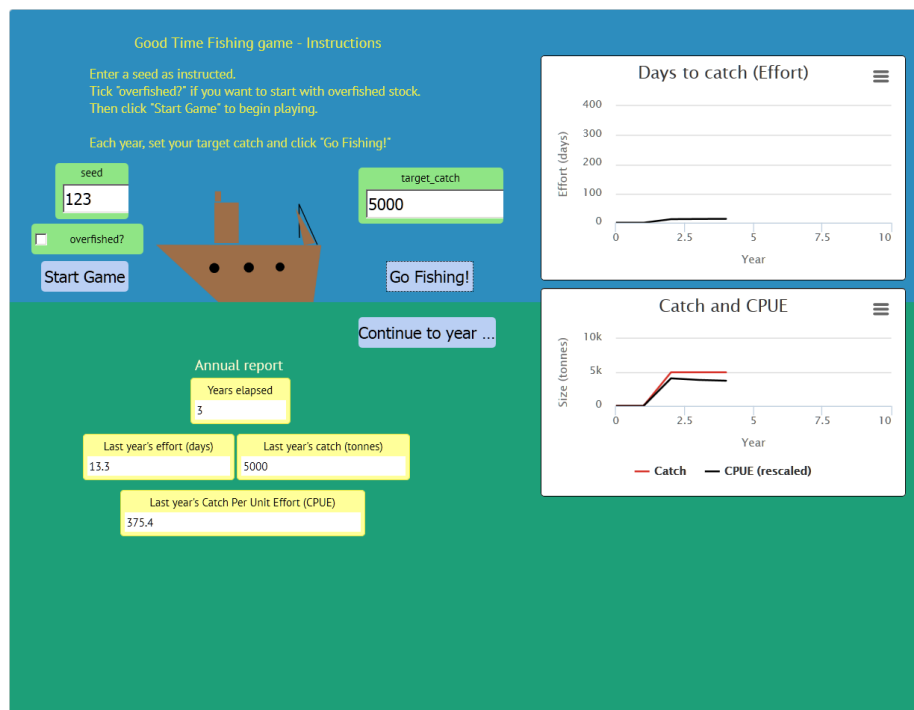


Figure 5.4: Black box simulation game

5.3 Methods

5.3.1 Ethical Approval

The ethical approval of the study was granted to by the General University Ethics Panel (GEUP) at the University of Stirling (see Appendix 8). The consent form and information sheet used in this study are in (see Appendix 2 and 3).

5.3.2 Methodology

The methodologies used in educational research could be qualitative, quantitative, or mixed methods combining both quantitative and qualitative data [219]. The use of mixed methods is encouraged [141] 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 [220]. This approach aims at acquiring different but balancing data on the same research question, thereby allowing cross-validation of results obtained by different methods. The reason for using a mixed-methods 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)” [221]. Mixed-methods design is employed when the researcher wishes to compare directly between quantitative datasets and qualitative results or is utilised for validation or expansion of quantitative data with qualitative results [221].

The mixed methods used in this case study to collect data are quantitative and qualitative methods. For quantitative data, a Learning Effectiveness Survey (LES) [152] was used to ask students to evaluate the effectiveness of their own

learning. a self-efficacy scale [194] was used to measure the students' perception of their capability to carry the simulation using either of the two ways to play the game. A performance test was used to evaluate the performance of the DEMO and USE groups. For qualitative data, an open-ended opinion questionnaire was used to get the opinion of students about the use of interactive simulation and which way of teaching it, i.e. active or passive, is better. Pre-testing of the questions of questionnaire was done by performing a pilot study with a small group of computer science students who participated voluntarily to ensure that the questions were unambiguous and answerable before running the actual study. Also, feedback on the questions of the questionnaires was received from the subject teacher and supervisory team. The purpose of that was to ensure that the questions of the questionnaire are clear and understandable [196].

5.4 Design of Intervention

The study compares the learning effectiveness of two different ways of using the “white box” teaching game with university students in a classroom (computer laboratory) environment. The game is intended to help students to understand the workings of the biomass production model, and to develop the skill of estimating the optimal TAC by observing trends in CPUE. The question 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 intervention was designed following the randomised controlled trial interventional study design [140]. The design of the study is shown in Figure 5.5. The students were split randomly into two groups of roughly equal size. Both groups heard the same lecture separately the DEMO group first then the USE group, lecture was given by the same lecturer, explaining the biomass production model and the relationship between CPUE and optimal TAC. Participants were unaware of which group they were in, both groups were treated identically except for the intervention. The DEMO group 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.

The questionnaire was in two parts. Part one, contained a Learning Effectiveness Survey (LES), based on an instrument developed by [193] to evaluate the effectiveness of learning interventions (see Appendix 10, Appendix 11). This consisted of 14 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 one of the questionnaire make up the quantitative data collected. Part two of the questionnaire contained 6 open-ended feedback questions, providing complementary qualitative data.

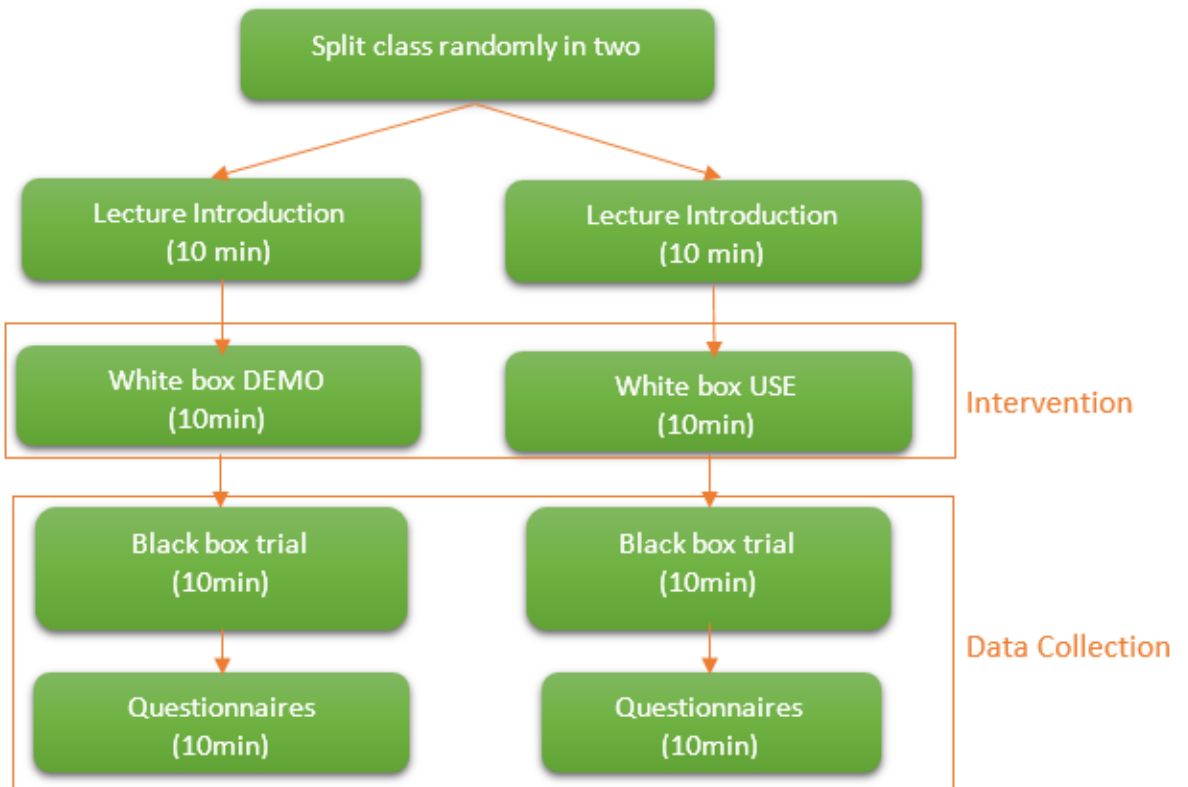


Figure 5.5: Intervention design

The learning effectiveness survey used a Likert scale of 5 scores for each question, where 1 means “not at all” and 5 means “extremely”. The survey contains 14 questions covering all the 5 factors of LES including Knowledge, Skill, Attitude, Learning effectiveness and Long-term learning. The survey responses were collected manually. The details of the survey questions and their associated construct can be seen from Table 5.2.

Q. No	Learning Effectiveness Survey Questions	Construct
1.	How much did you enjoy this class?	Learning Effectiveness
2.	The session began with a presentation by the lecturer. How useful was this for helping you to understand the biomass based production model?	Knowledge

3.	The lecturer then demonstrated how to estimate PMax using a “white box” simulation or you explored how to estimate PMax by using a “white box” simulation yourself. How useful was this for helping you to understand the biomass based production model?	Knowledge
4.	You then did an exercise using a “black box” simulation. How useful was this for helping you to understand the biomass based production model?	Knowledge
5.	How useful was the class as a whole at helping you to understand the biomass based production model?	Knowledge
6.	The lecturer showed you a demonstration of how to estimate PMax using a “white box” simulation or you explored how to estimate PMax using a “white box” simulation yourself. To what extent did you like this method of teaching?	Attitude
7.	To what extent would you have preferred to explore how to estimate PMax using the “white box” simulation yourself, instead of watching the lecturer demonstrate how to do it or to explore how to estimate PMax using the “white box” simulation yourself, instead of watching the lecturer demonstrate how to do it?	Attitude
8.	How well were you able to understand the user interface of the “white box” simulation?	Skill
9.	How attractive did you find the user interface of the “white box” simulation?	Attitude
10.	How well were you able to understand the user interface of the “black box” simulation?	Skill
11.	How attractive did you find the user interface of the “black box” simulation?	Attitude
12.	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?	Attitude
13.	How enthusiastic did you feel about using the “black box” simulation yourself?	Attitude

14.	How much would you like to have more exercises like this as part of your degree?	Long-term learning
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Table 5.2: Learning Effectiveness Survey Questions

5.5 Study participants

Participants were recruited by advertising the experiment through classes that were taught this topic at both undergraduate and postgraduate level by email mailing lists to undergraduate and taught postgraduate students studying Aquaculture and Computing Science in the years 2016 and 2017. 36 students took part in total. 13 participants were Aquaculture students on a master's programme, 17 were undergraduate marine biology students, and 6 were Computing Science undergraduates. 23 participants were male and the remaining 13 students were female. To provide replicate groups, 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 the replicate groups in the analysis to reach an adequate sample size [199], [200] that follows in the next section and compared between the DEMO and USE students from all groups.

5.6 Data Analysis

Participants completed a Learning Effectiveness Survey (LES), in which the answers were selected on an odd Likert scale with the following five values: Not at all, Slightly, Moderately, Very much, and Extremely. These five values were coded as numbers one to five, and then analysed using a Mann-Whitney test because the data was not normally distributed [197]. The Mann-Whitney test was also used to compare the results of the question on self-efficacy [194], [198].

Participants were also tested using a black box game, which they were asked to play several times, recording their estimates 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 and some students did not have time for 6 attempts (21 students each had 6 attempts, with number of attempts ranging from 2 to 12). The error in each student's final guess was measured as square of the difference between the guess and the theoretic true figure, differences between groups of students was tested using ANOVA with the log transformed error-squared [222]. Two students' final guesses were recorded as 0 and these students were excluded from this analysis.

Qualitative data was collected from the open-ended feedback questions were analysed using the NVivo software [205]. The responses were coded into themes and sub-themes for reporting.

5.6.1 Reliability of learning effectiveness survey (LES)

Cronbach's alpha is a popular measure used for internal consistency ("reliability"), frequently used for multiple Likert questions surveys (or questionnaires) that uses a scale. The internal consistency is measured to determine whether the scale is reliable or not. It is also commonly used in combination with statistical methods such as principal components analysis (PCA) a data reduction technique or methods such as factor analysis. It is recommended that the values of Cronbach's alpha are 0.7 or higher [201].

A reliability analysis was conducted on the survey questions used to measure each question in the learning effectiveness survey (LES). The Cronbach's Alpha result was of high levels of reliability (> 0.9).

5.6.2 Validation

The questions of the opinion questionnaire and teacher interview were created based on the same pattern of the learning effectiveness survey, but we were looking for more open-ended answers to verify and validate data gathered from quantitative data in the LES.

Triangulation is a verification procedure that increases the validity of data gathered to remove intrinsic biases or weakness and the issues that come from using a single data collection method. Triangulation is used for the purpose of confirmatory and comprehensiveness. Triangulation means to combine two or more data collection methods for the same study investigating a single phenomenon and is used for convergence on a single construct. Triangulation could be done using both quantitative and qualitative studies for validation and inquiry [202]. Thus, both (Quantitative and Qualitative) results in this case study were compatible [203].

5.7 Results

5.7.1 Quantitative Results: LES

Table 5.3 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.

Q. No	Questions	USE	DEMO	p Value
1.	How much did you enjoy this class?	3	4	>5
2.	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
3.	The lecturer then demonstrated how to estimate PMax using a “white box” simulation or you explored how to estimate PMax by using a “white box” simulation yourself. How useful was this for helping you to understand the biomass based production model?	4	4	>5
4.	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
5.	How useful was the class as a whole at helping you to understand the biomass based production model?	4	4	>5
6.	The lecturer showed you a demonstration of how to estimate PMax using a “white box” simulation or you explored how to estimate PMax using a “white box” simulation yourself. To what extent did you like this method of teaching?	4	4	>5
7.	To what extent would you have preferred to explore how to estimate PMax using the “white	2	3.5	>5

	box” simulation yourself, instead of watching the lecturer demonstrate how to do it or to explore how to estimate PMax using the “white box” simulation yourself, instead of watching the lecturer demonstrate how to do it?			
8.	How well were you able to understand the user interface of the “white box” simulation?	4	4	>5
9.	How attractive did you find the user interface of the “white box” simulation?	3	3.5	>5
10.	How well were you able to understand the user interface of the “black box” simulation?	4	4	>5
11.	How attractive did you find the user interface of the “black box” simulation?	3	4	>5
12.	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
13.	How enthusiastic did you feel about using the “black box” simulation yourself?	4	4	>5
14.	How much would you like to have more exercises like this as part of your degree?	4	4	>5
15.	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

Table 5.3: Comparison of quantitative results from a Mann-Whitney test comparing the USE and DEMO groups.

5.7.2 Performance Test

Students' success at the black box test is the difference between the student's estimate and the correct answer (which is known to the researchers but not to the students). Figure 5.6 illustrates the (log of square of) error in students' estimates in both USE and DEMO groups across all eight replicate classes 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 Figure 5.6. Figure 5.7 shows the distributions of errors in the students estimates at the sixth attempt (final 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, $p = 0.02$).

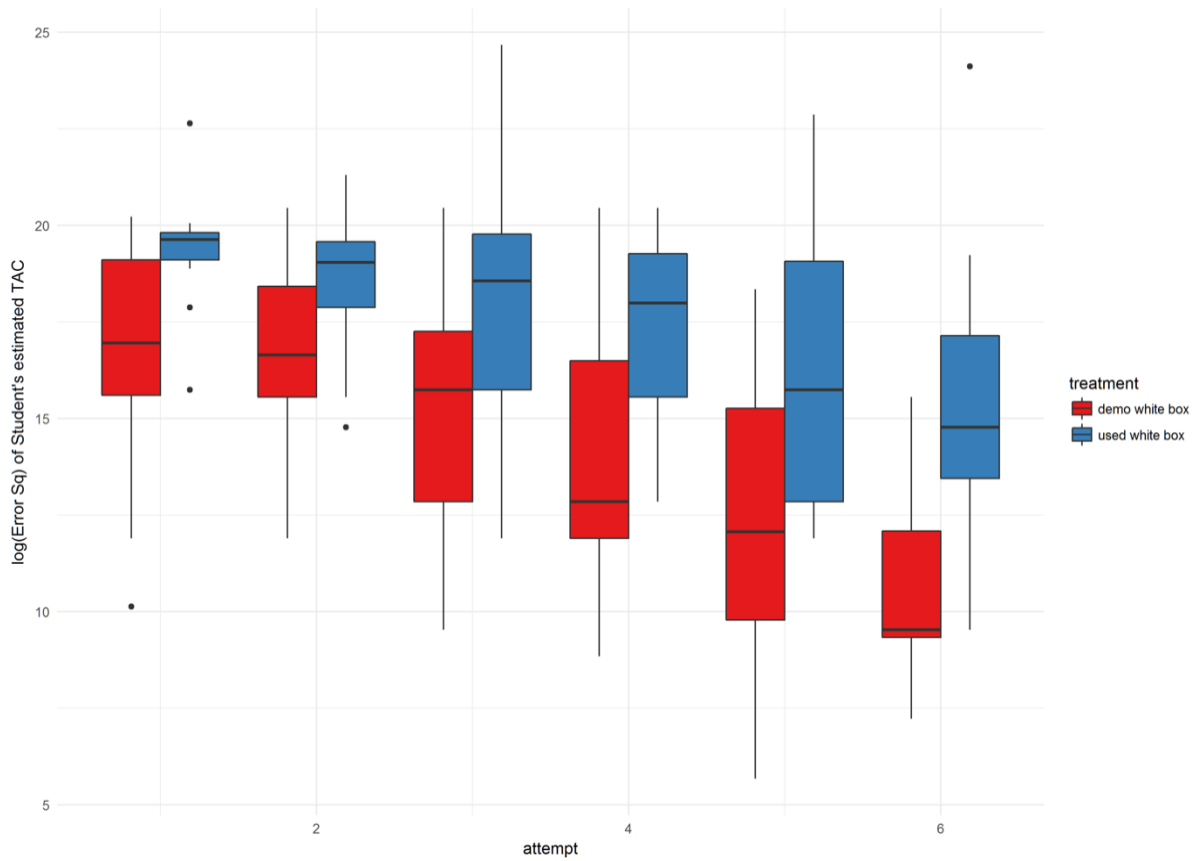


Figure 5.6: Box plots showing the distribution of $\log(\text{Sq}(\text{error}))$ for the USE and DEMO groups across six repeat attempts at playing the black box test game.

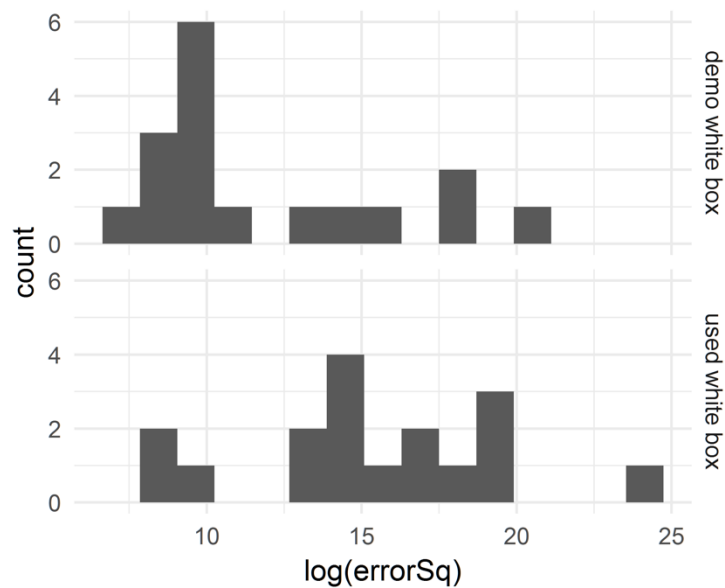


Figure 5.7: Histograms showing the distribution of $\log(\text{Sq}(\text{error}))$ for the USE and DEMO groups at the sixth attempt at playing the black box test game

5.7.3 Qualitative Results: Opinion questionnaire

Framework thematic analysis [223], [224] is used to analyse the open ended responses collected from the opinion questionnaire. Framework analysis is a flexible process for analysing qualitative data, allowing the user to either to do data analysis during the collection process, or collect all the data first and then analyse it. The gathered data is filtered In the analysis stage, recorded and sorted according to main issues and themes [224]. In this study the following six different themes were identified from students responses to the open ended questions. Six themes were identified from the questions.

5.7.3.1 *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 were cited for this, including that using the white box simulation gave the students an idea about what to look for in the black box simulation, helped them to understand some of the concepts effectively before playing with the black box simulation and 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)

5.7.3.2 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 learned better from the lecturer, but he also would have liked exploring the white box simulation himself. His 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, and they liked to play with the tools as it gave them more understanding about estimating the Pmax, 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 about 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)

5.7.3.3 *Best part of the class:*

18 students out 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, and they preferred the hands-on experience, it was interactive, preferred doing it themselves instead listening to it in detail, it was motivating for the students to find the correct number, enjoyed learning by having their hands on the simulation and helped them in understanding the simulation, the less information that was given 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 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, got to see how I affected everything more clearly, 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,

because they liked the lecturer's explanation with having something visual, they can 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)

5.7.3.4 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 Pmax 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 can see all the figures and they can try any numbers, helping them to understand the lecture more, it gave them a chance to practice for the black box simulation, additional information was available in the white box simulation which 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 to understand the concepts. Several reasons were mentioned, including that they were unfamiliar with some of the concepts, the lecturer explained them well, it helped them to 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 an $MSY(P_{max})$ could be estimated and the lecturer's comments put context to the simulation. Another student said the following:

“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.

5.7.3.5 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 include: effectiveness, enjoyable, helpful, interesting, different, more engaging, makes obtaining knowledge easy, helpful in understanding the concept, and it shows 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)

5.7.3.6 Suggestions and Comments

21 students out of the 36 made some suggestions and comments that include: that 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, allow attempts to 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)

5.7.4 Qualitative analysis of lecturer’s interview:

A semi structured interview was conducted with the teacher (see Appendix 11) to get his opinion on the use of NetLogo interactive simulation in teaching the marine ecology model. The questions of the interview were formed to investigate whether interactive simulation is an effective tool for teaching and which method do the teacher think is more effective, a demonstration of the white box simulation or letting the student explore it themselves without an expert demonstration? The questions covered the teacher’s perception on the NetLogo based Interactive

simulation and method of teaching. The teacher was given a copy of the information sheet to read before the start of the interview. The consent form for the interview was also signed. The interview was conducted in the teacher office and a digital recorder was used to record the interview. The interview was transcribed and emailed to the teacher to confirm the accuracy of the teacher answers to avoid any mistake in the translation processes. A framework approach was used to analyse the themes coded from the interview. The teacher found that the NetLogo based interactive simulation model is effective for teaching complex marine ecological models to his students. He thought that an expert's demonstration with the interactive simulation is a better way to teach student. He also thought that students responded very positively to the NetLogo based interactive simulation and found it very effective.

Theme	Implication	Supporting quotation from the teacher's interview
Interactive Simulation	The fact that it was an interactive simulation makes a big difference to the students understanding of it.	"I thought that the simulation went very well, and it definitely helps the students understand that topic much more so than if it was just a lecture material or I think even if it was a lecture backed up with something like paper and pen exercises. I think it's not just the simulation. the fact that it was an interactive simulation makes a big difference to the students understanding of it"
Graphics	I think it made a difference for the students to be able to see graphs	"There were some other features on the simulation because the number of fish in the background image could change but I don't think that made a difference. I think the thing made a difference was that the students can see the graphs"

Effective method of teaching	The DEMO version.	“I think my worry about that was that then they will sit in front of the computer and won’t know how to get started because they hadn’t done it on the computer before. The mechanics of operating the computer might be too slow for them to solve the problem if they don’t have the demonstration but the concepts are quite complicated so I kind of expected that probably the one when I give them the lecture they then find it easier”
Advantages of showing the students an expert demonstration	Coming across much more complicated ideas.	“the relationship between a CPUE variable and the hidden population size variable. You can tell the student and you can show in the demonstration why that is the case. They wouldn’t necessarily pick up on that just from their own experimentation. I think you need to explain points like that to them. So getting across the more complicated concepts I think is the advantage of teaching”
Advantages of letting the students explore the simulation for themselves	Build confidence on solving problem.	“when the students work out something for themselves that should make them more confident that they really understand it but perhaps for some of the poorer students, they then even if they do understand it they are not sure if they got it right so they must be quite dependent on the student and how they feel about their own abilities in the subject themselves”
Use of interactive simulation in future classes	Will definitely continue using it in that module.	“I think I will do it with, as I did with the demonstration. Possibly I can spend more time on it in future because I allocate, usually it’s a three hours lab that’s available so possibly I can allocate more time. It should allow them hopefully to do both things and its not like when we ran the experiment we needed to test the students and see how they reacted to it taking away that element of it allow

		more time for the experimentation. The thing I did in the old version of the software was they played a sort of competitive version.”
Learning Effectiveness	It did improve their skills, knowledge and attitude.	“in terms of the one way I demonstrated it I think it’s very good for teaching them the skills and the knowledge and I suspect they picked up better the way to work out the optimum using the data that was available so their ability to apply mathematical reasoning to the situation was probably better but I think for the ones had more time they had the time to experiment for themselves that probably gives them an improved attitude because they know they are not just following the procedure I just have given them. That’s really them playing the game themselves and solving the problem for themselves. I think that aspect of improving their attitude towards their own ability is probably a good reason to allow them to experiment more.”

Table 5.4: Thematic analysis of teacher interview

5.8 Discussion

The focus of the study conducted in this chapter 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 was conducted for teaching and learning of marine ecology concept in higher education. For this purpose, a difficult concept known as (sustainable management of fisheries) was selected. The study utilised same models (implemented using NetLogo) for both the methods. The findings obtained from this study illustrate that both the students and teacher preferred the interactive simulation with an expert demonstration is more favourable for learning and

teaching purpose of the selected concept, i.e. sustainable management of fisheries.

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 were 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, however, no significant difference was observed. On the other hand, the results obtained using performance test show statistically significant difference in performance of the “DEMO” group over the “USE” group. Lastly, the analysis of the obtained qualitative data demonstrated that majority of the students liked and indicated that the presence of an expert (or teacher) of the field to walk them through the white box simulation are more effective.

This study mainly focusses on comparing the active and passive way of teaching methods using interactive simulation. Such comparison has been already covered in other studies, however, in different context. E.g. The studies conducted in [225], [226] also compare active and passive teaching approaches but according to them, in the case of active, the students were actively using technology, whereas in the case of passive the students only viewed the use of technology. In both studies, they claimed that the performance of active students was better than the students in the passive group. In contrast, the study conducted in this chapter added an additional step of using a black box interactive simulation after the use of white box simulation in both methods, i.e. (active and passive). Furthermore, the results obtained from this study indicate

that the use of passive method, i.e. viewing of white box simulation with expert demonstration followed by active use of black box simulation demonstrate better results than the other group, i.e. who actively use white box simulation without demonstration of an expert followed by active use of black box simulation.

Other examples include studies conducted in [227], [96], where they only focused on active approach of using computer based simulation with or without expert (teacher) guidance. Their study found statistical significant difference between the performance of students who used the computer-based simulation with guided instructions compared to students who use computer-based simulation without any guidance. In contrast, the study in this chapter utilise both the active and passive methods at the first stage followed the active use of black box simulation. However, the results obtained in this chapter agrees with the results of all these studies [227], [96], i.e. the use of interactive computer-based simulation with expert guidance is more effective than the other method, i.e. use of interactive computer simulation without expert guidance.

5.9 Conclusion

This chapter evaluates the more effective method of using interactive simulation game in e-learning environment. The key focus is to determine that the use of interactive simulation game is better with or without an expert guidance in an e-learning classroom environment. For this purpose, a case study of teaching a mathematical model based on a complex adaptive system concept (population growth) known as (sustainable management of fisheries) in the area of marine ecology was selected. The chapter provides and explains the design of the

study, the associated ethical aspects, the adopted methodology, demonstrate the obtained results and the quantitative and qualitative analysis. The key findings of the study were reported. The study suggests that the use of interactive simulation is found to be more effective with an expert demonstration.

Chapter 6 - Conclusions and Future Directions

6.1 Overview

This chapter will summarise the conclusions, future directions and limitations of the work presented in previous chapters. It also focuses on the findings and contributions of the studies conducted. The first section of this chapter provides a summary of previous chapters. It also discusses the research question of this thesis and the answers through various case studies. The overall original contribution this thesis made will then be discussed, the chapter then concludes with presenting the limitations of the research and future research directions.

6.2 Conclusions

At the beginning in chapter one, the relationship amongst this thesis and the fields of HCI and E-Learning was justified. Both fields are associated to computer science because the case studies in this thesis involved the use of interactive computer-based simulation in the teaching and learning of complex concepts in ecology and marine ecology to university students in an e-learning classroom environment. The effectiveness of the interactive computer-based simulation was evaluated by the students. Examples from previous research were presented, where the effectiveness evaluation of computer-based simulations in teaching different complex concepts to students of different levels in higher education were investigated.

In chapter two, the importance and advantages of using computer-based simulation in educational settings were highlighted. Also, different definitions of simulation and associated terms were discussed. Different categories of

computer-based simulations were presented based on the pedagogies used in those simulations; instructive or constructive. Different examples of investigating the effectiveness of using computer-based simulation in school education were mentioned. Various examples of investigating the effectiveness of using computer-based simulation in higher education were cited. Some scenarios of using computer-based simulation in business management training were also mentioned. In addition, the use of computer-based simulation in teaching ecological concepts to students at secondary-school level or university-level were presented. These case studies demonstrated that utilisation of computer-based simulations provides an effective tool to teach ecological concepts. Several other examples were presented which demonstrated that the use of computer-based simulations is an effective tool in teaching the complex concepts of fish sustainability in marine ecology.

All the scenarios in chapter two demonstrated that using computer-based simulation is an effective tool in students teaching and staff training. The literature review also demonstrated that few of the studies utilised quantitative data only to evaluate the effectiveness of computer-based simulation and few of the researchers used mixed methods to evaluate the effectiveness of computer-based simulation.

The state-of-the-art review in chapter two, showed that computer-based simulation was used in teaching ecology or marine ecology, but the comparison was done either to compare the use of computer-based simulation to the traditional way of teaching without computers, or in a quasi-experimental way where the performance of students was evaluated before and after introducing

the computer-based simulation. The review identified a gap in studies and lack of interactive computer-based simulation uptake in higher education to teach concepts of ecology and marine ecology. Also, the effectiveness evaluation was analysed by comparing traditional learning methods (oral lectures) and the use of computer-based simulation, or by comparing two different settings of using the simulation in terms of duration (short-term versus long-term), or in term of comparing the use of the simulation in a restricted setting versus open access setting. In light of the review, a novel way of experimenting with interactive computer-based simulation in teaching complex concepts of ecology and marine ecology was presented.

In chapter three, different types of research paradigms were identified and an explanation regarding the selected research paradigm (for case studies) was provided accordingly. This thesis used a pragmatic research paradigm (mixed methods). This thesis used a pragmatic paradigm in evaluating the use of interactive computer-based simulation as an intervention in the case studies of teaching complex concepts of ecology and marine ecology in a university classroom environment. Different types of case studies were also presented in chapter three. This thesis used multiple evaluative and experimental case study approaches to investigate the use of interactive computer-based simulation in teaching ecology and marine ecology concepts to university students in classroom environment. It also used mixed data collection tools to measure the learning effectiveness of the participants. The learning effectiveness evaluation of the participants who used interactive computer-based simulation in learning ecology and marine ecology concepts was done, using the Learning

Effectiveness Survey (LES), to measure the learning effectiveness of the interventions in each case study. Open-ended questionnaires were also used to gather qualitative data from the participants, a performance test was also done in one of the studies to measure students' performance. Moreover, semi-structured interviews were conducted to gather data from the module teachers

This thesis posed four research questions: Will introducing the use of agent based interactive simulation in a university classroom to teach complex adaptive system such as ecology be an effective tool, what is more effective the use of agent based interactive simulation or a non-interactive computer base simulation?, Will the use of interactive simulation as serious game in teaching complex concepts such as marine ecology to university students be an effective tool, what approach of using the interactive simulation is better? Using the black box interactive simulation after active exploration of the white box simulation or using the black box simulation after passive viewing of an expert demonstration of the white box simulation.

Each of the research questions have been discussed in relation to their findings, to what extent they have been answered and the limitations encountered during the research will be discussed.

In chapter four, a case study about the use of an interactive simulation model to determine its effectiveness against the non-interactive version for learning and teaching purposes. This work is carried out with the help of a case study based on teaching of complex adaptive systems concepts in subjects such as ecology. The case study was conducted in an e-learning classroom environment. The

chapter provides and explains the design of the study, the associated ethical aspects, the adapted methodology, demonstrate the obtained results and the quantitative and qualitative analysis. The key findings of the study were reported. The study suggest that the use of interactive simulation is more effective in teaching and learning against the non-interactive counterpart. The responses obtained from the study participants were more favoured towards interactive simulation because of their interactivity and easy to use features.

The study conducted in this chapter assist the main goal of this thesis, which is to investigate the effectiveness of interactive simulation as an e-learning tool in higher education considering the regular students in classroom environment. The case study was conducted in a comparative setting to identify the effective tool between interactive and non-interactive based simulation for learning the same concepts. For this purpose, a difficult concept known as (Spatially-explicit predator prey interaction model) from Ecology domain was selected. The study utilised an R based non-interactive and a NetLogo based interactive models. The findings obtained from this study illustrate that both the students and teacher preferred the interactive based version of simulation for learning and teaching purpose of the selected concept, i.e. (Spatially-explicit predator prey interaction model). The main reasons for their preference summarised from qualitative data include some of the following aspects facilitated by the interactive version of the model: the capability of the interactivity and engagement with the model during the simulation time, ease and enjoyable procedure, feel like playing as a game.

The case study interventions were performed in three stages, where students were divided into two groups. Each of the group was given the chance to

experiment using both version of the simulations. The results obtained from first two stages were of quantitative nature, whereas, qualitative data were gathered in the last stage from all participants as well as the course teacher. The analysis of quantitative data indicates statistically significant difference at stage 1 in 15 out of 16 survey questions. However, at the stage 2, statistically significant difference was observed in 5 amongst 16 questions. The key reason behind the difference between stage 1 and stage 2 results was the improved knowledge of the students for the underlying concept, i.e. (Spatially-explicit predator prey interaction model) during stage 1. The obtained qualitative data are further analysed to validate the results and findings of the quantitative data. The qualitative data was analysed using NVivo software [204], [205] based on students' responses to the different open-ended questions belonged to ten different themes. The analysis of the participant responses hinted that the use of interactive simulation was the favourite choice and concluded as more effective due to the interactivity and engagement features during simulation time in comparison with the non-interactive version of the same model.

The overall analysis of both kind of results demonstrated that the use of interactive simulation can improve the e-learning experience in classroom environment. The findings of this study adhered some of the existing studies in this domain. E.g. the findings of the studies conducted in [107], [114], [206] informs the effectiveness of computer simulation programs as tutorial tool for teaching biology to students of different levels. Their findings conclude that the use computer simulation programs helped students to understand the dynamic nature of biological (and ecological) phenomena and how these can be

resembled using mathematical models. Analogously, the study conducted in this chapter approached at similar findings. However, the study focused in this chapter was to demonstrate the effectiveness of interactive against non-interactive simulation, whereas, the studies conducted in [107], [114], [206] were focused on the computer based simulations in general against traditional method of teaching. The closely related work to this chapter is the study conducted in [207], where they have studied the effectiveness of interactive simulation versus non-interactive simulation for emergency preparedness scenario. The findings reported in this chapter corroborated earlier findings and reaffirmed the fact that the use of interactive simulation for learning and training purposes is more effective in contrast to non-interactive simulation.

In chapter five, a case study was presented which evaluates the more effective method of using interactive simulation in e-learning. The key focus is to determine the use of interactive simulation is better with or without an expert guidance in an e-learning classroom environment. For this purpose, a case study of teaching a complex subject known as (sustainable management of fisheries) in marine ecology was selected. This chapter explains the design of the study, the adopted methodology, demonstrate the obtained results and the quantitative and qualitative analysis. The key findings of the study were reported. The study suggests use of interactive simulation to be more effective with an expert demonstration. The focus of the study conducted in this chapter 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 was conducted for teaching and learning of marine ecology

concept in higher education. For this purpose, a difficult concept known as (sustainable management of fisheries) was selected. The study utilised same models (implemented using NetLogo) for both the methods. The findings obtained from this study illustrates that both the students and teacher preferred the interactive simulation with an expert demonstration to be more favourable for learning and teaching purpose of the selected concept, i.e. sustainable management of fisheries. 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 were 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, however, no significant difference was observed. On the other hand, the results obtained using performance test show statistically significant difference in performance of the “DEMO” group over the “USE” group. Lastly, the analysis of the obtained qualitative data demonstrated that majority of the students liked and indicated that the presence of an expert (or teacher) of the field to walk them through the white box simulation are more effective. This study mainly focusses on comparing the active and passive way of teaching methods using interactive simulation. Such comparison has already been covered in other studies, however, in a different context. The studies conducted in [225], [226] also compare active and passive teaching approaches but according to them, in the case of active, the students were actively using technology, whereas in the case of passive the students only viewed the use of technology. In both studies, they claimed that the performance of active students was better than the students in

the passive group. In contrast, the study conducted in this chapter added an additional step of using a black box interactive simulation after the use of white box simulation in both methods, i.e. (active and passive). Furthermore, the results obtained from this study indicate that the use of passive method, i.e. viewing of white box simulation with expert demonstration followed by active use of black box simulation demonstrate better results than the other group, i.e. who actively use white box simulation without demonstration of an expert followed by active use of black box simulation.

Other examples include studies conducted in [227], [96], where they only focused on active approach of using computer based simulation with or without expert (teacher) guidance. Their study found statistical significant difference between the performance of students who used the computer-based simulation with guided instructions compared to students who use computer-based simulation without any guidance. In contrast, the study in this chapter utilise both the active and passive methods at the first stage followed the active use of black box simulation. However, the results obtained in this chapter agrees with the results of all these studies [227], [96], i.e. the use of interactive computer-based simulation with expert guidance is more effective than the other method, i.e. use of interactive computer simulation without expert guidance.

6.3 Contributions to Knowledge

This section highlights and discusses the original contributions made in this thesis.

6.3.1 A Novel Interactive Agent-based Simulation Methodology for effective e-Learning Design.

In the first study, the use of interactive agent-based simulation was demonstrated. An agent-based interactive simulation was utilised as an e-learning methodology to teach concepts of complex adaptive systems (predator-prey interaction) in subjects such as ecology, in university classroom environment. The study also, evaluated the learning effectiveness of the agent-based interactive simulation. The new proposed interactive agent-based simulation was preferred by both students and the lecturer as it allowed learners to interact and engage with the simulation more than the non-interactive simulation and helped the students to learn the complex ecological model in an easy and enjoyable way, with some students describing it as a game. The study concludes that using interactive simulation is an effective methodology to learn complex adaptive systems concepts in subjects like ecology. 38 university students successfully used the NetLogo (Interactive) and R (non-interactive) models. Mixed methods (LES + Opinion Questionnaire) were used to collect data during the evaluating process.

6.3.2 A Novel Interactive Simulation Game Approach based on expert guidance for effective e-Learning Design.

The second study demonstrated the effectiveness of developing and exploiting interactive simulation as a serious game, through involvement of human experts, to further enhance effectiveness of teaching a mathematical model based on a complex adaptive system concept (population growth) in subjects such as marine ecology to university students. The second study conducted an experimental evaluation of utilising interactive simulation as serious game in teaching complex

concepts of marine ecology to 36 undergraduate and postgraduate students in the University of Stirling. A novel approach of utilising interactive simulation game was experimented and evaluated by comparing two methods of using the new interactive simulation game; 1- In the first method, the students used the active exploration-based method, where they used the white box interactive simulation as a teaching game without an expert (teacher) demonstration. The teaching game was then followed by a black box interactive simulation as a testing game, or 2- In the second method, the white box interactive simulation was demonstrated by the expert (teacher) with passive viewing of students (i.e. without the active exploration by the students). This then was followed by using the black box simulation (i.e. the testing game). The results of the experiment and the evaluation for the learning effectiveness of the new interactive based simulation was done by using mixed evaluation tools in experimental design. The learning effectiveness survey showed no significant difference in the results but the mean of the students in the group who heard the teacher demonstration (DEMO) was higher than the mean of the group who actively explored the simulation without a lecturer demonstration (USE) for the some of the questions. However, results for the black box simulation (testing game) showed statistically significant difference in performance of the DEMO group over the USE group. This shows the learning effectiveness of using the black box interactive simulation after a passive viewing of a teacher demonstration of the white box interactive simulation compared with of the active exploration-based learning method without any teacher demonstration. The open-ended questionnaire showed that students preferred the use of the interactive simulation with teacher demonstration for teaching fishery management.

6.4 Limitations

Recruiting students to participate voluntarily in a real classroom environment to evaluate an intervention became a very difficult and time-consuming process. As it is required ethically to let the students participate voluntarily and if they chose not to participate then that should not affect their studies or marks, which made it difficult to get enough participants in the case studies. For example, in the first study the intervention was part of a compulsory class, so we couldn't design the intervention in a true experimental design, so we designed it as a crossover repeated intervention. In the second case study we were able to design the study in a true experimental design as participants were invited to participate in an extra lab and not part of their class which made it ethically possible to perform the study in a true experimental design but the number of students who participated in the intervention were less than the actual number of the students enrolled for the marine ecology module. Case studies were part of actual university modules which means that controlling the timing of the interventions and number of students participating was something beyond the power of the researcher.

6.5 Generalisability

This research has shown that interactive computer-based simulation is an effective tool in teaching complex concepts in subjects such as ecology to university students than the use of non-interactive computer-based simulation. It has also shown that it is an effective tool in teaching complex concepts in teaching subjects such as marine ecology to university students with an expert demonstration of the interactive simulation serious game instead of students exploring the simulation game on their own. The study was carried out with higher

education students from the University of Stirling. However, there is an issue of generalisability in this type of research, where interactive computer-based simulation or game-based learning have been used for teaching [228]. Although interactive computer-based simulation can be effective for learning different subjects, this does not inform us whether to use interactive computer-based simulation to teach a specific instructional concept in a certain way. Thus, we should not generalise on the effectiveness of one interactive computer-based simulation for a group of learners of a particular subject or concept to all interactive computer-based simulations for all learners or for all subjects. Generalisability is an issue of concern for the future of investigating the effectiveness of interactive-computer based simulation in education. Since it is impossible to take one interactive computer-based simulation and apply it in an area and then proceed to make generalisations. This is because the nature of case study research focuses on one aspect of a problem, conclusion drawn from the case study will not be generalised but rather related to one particular event [142].

6.6 Future Direction

There are many areas of future research that have been recognised throughout this PhD project. The use of agent-based interactive simulation could be introduced and explored further in teaching concepts of psychology such as modern theories of cognition, instruction, and learning. This will allow students to engage in an effective interactive e-learning environment from which they will be able to construct psychological models. As learning from real scenarios can be costly and is sometimes not enough and is commonly not practical for various

learning tasks. Hence, for effectiveness and learning efficiency the use of interactive simulations, micro worlds or any interactive learning environments could be suggested and experimented [229]. An interactive agent-based simulation model could be introduced as an e-learning tool to students of Psychology in a higher education level to investigate the effectiveness of teaching Psychological concepts with the use of interactive simulation in classroom environment.

Another area where the use of interactive simulation could be experimented and explored further is training employees in business data visualisation. Agent-based modelling and simulation in the field of data visualisation plays a key role in conveying, understanding and identifying the appropriate behaviours of models [230]. Agent based modelling and simulation could also provide a simulation of large markets showing interactions of consumers in a way that imitate real life interactions. Consequently, the use of interactive simulation tools in business training could influence powerful ideas to complex business problems [231]. This could be introduced to industries interested in using data visualisation and training of employees, to evaluate the effectiveness of utilising interactive simulation for training of company employees.

To further enhance effectiveness of interactive agent-based simulation, as a teaching methodology, a multi-level agent-based simulation framework could be developed. This could potentially serve as a unifying framework to promote further cross fertilisation of ideas in the complementary interdisciplinary fields of HCI, e-learning, gamification and complex adaptive systems.

Other challenges needing addressed in the future, include extending the current study to larger cohorts and exploring the potential effectiveness of serious games and interactive simulation-based teaching methods, for a range of complex STEM subjects, both in University and School settings. Also, the effectiveness of Intelligent Tutoring Systems (ITS) [232], [233] as Interactive learning systems in teaching STEM subjects, both in University and School settings could be explored. Finally, the unstructured qualitative feedback of participants can also be semantically evaluated in the future, by determining the polarity of participants' sentiments and opinions, using Artificial Intelligence (AI) and natural language processing techniques e.g. [234].

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Appendix 1

[Fwd: Ethics application, Omair Ameerbakhsh 2131092]

Psychology Ethics Submissions <psychethicssubs@stir.ac.uk>

11 November 2015 at 19:52

To: Omair Ameerbakhsh <oal@cs.stir.ac.uk>

Cc: Savi Maharaj <sma@cs.stir.ac.uk>, Psychology Ethics Submissions <psychethicssubs@stir.ac.uk>

Dear Omair,

Thank you for your ethics application. Your project titled:

"Towards an Interactive Simulation Framework for effective Blended-learning in University Classroom environments.
has been approved by the Psychology Ethics Committee.

Regards,

Lindsay

Lindsay Wilson

Chair, Psychology Ethics Committee

Appendix 2

Information Sheet

Project Title: Towards the use of Interactive Simulation for effective E-Learning in University Classroom environments

Researcher's name: Omair Ameerbakhsh

Principal Supervisor's name: Professor Amir Hussain

Second Supervisor's name: Dr Savi Maharaj

What is the research project about?

The purpose of this research is to compare different ways of using interactive computer simulation in teaching concepts in Aquaculture, to discover which is the most effective.

How do I take part?

The researcher will provide you with a consent form which you will sign to say you have agreed to participate in a laboratory practical and to complete a questionnaire for this research.

What will happen to what I write in the questionnaire?

With your consent, the scores and feedback from the questionnaires will be analysed by the researcher and used in a PhD thesis and academic publications. The questionnaires will be stored securely at the University of Stirling for as long as needed to complete the analysis, and will then be destroyed.

Will anyone find out what I wrote?

We will not use your name or registration number or any other personally identifying data in our data analysis or reporting.

What happens if I do not want to take part or if I change my mind?

You can change your mind at any time during the lab experiment and withdraw from participating and this will have no effect on the module you are studying.

What will happen at the end of the research?

The researchers will use the results of the study to inform the way that interactive computer simulation is used in teaching in Aquaculture and similar subjects.

What if something goes wrong? Who should I contact?

The researcher has been trained to help you with the simulation or how to answer the questionnaire. If you have any questions about the research study, please contact the researcher, Omair Ameerbakhsh, on oaal@cs.stir.ac.uk

Appendix 3

Towards the use of Interactive Simulation for effective E-learning in University Classroom environments

Consent Form

Tick

I agree to take part in a laboratory practical and to complete a questionnaire for this research

I understand that the information from this questionnaire will be used in any publications produced by the researchers

I understand that no information that could lead to me being identified will be shared in any reports or with anyone else

I understand that involvement is voluntary I can withdraw from the research at any time until November 2017

Signed

Date

Print
name

If you would like to be contacted later to learn about the results of the experiment, please complete the details below:

How would you like to be contacted in future? (please tick)

Phone

Text message

Email

Contact details (phone number, address or email address)

If you have any questions about the research study, please contact Omair Ameerbakhsh on oa1@cs.stir.ac.uk
This study has been reviewed according to Stirling University IRB procedures for research involving human subjects.

Appendix 4

Preview Survey: Post NetLogo Questionnaire Ecology Case Study

Survey Information

Description Please fill this questionnaire after using the Netlogo model

Instructions

Multiple Attempts This Survey allows multiple attempts.

Force Completion Once started, this survey must be completed in one sitting. Do not leave the survey before clicking **Save and Submit**.

Question Completion Status:

QUESTION 1

Please specify your group:

- A
- B

QUESTION 2

Have you used Netlogo before?

- Yes
- No

QUESTION 3

Age

- 18 -22
- 23 – 25
- 26 or above

QUESTION 4

Sex

- Male
- Female

QUESTION 5

Computing Programming Skills

- Beginner
- Intermediate
- Skilled

QUESTION 6

To what extent do you feel that you have learned from this version of the model in today's lab practical? (1 = nothing, 6 = a lot)

- 1
- 2
- 3
- 4
- 5
- 6

QUESTION 7

To what extent do you feel that the model helped you to explore the linkages between ecological processes and their representations in models? (1 = not at all, 6 = very much)

- 1
- 2
- 3
- 4
- 5
- 6

QUESTION 8

To what extent do you feel that the model helped you to explore how explicitly accounting for space affects ecological interactions? (1 = not at all, 6 = very much)

- 1
- 2
- 3
- 4
- 5
- 6

QUESTION 9

To what extent do you feel that the model helped you to explore ways to predict the outcome of predator-prey interactions? (1 = not at all, 6 = very much)

1 2 3 4 5 6

QUESTION 10

To what extent do you feel that the model helped you to design and execute a modelling study of predator-prey dynamics? (1 = not at all, 6 = very much)

1 2 3 4 5 6

QUESTION 11

How effective was this version of the model at helping you learn the key concepts? (1 = not effective, 6 = highly effective)

1 2 3 4 5 6

QUESTION 12

How easy was this version of the model to use? (1 = very difficult, 6 = very easy)

1 2 3 4 5 6

QUESTION 13

How engaging did you find the exercise using this version of the model? (1 = very boring, 6 = highly engaging)

1 2 3 4 5 6

QUESTION 14

How visually attractive did you find the user interface in this version of the model? (1 = not at all, 6 = very attractive)

1 2 3 4 5 6

QUESTION 15

How much did this version of the model help you understand the spatially-explicit predator prey concept? (1 = not at all, 6 = very much)

1 2 3 4 5 6

QUESTION 16

How able were you to manipulate this version of the model, as requested in the lab handout? (1 = very difficult, 6 = very easy)

1 2 3 4 5 6

QUESTION 17

How capable were you to evaluate the first suggested hypothesis: “the probability of prey survival decreases as their speed decreases and the predator speed increases”? (1 = not capable at all, 6 = very capable)

1 2 3 4 5 6

QUESTION 18

How capable were you to evaluate the second suggested hypothesis: “increasing the predator’s search radius decreases the probability of stable coexistence, whereas decreasing the search radius increases it...”? (1 = not capable at all, 6 = very capable)

1 2 3 4 5 6

QUESTION 19

How capable were you to investigate the third suggested hypothesis: “changing the resources needed for reproduction for predator and prey would affect their population sizes and stability”? (1 = not capable at all, 6 = very capable)

1 2 3 4 5 6

QUESTION 20

If you were unable to do all four manipulations described above, what difficulties did you experience? (Example: lack of time, software problems, etc).

QUESTION 21

How enthusiastic were you about using this version of the model? (1 = not at all, 6 = very much)

1 2 3 4 5 6

QUESTION 22

How much do you feel that this version of the model will help you in completing your assignment? (1 = not at all, 6 = very much)

1 2 3 4 5 6

QUESTION 23

Please rate how confident you feel about your ability to run and manipulate the simulation.

Rate your degree of confidence by recording a number from 0 to 100 using the scale given below Tick one:

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all
confident

Moderately can do

Highly

0 1 2 3 4 5 6 7 8 9 10
0 0 0 0 0 0 0 0 0 0

Click Save and Submit to save and submit. Click Save All Answers to save all answers.

Save and Submit

Appendix 5

Preview Survey: Post R Questionnaire Ecology Case Study

[Survey Information](#)

Description Please fill this questionnaire after using the R model

Instructions

Multiple Attempts This Survey allows multiple attempts.

Force Completion Once started, this survey must be completed in one sitting. Do not leave the survey before clicking Save and Submit.

✖ Question Completion Status:

QUESTION 1

Please specify your group:

Please specify your group

A

B

QUESTION 2

Have you used R before?

Yes

No

QUESTION 3

Age

18 - 22

23 - 25

26 or above

QUESTION 4

Sex

- Male
- Female

QUESTION 5

Computing Programming Skills

- Beginner
- Intermediate
- Skilled

QUESTION 6

How much do you feel that you learned from this version of the model in today's lab practical? (1 = nothing, 6 = a lot)

- 1 2 3 4 5 6

QUESTION 7

To what extent do you feel that the model helped you to explore the linkages between ecological processes and their representations in models? (1 = not at all, 6 = very much)

- 1 2 3 4 5 6

QUESTION 8

To what extent do you feel that the model helped you to explore how explicitly accounting for space affects ecological interactions? (1 = not at all, 6 = very

much)

1 2 3 4 5 6

QUESTION 9

To what extent do you feel that the model helped you to explore ways to predict the outcome of predator-prey interactions? (1 = not at all, 6 = very much)

1 2 3 4 5 6

QUESTION 10

To what extent do you feel that the model helped you to design and execute a modelling study of predator-prey dynamics? (1 = not at all, 6 = very much)

1 2 3 4 5 6

QUESTION 11

How effective was this version of the model at helping you learn the key concepts? (1 = not effective, 6 = highly effective)

1 2 3 4 5 6

QUESTION 12

How easy was this version of the model to use? (1 = very difficult, 6 = very easy)

1 2 3 4 5 6

QUESTION 13

How engaging did you find the exercise using this version of the model? (1 = very boring, 6 = highly engaging)

1 2 3 4 5 6

QUESTION 14

How visually attractive did you find the user interface in this version of the model? (1 = not at all, 6 = very attractive)

1 2 3 4 5 6

QUESTION 15

How much did this version of the model help you understand the spatially-explicit predator prey concept? (1 = not at all, 6 = very much)

1 2 3 4 5 6

QUESTION 16

How easy did you find it to manipulate this version of the model, as requested in the lab handout? (1 = very difficult, 6 = very easy)

1 2 3 4 5 6

QUESTION 17

How capable were you to evaluate the first suggested hypothesis: “the probability of prey survival decreases as their speed decreases and the predator speed increases”? (1 = not capable at all, 6 = very capable)

1 2 3 4 5 6

QUESTION 18

How capable were you to evaluate the second suggested hypothesis: “increasing the predator’s search radius decreases the probability of stable coexistence, whereas decreasing the search radius increases it...”? (1 = not capable at all, 6 = very capable)

1 2 3 4 5 6

QUESTION 19

How capable were you to investigate the third suggested hypothesis: “changing the resources needed for reproduction for predator and prey would affect their population sizes and stability”? (1 = not capable at all, 6 = very capable)

- 1 2 3 4 5 6

QUESTION 20

If you were unable to do all four manipulations described above, what difficulties did you experience? (Example: lack of time, software problems, etc).



QUESTION 21

How enthusiastic were you about using this version of the model? (1 = not at all, 6 = very much)

- 1 2 3 4 5 6

QUESTION 22

How much do you feel that this version of the model will help you in completing your assignment? (1 = not at all, 6 = very much)

- 1 2 3 4 5 6

QUESTION 23

Please rate how confident you feel about your ability to run and manipulate the simulation.

Rate your degree of confidence by recording a number from 0 to 100 using the scale given below Tick one:

0 10 20 30 40 50 60 70 80 90 100

Cannot do at all
confident

Moderately can do

Highly

0 1 2 3 4 5 6 7 8 9 10
0 0 0 0 0 0 0 0 0 0 0

Click Save and Submit to save and submit. Click Save All Answers to save all answers.

Save and Submit

Appendix 6

Preview Survey: Collecting Opinion Ecology Case Study

Survey Information

Description Please fill this questionnaire after completing the post R and post Netlogo questionnaires

Instructions

Multiple Attempts This Survey allows multiple attempts.

Force Completion Once started, this survey must be completed in one sitting. Do not leave the survey before clicking Save and Submit.

▼ Question Completion Status:

QUESTION 1

What software did you like better?

- R
- Netlogo

QUESTION 2

Please explain the reason why you liked it?

QUESTION 3

Which one do you think is more powerful?

- R
- Netlogo

QUESTION 4

Which software helped you to learn the concept more effectively?

- R
- Netlogo

QUESTION 5

If you had the option of only using one software for this simulation, which one would you chose?

- R
- Netlogo

QUESTION 6

What are the advantages of the R model compared to the Netlogo model?

QUESTION 7

What are the disadvantages of the R model compared to the Netlogo model?

QUESTION 8

What are the advantages of the Netlogo model compared to the R model?

QUESTION 9

What are the disadvantages of the Netlogo model compared to the R model?

QUESTION 10

Any suggestions / comments for improvement of both models?

QUESTION 11

If you are willing to participate in a short interview, then please provide your email address:

Appendix 7

Ecology Teacher Interview Transcript

Me: Q1- What made you look for another software than R?

Ecology Teacher: Really it was an opportunity that came up there is a student there in computing science a visiting student that came from France who wanted to get experience in model and took a model that I have written in R and made it in Netlogo and so it was really building out of that I did not do this with the intention of trying to find something else but it was an opportunity that presented itself.

At that time, I hadn't made it as a practical for teaching I had just made that model something that is interesting and it turned out to something that is useful in teaching and then I got involved in to Savi and she suggested that we make in Netlogo so it really just happened by chance.

Me: Q2- How did you find Netlogo? I.e. did it fulfil what you were looking for?

Ecology Teacher: Yes, it did. I am tempted to look at Netlogo as a toy programme as something that is not feature rich and maybe not as robust as another modelling platform.

Me: so, as a game like game-based learning.

Ecology Teacher: Yes, as game. As a game and part of that because of it kind of looks like a game. With little wolves and a little mmmm.

Me: and Interactive as well.

Ecology Teacher: Yeas and I think that as a teaching tool that could be very useful. It's good to have something that's approachable and not intimidating for

students who to be honest have not had a lot of experience in doing these things before.

Me: Did you find it more interactive than R?

Ecology Teacher: mmm so we will come back to this I am sure later. But what I realised during the practical is that I had written a revised version of the model in R that made prettier graphs and what the students actually used was an older version where the graphics part of it wasn't very good and so in the end graphically the Netlogo programme that the students used was much better, much more attractive than that.

Me: it was but simple (Netlogo version), it could be more developed, and it could've been more interactive as well.

Ecology Teacher: Yes, it could. It could've been.

Me: The thing I was looking for was looking for was interactivity, playing with the pictures. I think with R my experience was you just get the picture coming and you just seem and you can interact with them.

Ecology Teacher: Yes, well you can't interact with the Netlogo pictures either.

Me: Aha.

Ecology Teacher: But with Netlogo for example you can adjust the parameters for the model during the run, which can be good but if you are interested in seeing how does changing something affect the outcome, you don't want to change it in the middle of the stream. You want them to do it at the beginning and let it run and then change it and then run it again. So I think Yes I was happy with it, with the Netlogo model but I still think that honestly both models could be improved.

Me: Yes.

Ecology Teacher: and so that was the third year that I have taught this particular course and each year it changes and each time I hope it get a little bit better and next year I can learn from this years' experience. And do it again.

Me: hopefully yes.

Me: Q3- Can you explain your answer above?

Did not ask this question because there was a lot of explanations in the second question that made me skip the third question.

Me: Q4- Can you kindly tell us some features of Netlogo that you didn't find in R?

Ecology Teacher: Well that ability, the ability to change parameters values during a model run that is something you can't do in R also the ability to make multiple graphs during run of the simulation you can do that in Netlogo but it's not easy to do that in R. The graphing capabilities of "R" are good but they are not that good. So that type of dynamic figure that type of dynamic graphic something it can be done in NetLogo.

Me: Q5- From your point of view what do you think are the advantages of the NetLogo model over the R model?

Ecology Teacher: So, abstraction is probably the key thing. What I mean by that is in NetLogo the students never will have to see the code they never even have to see anything that looks like code they can deal with a graphical user interface, they can deal with the entire model using their mouse, they never have use the keyboard so I think for a lot of students that is attractive. In the "R" model I have abstract a lot of the code I have functions and hidden them from the students and that's good but still they have to run a short script in order to

start the model, set parameters and run the model. and so I think that a good thing in Netlogo that it is so easy to run as a graphical user interface. In the other hand, R is a really useful software package not only for types of models that we used in this course but for what most scientists use it for, is Statistics.

Me: Yes.

Ecology Teacher: It is incredibly good statistical platform.

Me: Yes.

Ecology Teacher: And so, I think it is actually very useful thing that students do engage with the code to some degree. It is not a programming class in the other hand. Right! So having.

Me: It's a tool used to assist in teaching.

Ecology Teacher: Exactly.

Me: This is what we are trying to look for.

Ecology Teacher: Exactly, I am trying to use this model and use "R" and used NetLogo to make concrete some of the theories and some of the concepts that we discuss.

Me: So, you are already using e-learning (Educational Technology) you are using "R" but we wanted to do a comparison between using normal coding software and bit of interactive software and see what is the difference.

Ecology Teacher: Yes. Yes.

Me: Q6- What do you think that you can find in R and not in Netlogo or vice versa?

Ecology Teacher: Mmm, I have not worked with Netlogo code and so I don't know what I actually could do in Netlogo but what I know in "R" is that there is essentially infinite possibility in "R" if you can write it you can run anything in

“R”. I mean there is anything incredibly. You can write your own functions and there also thousands of existing libraries of functions that are out there to do any type of simulation, analysis, statistics that you would like to do and so I think that, I think there is a great of power and flexibility. I mean other things. So “R” can for example interface with “C” (Programming Language). So se “R” is a ...

Me: “R” can work with Netlogo if you know.

Ecology Teacher: “R” Can work with Netlogo. So from within “R” I can run any arbitrary system command. Right! So it’s actually very powerful that way. If you have got control of “R” you can control the whole computer, which is a bit dangerous. But what that means is that “R” code is not a compiled code so it’s slow. Right! But because it can also interface with “C” etcetera it can be very fast and so I think that flexibility is probably what I miss in Netlogo. In the other hand, if I were a professional Netlogo developer I might say something that very different. I don’t have the experience in doing that.

Me: This is what some of the students said. So this is there view as well. (having no previous experience of Netlogo).

Me: Q7- From your point of view which software is more powerful? Why?

Ecology Teacher: Well as I just said, I use “R” every day and I see it as a very powerful set of software. I mean a lot of my colleagues use GIS to do spatial analysis. You can do it in “R” too. You know I mean a lot of these things are possible in there. So yes, I will choose “R” for my personal use.

Me: Q8- From your teaching experience which model is potentially more effective, R or Netlogo and why?

Ecology Teacher: That's a harder question, it's a harder question because I think about, how I could use Netlogo in some of the other weeks of the course which you (Omair) didn't see. But for this particular week an agent-based model is perfect. It is exactly what I want as a teaching tool but other weeks they are not agent-based and not individual-based. I think that agent-based modelling wouldn't be helpful for other topics in the course. And so I have thought, would've be useful to change over entirely to use Netlogo but I don't think that would be effectible for this particular model.

Me: But for that (particular exercise of the week) it will run.

Ecology Teacher: Yes, for that one there is pros and cons. Pros of using "R" is that they have already done so they know how to use "R" they are familiar with it and introducing them to a new software in the last week of the model and say ok! now we are going to do something totally different I think that is a challenge I mean that I think that one thing that students need is some degree of continuity.

Me: But from there feedback and from the points (marks) of the exam.

Ecology Teacher: They looked very happy of using it, and most of them shows to use NetLogo and they did well.

Me: Only three of them used "R" for the exam.

Ecology Teacher: Yes, and I think many of them chose Netlogo because it was easier to use and I think that is a strong vote in favour of using Netlogo and I think that's a really important point that if a tool is too difficult to use even though it may be the best possible tool. Students aren't going to learn from using it. Especially if it's too challenging.

Me: Specially if its new to them (Netlogo) and they liked what they were used to (“R”) and then they chose the new one (Netlogo) for their exam. I think this is a good thing.

Ecology Teacher: I think that is a good sign that they found Netlogo very very useful.

Me: Q9- From your observation of the class, how did your students perceive, react and interact with Netlogo?

Ecology Teacher: I think that they responded very positively to Netlogo. I think that they found it relatively easy to use. I think that there were a few confusions also in using Netlogo. Some of which were simply because I don’t think we explained thing as clearly as we could have when we were introducing Netlogo. For example, Netlogo provides a window that shows the predators and prey as they move around on the arena but what I realised was that most students, that window was may be this big! (Indicating with his hands that it was big) But the students could only see this because their computer monitors were only this big (indicating with his hands that they only could see a small window on their screens) so they only could see half of that display we didn’t even realise that until half way through the experiment. And so I think there were things in setting up the comparison I think there were thing that we could have done to....

Me: Things to train them more in how to use Netlogo and introduce Netlogo more to them?

Ecology Teacher: Yes, I think it was a bit confusing because at the beginning of that session we introduced the topic of the day and then we also had to introduce how to use the “R” model and how to use the Netlogo model and that’s simply a lot of information.

Me: and I am surprised they still did well and they did good and that is a good thing?

Ecology Teacher: Yes, and I think that they were a very good group of students and I think they worked hard in that model so I appreciate that they did that.

Me: Q10- Did you find any drawbacks in Netlogo? if yes then what are they?

Ecology Teacher: So, I mean as we talked a little bit about just a bit of flexibility like I know pretty straight forwardly you would like to use that type of model to model a slightly different situation in "R" it's quite easy to go into that code and modify it. In Netlogo I guess it is (easy) but I just don't have that experience.

Me: But probably it is a bit easier. Like people model a lot of different other....

Ecology Teacher: They sure do and what is amazing about Netlogo is that many people have put up on the internet the examples of the models they have used.

Me: Q11- What's your future plans in regards to which software are you choosing to use in teaching thins model R or Netlogo and why?

Ecology Teacher: So, this coming year. This coming autumn I will actually be changing this course to some degree of it getting merged with another course so there will be a little bit complicated, but I will probably have that same topic and it could be quite good to run this experiment again and use both. I think it would be interesting to do it again with a new group of students.

Me: It will be good for them and good for us as well.

Ecology Teacher: Yes.

Me: We will see other people's reaction and they will be getting the opportunity to learn from using two software.

Ecology Teacher: Yes.

Me: and see both and they can make their own choice and we can see what they make and what they choose later.

Ecology Teacher: absolutely, Yes. I very much agree. Yes, that we will work well. I also expect more students to sign up. This past year I think approximately they were twenty students and I am expecting the course to grow so maybe as many as fifty or sixty students so then we will have more data for you.

Me: anything else regarding the experiment?

Ecology Teacher: I don't think so. I think that really about it.

Appendix 8



Omar Ameerbakhsh
Computing Science & Mathematics
Faculty of Natural Sciences
University of Stirling
Stirling FK9 4LA

21/12/2016

General University Ethics Panel (GUEP)
C/O Faculty of Social Sciences
University of Stirling
Colin Bell Building
Stirling
FK9 4LA
Scotland UK

E: GUEP@stir.ac.uk

Dear Omar,

Ethics Application: Towards an Interactive Simulation Framework for effective E-learning in University Classroom environments (GUEP22)

Thank you for making the requested revisions to your submission of the above project to the General University Ethics Panel.

I am pleased to confirm that GUEP has approved your application, and you can now proceed with your research.

Please note that should any of your proposal change, a further submission (amendment) to GUEP will be necessary.

If you have any further concerns or queries, please do not hesitate to contact the Committee by email to guep@stir.ac.uk.

Yours sincerely,

A handwritten signature in black ink, appearing to read "Helen Cheyne".

Pp

On behalf of GUEP
Professor Helen Cheyne
Deputy Chair of GUEP

Appendix 9

Marin Ecology Control Group Questionnaire



Fishing Game Experiment Participant Questionnaire

Participant ID: E0.....

Please consider the class that you have attended and complete the following questionnaire. Be honest in your responses and answer the questions as fully as possible.

Part 1

Circle the answer that most closely represents your views.

1. How much did you enjoy this class?

Not at all Slightly Moderately Very much Extremely

2. The session began with a presentation by the lecturer. How useful was this for helping you to understand the biomass based production model?

Not at all Slightly Moderately Very much Extremely

3. The lecturer then demonstrated how to estimate PMax using a “white box” simulation. How useful was this for helping you to understand the biomass based production model?

Not at all Slightly Moderately Very much Extremely

4. You then did an exercise using a “black box” simulation. How useful was this for helping you to understand the biomass based production model?

Not at all Slightly Moderately Very much Extremely

5. How useful was the class as a whole at helping you to understand the biomass based production model?

Not at all Slightly Moderately Very much Extremely

6. The lecturer showed you a demonstration of how to estimate PMax using a “white box” simulation. To what extent did you like this method of teaching?

Not at all Slightly Moderately Very much Extremely

7. To what extent would you have preferred to explore how to estimate PMax using the “white box” simulation yourself, instead of watching the lecturer demonstrate how to do it?

Not at all Slightly Moderately Very well Extremely well

8. How well were you able to understand the user interface of the “white box” simulation?

Not at all Slightly Moderately Very well Extremely well

9. How attractive did you find the user interface of the “white box” simulation?

Not at all Slightly Moderately Very attractive Extremely
attractive attractive attractive attractive attractive

10. How well were you able to understand the user interface of the “black box” simulation?

Not at all Slightly Moderately Very well Extremely well

11. How attractive did you find the user interface of the “black box” simulation?

Not at all Slightly Moderately Very attractive Extremely
attractive attractive attractive attractive attractive

12. How enthusiastic did you feel about watching the lecturer demonstrate the “white box” simulation?

Not at all Slightly Moderately Very Extremely
enthusiastic enthusiastic enthusiastic enthusiastic enthusiastic

13. How enthusiastic did you feel about using the “black box” simulation yourself?

Not at all Slightly Moderately Very Extremely
enthusiastic enthusiastic enthusiastic enthusiastic enthusiastic

14. 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.

Part Two

1. The lecturer demonstrated how to estimate PMax using a 'white box' version of the simulation first, and then you completed an exercise using a 'black box' version. Did you find this an effective way of learning? Please explain why or why not.

2. Do you feel that you could have learned more from exploring how to estimate PMax using the "white box" version yourself, instead of watching the lecturer demonstrate it? Please explain why or why not.

3. What part of the class did you like best? Please explain the reason for your preference.

Listening to the initial lecture	<input type="checkbox"/>
Watching the demonstration of the "white box" simulation	<input type="checkbox"/>
Doing the exercise using the "black box" simulation	<input type="checkbox"/>

4. Which part of the exercise helped you most to understand the concepts?
Please explain the reason for your preference.

- Listening to the initial lecture
- Watching the demonstration of the “white box” simulation
- Doing the exercise with the “black box” simulation

5. Would you like to have more exercises like this as part of your degree?
Please explain why or why not.

6. Do you have any suggestions or comments for improving this exercise?

Finally, please tell us a little about you:

Sex: Male Female

Level of expertise

using computers: Beginner Moderate Expert

Year of study: 1st year UG 2nd year UG 3rd year UG 4th year UG
PG MSc PhD

Appendix 10

Marine Ecology Treatment Group Questionnaire



Fishing Game Experiment Participant Questionnaire

Participant ID: F0.....

Please consider the class that you have attended and complete the following questionnaire. Be honest in your responses and answer the questions as fully as possible.

Part 1

Circle the answer that most closely represents your views.

16. How much did you enjoy this class?

Not at all Slightly Moderately Very much Extremely

17. The session began with a presentation by the lecturer. How useful was this for helping you to understand the biomass based production model?

Not at all Slightly Moderately Very much Extremely

18. You then explored how to estimate PMax by using a “white box” simulation yourself. How useful was this for helping you to understand the biomass based production model?

Not at all Slightly Moderately Very much Extremely

19. You then did an exercise using a “black box” simulation. How useful was this for helping you to understand the biomass based production model?

Not at all Slightly Moderately Very much Extremely

20. How useful was the class as a whole at helping you to understand the biomass based production model?

Not at all Slightly Moderately Very much Extremely

21. You explored how to estimate PMax using a “white box” simulation yourself.
To what extent did you like this method of teaching?

Not at all Slightly Moderately Very much Extremely

22. To what extent would you have preferred to watch the lecturer demonstrate
how to estimate PMax using the “white box” simulation, instead of trying it
out yourself?

Not at all Slightly Moderately Very well Extremely
well

23. How well were you able to understand the user interface of the “white box”
simulation?

Not at all Slightly Moderately Very well Extremely
well

24. How attractive did you find the user interface of the “white box” simulation?

Not at all Slightly Moderately Very Extremely
attractive attractive attractive attractive attractive

25. How well were you able to understand the user interface of the “black box”
simulation?

Not at all Slightly Moderately Very well Extremely
well

26. How attractive did you find the user interface of the “black box” simulation?

Not at all Slightly Moderately Very Extremely
attractive attractive attractive attractive attractive

27. How enthusiastic did you feel about using the “white box” simulation
yourself?

Not at all Slightly Moderately Very Extremely
enthusiastic enthusiastic enthusiastic enthusiastic enthusiastic

28. How enthusiastic did you feel about using the “black box” simulation
yourself?

Not at all enthusiastic Slightly enthusiastic Moderately enthusiastic Very enthusiastic Extremely enthusiastic

29. 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.

0 10 20 30 40 50 60 70 80 90 100
Not confident at all Moderately confident Highly confident

30. How much would you like to have more exercises like this as part of your degree?

Not at all Slightly Moderately Very much Extremely

Part Two

7. You explored how to estimate PMax using a 'white box' version of the simulation first, and then you completed an exercise using a 'black box' version. Did you find this an effective way of learning? Please explain why or why not.
8. Do you feel that you could have learned more from watching the lecturer demonstrate how to estimate PMax using the white box model, instead of exploring it yourself? Please explain why or why not.
9. What part of the class did you like best? Please explain the reason for your preference.
- | | | |
|--|--------------------------|--------------------------|
| Listening to the initial lecture | <input type="checkbox"/> | <input type="checkbox"/> |
| Exploring the model using the "white box" simulation | <input type="checkbox"/> | <input type="checkbox"/> |
| Doing the exercise using the "black box" simulation | <input type="checkbox"/> | <input type="checkbox"/> |

10. Which part of the exercise helped you most to understand the concepts?
Please explain the reason for your preference.

- Listening to the initial lecture
- Exploring the model using the “white box” simulation
- Doing the exercise with the “black box” simulation

11. Would you like to have more exercises like this as part of your degree?
Please explain why or why not.

12. Do you have any suggestions or comments for improving this exercise?

Finally, please tell us a little about you:

Sex: Male Female

Level of expertise

using computers: Beginner Moderate Expert

Year of study: 1st year UG 2nd year UG 3rd year UG 4th year UG
PG MSc PhD

Appendix 11

Marine Ecology Teacher Interview Transcript

Me: Q1 What do you think of the use of interactive simulation in the practical class?

Marine Ecology Teacher: I thought that the simulation went very well, and it definitely helps the students understand that topic much more so than if it was just a lecture material or I think even if it was a lecture backed up with something like paper and pen exercises. I think it's not just the simulation. the fact that it was an interactive simulation makes a big difference to the students understanding of it.

Me: What did you think about the NetLogo Interactive simulation, I think you had some other simulation before?

Marine Ecology Teacher: Before we had it. It was much more just a text. it was like a 1980s-computer game where you type things in and the computer gives you back some text as a result and I think it made a difference for the students to be able to see graphs. There were some other features on the simulation because the number of fish in the background image could change but I don't think that made a difference. I think the thing made a difference was that the students can see the graphs, and we had several iteration of design as we developed the software. So the first NetLogo version was all text base just as the original version I had and then it took us a while of tweaking it to get the layout that make sense and in particular Savi and I came with the idea of that some of the information were in top part of the screen and that was what was

going to be visible in both version of the software and the other information which was under the sea was the stuff that was hidden in the black box simulation. It took us a long time to come with that and I think the text based simulation worked but it did not work as well. You would have to force the students to draw their own graphs or something which is too time consuming to do in a class. So definitely the graphs were the element that came from the NetLogo version which made a big improvement over the original version.

Me: Q2 Which method of using the interactive simulation seemed more effective to you?

Marine Ecology Teacher: I think when I was doing the class; it seemed that the one when I was lecturing them worked better. I think my worry about that was that then they will sit in front of the computer and won't know how to get started because they hadn't done it on the computer before. The mechanics of operating the computer might be too slow for them to solve the problem if they don't have the demonstration but the concepts are quite complicated so I kind of expected that probably the one when I give them the lecture they then find it easier. I was a bit concerned the ones who had a demonstration might not have the same confidence, or they might not of confidence that they are solving the problem rather than just following a protocol that they don't understand. Whereas the ones who were doing the self-exploration, once they find the method of solving the problem they should be more confident that they are doing for themselves, so I would expect that their long term view and the confidence on their own ability to solve the problem would be more higher.

Q3 Can you explain your answer above?

Details explained in the above answer

Me: Q4 from your point of view what do you think are the advantages of showing the students an expert demonstration of how to use the simulation?

Marine Ecology Teacher: So that comes to the same thing. I think with demonstration the advantage is you come across much more complicated idea. So the relationship between a CPUE variable and the hidden population size variable. You can tell the student and you can show in the demonstration why that is the case. They wouldn't necessarily pick up on that just from their own experimentation. I think you need to explain points like that to them. So getting across the more complicated concepts I think is the advantage of teaching.

Me: ok

Marine Ecology Teacher: But the advantage of not doing the teaching.

Me: that's for the next question.

Me: Q5 from your point of view what do you think are the advantages of letting the students explore the simulation for themselves without seeing an expert use it?

Marine Ecology Teacher: yes so for the next question, when the students work out something for themselves that should make them more confident that they really understand it but perhaps for some of the poorer students, they then even if they do understand it they are not sure if they got it right so they must be

quite dependent on the student and how they feel about their own abilities in the subject themselves.

Me: Q6 Which method do you think the students preferred? Can you say why? From you class observation?

Marine Ecology Teacher: I think it was hard to tell. I don't think I can tell that from the class. From how they actually acted in the class. And certainly in both classes when I went round looking at what they were doing and giving them pointers when they were stuck with the software both versions of the class. Some of them seemed ahead and they did it really quickly and some of them got stuck and they weren't really sure what to do. So basically, in the feedback they give I think they prefer to interact with the system, but I don't think it was easy to tell in the class.

Me: in the qualitative data they all chose a lecture as well with the interactive simulation.

Marine Ecology Teacher: Yes

Me: I think maybe 2 or three.

Marine Ecology Teacher: said they wouldn't want a lecture at all.

Me: Yes, they would like trial and error.

Marine Ecology Teacher: Yes.

Me: But most of the students wanted a demo before it.

Marine Ecology Teacher: Yes

Me: Q7 What plans do you have for using interactive simulation in this module in future? Have these plans been influenced by your observations during the experiment?

Marine Ecology Teacher: I'll definitely continue using it in that module.

Me: How will you use it with a demo or without?

Marine Ecology Teacher: I think I will do it with, as I did with the demonstration. Possibly I can spend more time on it in future because I allocate, usually it's a three hours lab that's available so possibly I can allocate more time. It should allow them hopefully to do both things and its not like when we ran the experiment we needed to test the students and see how they reacted to it taking away that element of it allow more time for the experimentation. The thing I did in the old version of the software was they played a sort of competitive version. Whether we can change this new version of the software to allow them to do that? I am not sure, which makes it more of a class experience.

Me: OK more like a game?

Marine Ecology Teacher: I think that a competitive game, Yes.

Me: so, this is like future development.

Marine Ecology Teacher: That would be a way that we might redevelop it in the future yes. But that was to get across a different teaching point and the fact that what's optimal, if you play the game by yourself it's not the same optimum

when you compete with somebody else. They might just steel everything from you. So, it was to get across a different point.

Me: So, when we evaluate learning effectiveness, we look at three points, skills, knowledge and attitude of the students towards the simulation. So from your experience, what do you think, what kind of method help them in improving their skills, knowledge and attitude?

Marine Ecology Teacher: So in terms of the one way I demonstrated it I think it's very good for teaching them the skills and the knowledge and I suspect they picked up better the way to work out the optimum using the data that was available so their ability to apply mathematical reasoning to the situation was probably better but I think for the ones had more time they had the time to experiment for themselves that probably gives them an improved attitude because they know they are not just following the procedure I just have given them. That's really them playing the game themselves and solving the problem for themselves. I think that aspect of improving their attitude towards their own ability is probably a good reason to allow them to experiment more.

Me: I think in the attitude, they normally say there is something which helped with short term learning and something which helped with long term learning.

Marine Ecology Teacher: Yes, so it probably gives an advantage in the long term that they have solved the problem for themselves assuming that they have got to a solution that works. So, whether in the future I will get, I don't know whether I will get them to experiment and then tell them what to do and then get

them to experiment some more or whether I will tell them stuff for the first and then. So, I need to think about how I am going combine the two approaches.

Me: Some students suggested that you should do it in a walk-through way for example give them the experiment to play with it and then walk them through it.

Marine Ecology Teacher: Yes, walk them through it and then have them try a new situation. That's probably a good idea.

Me: Do you have anything else to add?

Marine Ecology Teacher: I will defiantly be using it in the future, is definitely an advantage in that sort of topic.

Me: So, using an interactive simulation is an advantage.

Marine Ecology Teacher: Yes, I think computer-based simulation works, but it does need to be integrated in a classroom situation rather than just give them something and then get on with it. But I think its defiantly been a successful tool in teaching those concepts.

Me: Thank you very much for your time.