CRITICAL EVALUATION OF SIMULATIONS AND GAMES AS TOOLS FOR EXPANDING STUDENT PERSPECTIVES ON SUSTAINABILITY

Jon-Erik Dahlin[1,3], Richard Fenner[2], Heather Cruickshank[2]
[1] Department of Energy Technology, Royal Institute of Technology, Sweden
[2] Centre for Sustainable Development, Department of Engineering, University of Cambridge, UK
[3] jonerikd@kth.se

Abstract: Games have been used at the Royal Institute of Technology (Sweden) and the University of Cambridge (UK) to aid the teaching of sustainable development to diverse groups of engineering students. This paper explores how games have helped students at two institutions to reflect on issues from different perspectives. More specifically, the work addresses whether games helped to stimulate students' learning of facts; student reflections; and student peer discussions. The games evaluated include: Building Futures; Democracy; Dilemma; Fishbanks; GaSuCo; Power Grid; and Puerto Mauricio. Methodologies used include: student surveys; deep interviews; group interviews; and essays, written assignments and tests. The main findings are that games contribute strongly to the learning of sustainability and improve critical reflection as well as facilitate interpersonal communication. .

1 INTRODUCTION

Games are effective ways of learning about Sustainable Development issues, as "they simulate mutually accepted rules, roles, conditions and assumptions" (Dielman & Huisingh, 2006). Game-based learning with groups of engineering undergraduates has been used by Darling *et al.* (2008) and they found the approach was an excellent way of improving teaching efficiency and encouraging an element of competition in a non-threatening environment. They concluded that learning by doing in a game environment seemed to be a successful way of managing large group teaching, and was a good way, early in the academic year to break down barriers and improve staff/student relations.

A key advantage of using games is that they allow the ability to introduce environments that would otherwise be too costly to experiment with, and provide a means of accommodating different learning styles such as verbal, visual, logical and aural (Morsi R & Jackson E, 2007). They can also enhance students' information processing ability, enable quick decision making on what is necessary for solving the task and what is not, and enhance data organisation skills. In reflecting a range of dilemmas or messy problems that lie at the heart of many sustainable development problems, games encourage both critical thinking and problem solving skills to develop. Deshpande & Hunang (2011) present a detailed review of simulation games in engineering education including by Torres & Macedo (2000) and conclude that their use can provide a powerful tool to maximise the application of a student's academic knowledge to real world problems and industrial settings. The use of board games to stimulate conversations around sustainability is described by Dahlin J-E *et al.* (2013) in which synergistic effects between large group lectures and board game play are described. Such an approach also has the benefit of facilitating contact between group individuals at the beginning of a programme or course.

An important aspect to understanding the broader context in which engineering solutions must be delivered is to create an emotional attachment to the outcome of the decision (Fenner *et al.*, 2014). Experiencing something of the (perhaps irrational) passion displayed when decision stakes are high over an issue relating to a large infrastructure project, for example, can enable students to have more empathy

towards real stakeholders. Dieleman and Huisingh (2006) argue that using role play based around cases of specific development projects can provide the circumstances to understand the behaviour of people within these contexts and to understand the linkages between certain problems, the behaviour and technologies within these contexts and the problems that result. Most importantly it can encourage contextual thinking and explores issues such as trade-offs, uncertainty, dealing with people and change.

Gourmelon *et al.* (2012) describe a role play game based on a multi–agent model for the development of likely scenarios for the study site. This allows individuals to participate through hands-on experience and to effectively explore the issues involved in an interdisciplinary forum (Gourmelon *et al.*, 2011). Liarakou *et al.* (2012) explore how games can provide valuable pedagogical tools which provide opportunities for students to experience complexity and abstract issues of sustainability and conclude there is scope for improvement in terms of the holistic approach (covering the environmental, societal and economic dimensions of sustainable development), construction of knowledge, negotiating of conflicting values and promotion of problem solving. Fenner *et al.* (2014) describe how games can be used as an important component of creating a mindset change in young professional engineers.

This paper compares and reflects on the experiences of using three types of games: structured board games; role playing games; and simulation games at the Royal Institute of Technology (KTH) in Sweden and University of Cambridge in the UK. The pedagogical objective of each game is described in terms of development of the following: know how; awareness; understanding; exploring attitudes and values; systems thinking; information processing; decision making; collaborative working; and communication skills. The manner in which some of the games are used differently in each institution is also described and the way each activity has been received by students is analysed.

2 STUDENT GROUPS AT KTH AND UNIVERSITY OF CAMBRIDGE ENGINEERING DEPARTMENT

In total, twelve student groups (eight at KTH and four at Cambridge) were evaluated. In Table 1, relevant data about the student groups are given.

Table 1: Student groups at KTH and University of Cambridge included in this study

Student group / study programme	Academic year	#of students	Games used [6]	Collective group
Mechanical eng. 5Y[1]	2013/2014	160	G	1st year *U/G* (KTH)
Mechanical eng. 3Y[2]	2013/2014	120	G	1st year *U/G* (KTH)
Design & Products 5Y[1]	2013/2014	140	G	1st year *U/G* (KTH)
Industrial Engineering 5Y[1]	2013/2014	180	G	1st year *U/G* (KTH)
MEng Engineering 4Y[3]	2013/2014	52 (92)[7]	G+FB	4th year *U/G* (Cam.)
MPhil in Engineering for Sustainable Development 1Y[4]	2013/2014	38	G+FB+PM +BF	*P/G* MPhil (Cam.)
Mechanical eng. 5Y[1]	2014/2015	160	D+FB	1st year *U/G* (KTH)
Mechanical eng. 3Y[2]	2014/2015	120	G+FB	1st year *U/G* (KTH)
Design and Products 5Y[1]	2014/2015	140	G+FB	1st year *U/G* (KTH)
MEng Engineering 4Y[3]	2014/2015	28 (71)[7]	G	4th year *U/G* (Cam.)
MPhil in Engineering for Sustainable Development 1Y[4]	2014/2015	28	G+FB+PG+PM +BF+DEM	*P/G* MPhil (Cam.)
M.Sc. ICT 2Y[5]	2014/2015	150	FB	*P/G* MSc (KTH)

[1] 5Y = 5 year programme leading to MSc degree; [2] 3Y = 3 year programme leading to BSc; practical engineering) degree; [3] 4Y = 4 year programme leading to MEng degree; [4] 1Y = 1 year post-graduate taught programme leading to MPhil degree; [5] 2Y = 2 year post-graduate programme leading to MSc degree; [6] G = GaSuCo, D = Dilemma, FB = Fishbanks, PG = Power Grid, PM = Puerto Mauricio, BF = Building Futures, DEM = Democracy; [7] Mixed group: number of U/G; (total class size within brackets)

At KTH most of the students were 1st year undergraduate students and some were post-graduate (masters level) students. All undertook studies in sustainability as part of a mandatory course module, and were thus non-self-selected students in that sense. The course module in Sustainable Development for Engineers included large class lecture (up to 180 participants), with a strong element of interactivity and debate, and a series of seminars in smaller groups, which were where students were playing games.

At Cambridge two student groups were evaluated. Most of the games were played with postgraduate Masters students on the professional practice MPhil in Engineering for Sustainable Development. 28 students were enrolled in 2014-15 on this programme and came from a large variety of countries and engineering disciplines .Games were also introduced to final (4th) year MEng Engineering undergraduates in a specialist elective module on Sustainable Development. Activities with the Masters group at Cambridge could be introduced in an open ended way with no significant time restrictions whereas the undergraduates were restricted to the timetabled lecture slots (2 hours) to complete their work.

3 GAMES IN THIS STUDY

The games studied in this work are briefly described below, with an indication as to where modifications to the game play have been introduced to meet specific learning objectives.

3.1 Board games

3.1.1 GaSuCo (KTH and Cambridge)

GaSuCo (Larsson) is a discussion based board game for learning about sustainable development. Focussing on communication and reflection it contains over 250 questions, discussions and concepts for university level training. Skills developed by this game: awareness, exploring attitudes and values.

At KTH GaSuCo is used in a seminar series associated with class lectures, as a catalyst for critical thinking and debate. As students are introduced to sustainability issues through the game, they are encouraged to debate those in small groups. Those issues are then already well known to them when they appear in interactive large class lectures. At Cambridge GaSuCo is one of the first activities that the MPhil students engage in and it acts as an excellent icebreaker to set up conversations around sustainability in groups of 4 players. It is used to introduce topics such as the impacts of climate change, resource depletion or biodiversity loss. At the undergraduate level it was used at the end of the taught module to test and consolidate understanding of key concepts and to broaden discussion.

3.1.2 Dilemma (KTH)

Dilemma (Dahlin) is a board game where participants have to both know about facts of sustainability and debate various dilemmas to be successful. The game includes fact-based challenges that participants can solve by using various clues, and sustainability dilemmas that challenge participants to argue for or against a certain opinion. Skills developed by this game: awareness, exploring attitudes and values.

At KTH, the Dilemma board game is used to supplement the course literature as a tool for learning concepts and facts, and as a catalyst for critical thinking and debate on various sustainability dilemmas.

3.1.3 Power Grid (KTH and Cambridge)

In the Power Grid (Friedemann), each player or team represents a company that owns power plants and tries to supply electricity to cities. The players bid on power plants and buy resources to produce electricity to provide power to the growing number of cities in their expanding network. Skills developed by this game: systems thinking, information processing, decision making.

At KTH, Power Grid is used in an elective course in Sustainable Energy Systems for 3rd year engineering students, who asked to rewrite the rules of the game to incorporate CO_2 emissions trading. At Cambridge the Power Grid game forms the basis of an assignment to explore issues relating to complex systems. After playing the game students are asked to develop a causal loop diagram of the key

components and actions of the game; comment on the location of the system boundary and identify the externalities which are not incorporated in game, and then modify the causal loop diagram to incorporate these externalities and suggest modifications to the game play which would allow them to be incorporated into the game. Linked to a reading of Meadows (1999), students then discuss suitable places in their representation of the Power Grid where action to mitigate climate change might be most effective.

3.2 Role play games

3.2.1 Puerto Mauricio (Cambridge)

Puerto Mauricio (van der Wansem *et al.*, 2003) is a role play based on a fictional coastal town in which a large and culturally significant parcel of land is about to be sold. Skills developed by this game: collaborative working, communication skills, decision making.

At Cambridge students take on the roles of stakeholders and try to reach agreement on the development plans for the area. A second stage requires a stakeholder group from Puerto Mauricio to advocate their solutions to a Committee representing national Government Departments, where the proposals are under scrutiny for meeting the Governments' stated sustainability goals.

3.2.2 Building Futures (Cambridge)

This is a modified version of Building Futures (RIBA/CABE 2008) originally designed as a tool to help communities to think about the future of their neighbourhood. Skills developed by this game: communications skills, decision making.

At Cambridge, students take on character roles to explore the issue of trade-offs in town planning where various options have designated financial cost 'points' associated with them and participants must allocate a 'spend' of those points against a planning timeline while also meeting some overarching objectives. Analysis of this game allows students to reflect on the need to balance early wins with long-term plans and to address the diverse needs and desires of different members of a community. The aim is to encourage students to look for non-technical as well as the more traditional engineering solutions.

3.3 Simulation gamesFishbanks (KTH and Cambridge)

Fishbanks (Meadows , 2004 is a multiplayer computer-aided simulation game, in which participants play the role of fishing companies seeking to maximise their net worth as they have to deal with variations in fish stocks and catch. Skills developed by this game: information processing, system thinking.

At KTH the Fishbanks simulation game is played in a 3.5 hour seminar with the standard setting. After debriefing the game, students are given a home assignment to write a reflection on the learnings from the game: they should think of another system (natural or anthropogenic) that bears similarities with and perhaps differences to ocean fishing regarding system dynamics.

At Cambridge a modified version of Fishbanks is played in which initial fleets of boats of different sizes and owned by a range of operators from families to multinational corporations seek to optimize their fishing catches and profit whilst staying in business. The game is played with the target of maximising total profit across all teams. If successful, the cohort can avert the over-extraction of the resource and operate at an appropriate level of consumption making more profit overall and sustainably over the long-term. This teaches skills of negotiating, teamwork, systems thinking and understanding feedbacks determined in a context of incomplete information.

3.3.2 Democracy (Cambridge)

Democracy 3 (Positech Games) is a software-based simulation game where game players run a national government by adjusting policies. Policy categories include: Law and Order; Transport; Foreign Policy; Welfare; Economy; Tax; and Public Services and as such represent sustainability considerations. Voter groups include: religious minorities; patriots; parents; capitalists; socialists; liberals; conservatives; and

others. If the policies are popular with a significant proportion of the voting population then the character will be re-elected to serve another political term but if they are sufficiently unpopular with any particular stakeholder group they may be assassinated.

The code behind the game is based on a neural network. Students were tasked with playing the game to understand the mechanisms and then to use the modifications options to improve the game's evidence base and to incorporate sustainable development principles. Aptitude at the game requires players to run it several times and this necessitated students committing time outside class.

4 METHODS

Specifically, this study addresses the following key aspects regarding to what extent simulations and games can be successfully used as tools for expanding student perspectives on sustainability:

- The extent to which the use of games stimulate participation in class room discussions;
- How the use of games stimulate students' individual reflection on sustainability issues;
- How the use of games stimulate students' ability to formulate sustainability arguments;
- How the use of games in sustainability training can enhance student deep learning;
- How the use of games in sustainability training can enhance the students' conception of sustainability as a subject of values rather that an academic subject.

For each student group (Table 1), one or several of the following evaluation methods were implemented: student surveys/questionnaires; deep interviews with students; group interviews with students; essays, written assignments and/or tests. Table 2 summarises which evaluation methods were used for which students groups.

Table 2: Evaluation methods used for each student group

Student group (KTH/Cam.) *	questionnaire	deep interviews	group interviews	essays, written assignments and/or tests
1st year *U/G* KTH	X	X	X	X
P/G MSc KTH	X			
P/G MPhil Cam.	X			X
4th year *U/G* Cam.	X		X	

* *P/G* = post-graduate students, *U/G* = undergraduate students

4.1 Questionnaires

At KTH students were asked to answer a questionnaire after the course module. Some questions were open and some were closed. See Table 3 for examples on specific questions.

At Cambridge, the MPhil students were asked to rate each game (1-5) in their termly feedback questionnaires and were free to offer comments on each game. The MEng class was debriefed using group interviews immediately after each game and also comments were collected in the regular termly feedback on the module as a whole.

4.2 Student interviews

At KTH, in the undergraduate programmes of the academic year 2013/2014, a number of students were interviewed after completing the course module. They had been invited to the interviews before the module began, with an explicit objective to gather other students' views as well.

At Cambridge, the views of any of the students who wished to comment were conveyed via the course representatives and the Staff-Student Liaison Committee meetings and minutes.

4.3 Essays, written assignments and tests

At KTH most of the game exercises were associated with a concluding written assignment, These reports have shown to be valuable documents for assessing how well game performed as training tools. At Cambridge an assignment based on the Power Grid was described earlier (3.1.3)

5 RESULTS

The fulfilment of learning objectives was measured partly in conventional assessment through essays, written assignments and tests. Assessment records reveal that the student learning on the subject is indeed satisfactory. In this section we summarise the results regarding how games contributed to fulfilling learning objectives with the focus on what the student reception on games was.

5.1 KTH results

In addition to conventional assessment, questionnaires and interviews were performed. The analysis of statistics from the transcripts of those generated vast amounts of material that is not presented in detail in this paper. However, the general observations made by teaching personnel and during interviews with students give that trainers experienced games to be efficient teaching/learning tools in this context, and that the student reception was in general good to very good. This observation is for the most part confirmed by the statistical material from the questionnaires. In Table 3, we present the student response to the set of closed questions regarding how students experienced and to what extent games contributed to their learning in sustainability. The student groups subject to data in Table 3 were three KTH undergraduate programmes in academic year 2014/2015 (Table 1).

Table 3: Student responses to games at the KTH undergraduate programmes

Question	1-2 (no/little/ disagrees)	3 (undecided)	4-5 (yes/a lot/agrees)
Q A In your opinion, did the use of board games in the course deepen your understanding of sustainability?	11 %	32 %	57 %
Q B In your opinion, to what extent did the board game sessions trigger discussions during the debriefings?	10 %	26 %	64 %
Q C To what extent did the board game sessions prepare you for the discussions during the debriefings?	7 %	33 %	61 %
Q D Do you agree that the board game sessions have made you connect socially with more people in the course? 1 (strongly disagree) to 5 (strongly agree)	26 %	35 %	39 %
Answers were given on a scale from 1 (no/not at all/strongly disagrees) to 5 (yes/a lot/strongly agrees). For clarity, answers 1-2 and 4-5 have been grouped together			

The student reception was measured in interviews and questionnaires, which revealed that students felt that games were both fun and contributed strongly to their learning of the subject.

5.2 Cambridge results

The use of games by the Cambridge Masters students was very positively received. The responses for academic year 2014/2015 are summarised in Table 4.

Table 4: Student responses to games at the Cambridge MPhil programme

Game	GaSuCo	Power Grid	Building Futures	Democracy	Puerto Mauricio
Rating out of 5	4.1	4.5	3.8	Not rated	4.5

Typical comments on the activities described above were as follows: “The Puerto Mauricio negotiations exercise was the highlight of the seminars as they provided a very hands-on experience for students to engage and actual negotiations”; “The Power Grid game includes many fascinating dynamics giving players the opportunity to see system dynamics over very short timeframes. This gameplay is a great way to learn about the dynamics of the real world, without requiring years of (probably expensive) feedback delay. I learned a lot about systems dynamics and the interaction of various market forces. This was a very valuable exercise”; “Power Grid was a unique and fun approach to provide a basic understanding of the interdependencies involved in the energy industry, which helped immensely in the assignment”; “I felt the concepts explored in the GaSuCo Game and the Puerto Mauricio game were topical and allowed for class interaction and discussion”; “The Power Grid game was fun to play and a fresh learning style”; “I gained negotiation skills from Puerto Mauricio, political mind from Democracy Game, theoretical Sustainability from GaSuCo”.

Students also commented on the logistics of the games and several suggested more time was needed. The Democracy game was played last when students were busy meeting assignment deadlines and students responded more negatively to this as it wasn’t embarked on for any assessment credit. This demonstrates the importance of linking activities to credit parts of the course in order to ensure full student commitment where they are required and expected to undertake activities outside the classroom.

In terms of evaluating the learning outcomes the systems dynamics assignment was evaluated against the following criteria: Causal loop diagram of key components; Comments on system boundary and externalities; Suggested modifications; Leverage points to mitigate climate change; Overall layout and reflection / outcomes / conclusions.

A similar exercise had been previously carried out using a narrative reading rather than a game in 2013/14 and the results were compared and showed no significant difference in student performance.

6 DISCUSSION

In this paper, we have described a number of structured board games, role play games and simulation games that were used at KTH and Cambridge in the respective institutions’ engineering education. Some of these games were used exclusively in one of the two institutions whereas some were used in both but they were used differently or with different modifications. Both institutions have measured the student reception and the extent to which games contributed to fulfilling learning objectives. Both institutions found that games indeed contributed in a positive and efficient way when used in conjunction with more traditional teaching styles, and that the student reception was in general very positive (section 5).

In particular, five key aspects regarding the extent to which games were successful as tools for expanding student perspectives on sustainability were addressed (section 4). Games were used in different manners in each institution, student groups were different and also the analysis was non-identical, leading however to very similar conclusions regarding the role that games played in the respective learning environments. This verifies our findings to a large degree. Further, the descriptions found in this paper on how we use games (section 3) may also be of interest to the reader as we intend these to be an inspiration for creative and unconventional pedagogics for sustainability in engineering.

7 CONCLUSIONS

Our basic hypothesis was that games contribute strongly to the learning of sustainability as they contribute to critical reflection and interpersonal communication. More specifically, the pedagogical objectives for using games as training tools were to contribute in know-how, awareness, understanding, exploring attitudes and values, systems thinking, information processing, decision making, collaborative working and communication skills. The conclusion of this work is that we indeed do make observations that contribute to confirm the basic hypothesis.

References

Darling J., Drew B., Joiner R., Lacovides I, Gavin C., (2008) Game based learning in Engineering Education International Conference on Innovation, Good Practice and Research in Engineering Education, Loughborough University, England, P070, 2008

Dahlin J.-E., Larsson P., Erlich C., (2013) The use of board games in the engineering education for the purpose of stimulating peer participation in lecture theatre discussions 6th International Conference in Engineering Education for Sustainable Development EESD 13 22-25 September, Cambridge UK

Dahlin J.-E.: "Dilemma", http://www.jonerikdahlin.com/dilemma

Deshpande A., Hunag S.H., (2011) Simulation games in engineering education: a state of the art review. Computer Applications in Engineering Education Volume 19, Issue 3, pages 399–410, September 2011

Dieleman H., Huisingh D., (2006) Games by which to learn and teach about sustainable development: exploring the relevance of games and experiential learning for sustainability. Journal of Cleaner Production 14 (2006) pp 837-847

Fenner R.A., Cruickshank H.J. Ainger C., (2014) Sustainability in Civil Engineering Education: why, what, when, where and how. Proceedings of Institution of Civil Engineers, Engineering Sustainability: October Volume 167 ES 5 pp 228-237 October 2014

Friedemann F., Rio Grande Games: "Power Grid", http://riograndegames.com/games.html?id=5

Gourmelon F., Chlous-Duchatrme F., Kerbirou C., Rouan M., Bioret F., (2013) Role playing game developed from a modelling process: a relevant participatory tool for sustainable development? A co-construction experiment in an insular biosphere reserve.

Gourmelon F., Rouan M., Lefevre J-F, Rognant A (2011) Role playing game and learning for young people about sustainable development stakes: an experiment in transferring and adapting interdisciplinary scientific knowledge. Journal of Artificial Societies and Social Simulation Vol 143 (4) 21

Larsson P.: "GaSuCo", http://gasuco.com/

Liarakou G., Sakka E, Gavrilakis C., Tsolakidis C., (2012) Evaluation of Serious Games, as a Tool for Education for Sustainable Development . European Journal of Open, Distance and E-Learning http://www.eurodl.org/?p=special&sp=articles&inum=4&article=546

Morsi R, Jackson E., (2007) Playing and learning? Educational gaming for Engineering Education. 37th ASEE/IEEE Froniters in Education Conference, October 10-13 2007 Milwaukee. .

Tores M., Macedo J., (2000) Learning Sustainable Development with a new simulation game. Simulat gaming 31 (2000) 119-126

Meadows, D. (1999), Leverage Points: places to intervene in a system, The Sustainability Institute, Hartland, VT.

Meadows, D. (2004), Game, The Laboratory for Interactive Learning, FishBanks Ltd, Durham, NH.

Positec Games: "Democracy", http://www.positech.co.uk/democracy/

RIBA / CABE (2008) Building Futures Game: Developing Shared Visions for Neighbourhoods Created and developed by AOC (www.theaoc.co.uk)

van der Wansem, M., Tracy Dyke, T. and Susskind, L. (2003), Puerto Mauricio Development Conflict Simulation, Consensus Building Institute and Vereniging Natuurmonumenten, Cambridge, MA.