Integration of an Inductive Teaching Approach with System Dynamics Computer Simulation

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Abstract

The system dynamics methodology analyzes problems by developing mental model structures and then performing computer-aided simulations of these structures. We propose the use of this methodology alongside inductive modes of teaching. The integration leads to a middle-path approach of case-study techniques and inquiry-based learning. It allows students to identify, assimilate and eventually respond to problems, which are of importance to them. We test the approach by conducting two types of experimental studies. The first is a single-session instruction on a geography syllabus for secondary students. Meanwhile, the second experiment involves a semester course on an industrial engineering subject for a cohort of tertiary students. The experiments generally led to favorable results such that lessons were made more engaging and interactive. The use of the approach likewise led to positive reception from the students. In effect, this created a collaborative classroom environment, which instilled greater interest and subject matter retention to the students. These experiments showed that by allowing students to build, process and analyze their own mental models, they were able to closely identify with the topics being covered in the respective subjects. Furthermore, it was found that the approach encouraged students to extend what they have learned inside the classroom into their own individual interests and projects.

Keywords: Inductive teaching approaches, experimental studies

Introduction

Good quality high school and college education is fundamental in the growth and development of any country. This, in particular, is true for the natural resource-deficient city state in Singapore, where human capital is the essential asset in shaping the country's economy (Prince & Felder, 2006). A strength of the education system of Singapore lies in its broad-based curriculum which enables students to acquire relevant skills and abilities to survive in competitive environments. However, there have also been growing concerns about the effectiveness of the instruction approaches. For instance, questions have been raised if there had been too much focus on rote learning and regurgitation (Prince & Felder, 2007; Biggs, 1996), which may greatly limit the students' ability to cope with the complexities of growth, competition and changes in this dynamic world.

There have been several efforts made by the Ministry of Education (MOE) of Singaporeover the years, which had promotedcreativity, thinking skills and the use of information technology (IT) in teaching. Due to these initiatives, teachers have since been trained to acquire a body of pedagogical strategies, skills or techniques which would allow them to teach higher-order thinking and creativity in both curricular and non-curricular contexts (Deng & Gopinathan, 2001). For example, "teach less, learn more" is now a current focus in the Singapore Education System. This catchy yet paradoxical quote corresponds to what Singapore's Prime Minister Lee Hsien Loong mentioned during the 2004 National Day Rally: "…we have got to teach less to our students so that they will learn more" (Lee, 2004).

The propagation for creativity and thinking skills has also been anchored on the use of information technology in teaching. Singapore's MOE continues to encourage the integration of IT into curriculum planning, assessments and pedagogy (MOE, 2008). This includes designing classroom activities through computer-based learning such as multimedia and computer packages.

Inductive Learning Methods

In pedagogical research, inductive learning is widely acknowledged to effectively supplement conventional or 'deductive' modes of learning. Inductive teaching is based on the claim that knowledge is built primarily from a learner's experiences and interactions with phenomena. Students learn largely via 'constructivism' (Biggs, 1996), where they develop mental models of their experience, and relate new information to existing mental models.

Constructivism has its origins from Piaget (Piaget, 1983) who hadstipulated four key concepts in learning: schemas, assimilation, accommodation and equilibrium. These concepts describe how studentslearn through adaptation and organization. Schemas represent the organization of thoughts, which are basically the mental models of one's environment. These are then processed through assimilation. One tries to make sense of external events and accommodate the events by fitting them into his or her mental structures (Bhattacharya & Han, 2001). Equilibrium is achieved when one is able to strike a balance between assimilation and accommodation.

Inductive learning typically starts from addressing issues or solving specific problems. The more the problems are closely identified by students, the closer the bearing of the problem would be to their existing mental models. Students modify existing mental model structure by necessity in order to assimilate the new knowledge to address the posed issues or solve the problem. Implementation of

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inductive learning may be broadly classified into the following four approaches, i.e. inquiry-based learning (Bateman, 1990; Lee, 2004), problem-based learning (Barrows & Tamblyn, 1980; Boud & Feletti, 1997; Tan, 2003) case-based learning (Kardos & Smith, 1979; Lynn, 1999; Kardos, 1979) and project-based learning (de Graff & Kolmos, 2003; Heitmann, 1996).

Inductive learning techniques are well-known to encounter strong resistance and even hostility from students. In particular, those with little prior experience in these classroom instruction modes. To address these issues, we propose a hybrid inductive learning approach termed as the *case-storytelling* method, which can be viewed as a middle-path approach of case-study technique and inquiry-based modes of inductive teaching. The potential advantages of the proposed case-storytelling approach are the following; first, it places technical content in a problem-solving context. This gives students an appreciation of the complexity of real-world problems. A storytelling style of delivery is adopted, which is very powerful in engaging students in the learning process. It also facilitates to break the monotonic pace and tone of a conventional lecture mode. Case-storytelling is flexible and easy to integrate with other different variations of inquiry-based learning. This method will be discussed further in Section 2.

Systems Thinking

Beyond inductive learning, it is also important that students be trained systematically on how to extend classroom knowledge to analyze real-world problems. In real world problems, cause-and-effect relationships are usually less straightforward and originate at a different space and time. Furthermore, a complex feedback system might be present which misleads one from the system's root cause of interest. The apparent cause identified is often just a coincident symptom which provides little effect for producing improvement in the overall system. Presently, education might not prepare students for such complexity such that the lessons learnt today could possibly point them in the wrong direction.

The approach of thinking about systems as a whole with the explicit emphasis of the relationships and interactions between its constituents and environment is a fundamental tenet in the holistic mental framework and worldview of systems thinking (Senge, 1990). Frameworks to develop systems thinking skills in high school and college education have been proposed for Catalina Foothills School District (Draper, 1993). Assaraf & Orion (2010) proposed the System Thinking Hierarchical Model that characterizes eight emergent system thinking skills in the context of the Science subject in elementary level.

The system dynamics (SD) methodology (Forrester, 1990), referred to commonly as the stock-flow simulation model, is a widely-used simulation approach in the research of large-scale socio-technical systems. It is used to model system structures that often form feedback loops among important cause-and-effect relations. The combination of feedback loops, delay elements, and nonlinear relationships are building blocks of complex dynamic behaviours in systems. All commercially available SD simulation products provide easy-to-use development interfaces for modellers, and perform the conversion of stock-flow diagrams into corresponding nonlinear ordinary difference equations (ODEs) and their numerical solutions in the background. In this paper, we propose a blend of the inductive learning mode of case-based learning with the hands-on mode of system dynamics computer simulation to create a unique classroom experience suitable for adaptation in high school or college level education in various fields.

Applying the System Dynamics Methodology in Education

The motivation of why SD is chosen as an education platform is clear. First, SD can be applied widely to almost any field of study due to the growing knowledge of feedback systems in today's world. We are all surrounded by the dynamics of social, business, environmental and economic behavior of the world. These activities are all governed by feedback loops that connect actions to a future resultant action or consequence. Understanding system dynamics is paramount to making changes and appropriate decisions to the systems of interest.

Secondly, the ease of use of digital computers in today's technological context enables students to deal with concepts and dynamics of systems' behavior, which used to be restricted to the realm of advanced research laboratories. This new approach of learning can be made possible with the aid of many user friendly computer programs available today, such as iThink (Richmond, 1985), which had been inspired from the recent popularity of SD. Furthermore, pedagogical experiments (e.g. Glinkowski, Hylan & Halligan, 1996 from Rensselaer Polytechnic Institute have demonstrated that computer lab-based learning can enhance the effectiveness of classroom delivery and learning) allows students to interact freely between the lecturers and their peers to learn at their own pace with the help of their personally assigned computers.

Forrester, the pioneer of SD (Forrester, 1990), believes that the continuous developments of SD and the focus of a learner-directed learning today promise a learning process that enhances depth, breadth and insights in education (Forrester, 2007). According to Forrester, it is possible to use systems thinking as a common foundation for all subjects, be it mathematics, history, social sciences, physical sciences and so on. In addition, Forrester strongly feels that education should be structured like in real life and SD plays a crucial role in doing so. The present education system trains students to solve problems with the necessary tools provided. With a systems approach, students will search for ways to respond to problems which they identify to be important, which are more practical and useful for their future. The use of SD modeling has also been proposed as a unifying theory to teach physical processes in the Zurich University of Applied Sciences (Fuchs, 1999), and Earth system science (ESS) in Gonzaga College High School (Mahootian, 1997).

This study explores the integration of the SD methodology with a case-storytelling approach. We look into the how the SD methodology could build upon the inductive learning process. We seek to identify whether learner participation could be engaged through case-story telling and if problems could be identified and solved through model building and simulations.

The remainder of the paper is outlined as follows. In Section 2, the various components that make up our proposed case-storytelling instruction approach with SD computer simulation are described, with various examples given. Section 3 presents the findings of our two experimental studies. In particular, the first is a single-session instruction on Singapore-Cambridge General Certificate of Education (GCE) A-level geography syllabus for A-level students. The second involves a cohort of industrial engineering students at the sophomore level class over a semester. Quantitative and qualitative evaluation results are then presented. Finally, Section 4 concludes our work.

Elements of the proposed methodology

Brainstorming: Clarifying Causal Connections

The purpose of the brainstorming stage is to bring about a focus on the students to the general context of the subject matter of interest to be delivered. The typical scenario includes having the instructor pose a simple question, and then prompting the students, either by calling out names, or through small group discussion, to describe what they think are some of the key factors, causal connections, and issues involved in the specific topic. This also serves as an exercise to elicit the current mental models of the students, so that their impressions of the topic are articulated and clarified. It is recommended that simple diagramming tools are used in this stage to quickly facilitate the bouncing of ideas. For instance using causal loop diagrams (CLD), Ishikawa diagrams (Fishbone chart) and subsystem diagrams.

Example

As an illustration, in a session to teach an A-level curriculum in Geography, the students are first introduced to basic concepts of population with the help of a Demographic Transition Model (DTM). Students are then encouraged to brainstorm and suggest possible factors which will affect population. A CLD on Population is then drawn together with the students to show the interconnections between the various factors and possibly even feedback loops (see Figure 1). The CLD is hence a *high-level summary* of the current state of understanding and perception about the population. After the CLD is drawn and understood, the students are prompted to suggest how the population will grow or behave intuitively based on the various factors. Typically, it is very difficult to predict the dynamic behavior even for very simple systems, and so the purpose is obviously not for students to know the answers at this stage. Nor should the instructor reveal the answers. Such inquiries engage the students' minds and motivate them to look for answers as the session continues.

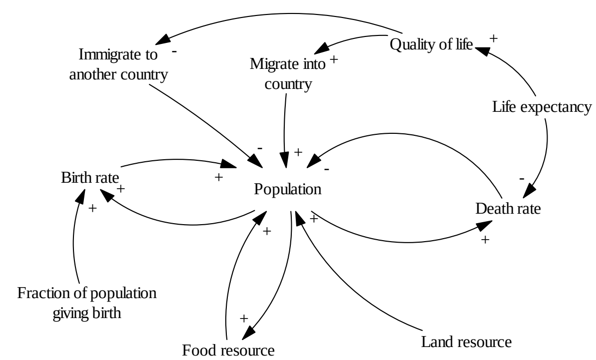

Figure 1: Causal Loop Diagram for Geography Brainstorming Session

Case-Story Telling: Engaging Learner Participation

We describe some basic features typical in the proposed case-story telling approach. For high school and freshman level college students, instructors are advised to provide extensive scaffolding support and guidance when students are first introduced to inductive learning methods, followed by gradual withdrawal of the support as the students gain more experience and confidence.

Prior to the actual lecture delivery, the instructor may use a case-background article to be read by the students before they attend class proper. Unlike case-studies, these background materials are not necessarily very lengthy and detailed. The purpose is to set up the problem situation and introduce the main protagonists in the case-story. Some simple questions may be appended at the end of the article for the students to think through and be answered during class. The class may be started by calling on students to answer some of these questions, or it can be a more elaborate brainstorming exercise as described in the previous subsection. This serves the purposes of aligning the interpretation and expectations of the class, gauging the level of classroom engagement and enthusiasm, and building the atmosphere of problem-solving and active participation.

The proper classroom material is introduced by using a story-*like structure, with an emphasis on protagonists in case-story* via a light-hearted approach. For instance, protagonists engage in dialogue with each other in the description of the problems and motivation. Student participation can be encouraged via role-playing, by calling out students to read portions of the notes by certain characters. The story is used to provide direction and purpose for introducing the technical concepts when the protagonists encounter new issues or challenges they cannot resolve. The role of the instructor is to facilitate the 'unfolding' of events and whenever appropriate should step in to check that students identify with the challenges and issues.

Examples

In the classroom example of the geography lesson on population, a case study of Easter Island is introduced to illustrate the impacts of food resource to population. In the late 1300s, the population of Easter Island starts to fall drastically from a population figure of 7000 to 2000 by the end of 1700. There are theories hypothesizing over the sharp fall of population in the 1600s. One possible theory revolves around the idea of renewable resources such as food resources not replenished fast enough to sustain the population (Ponting, 1993). Students follow the story to build a SD model that represents this theory.

In an example of an industrial engineering class, a case-story depicting a meeting among senior management and engineers of a semiconductor device manufacturer is used to facilitate the teaching of proper demand forecasting and process modelling techniques. The case story required the development of a production process model and a forecasting model, using the SD software. At the beginning of the session, several issues about bottoms-up forecasting are discussed, culminating in a CLD shown in Figure 2 that describes the phenomena of defensive orders in a supply chain. Students were picked to play the roles of the senior and junior engineers, and through a question and answer type of dialog, and the instructor stepped in when necessary to introduce the necessary tools required to extend the SD model in order to resolve the issues raised by the protagonists.

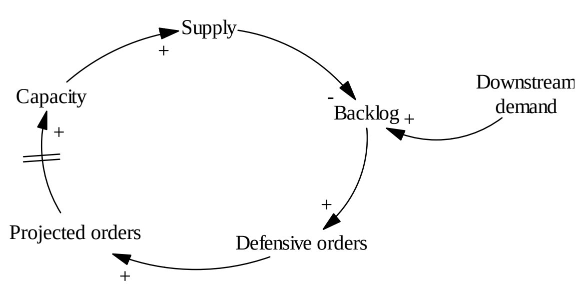

Figure 2: Illustrating Defensive-Ordering in Supply Chain via Case-storytelling

Unlike in case-study methods where students are expected to utilize their existing technical knowledge to propose solutions for the case problem at hand, case-storytelling reveals the solution approach and technical information to the students at the appropriate junctures. For instance, by adding appropriate structures to their computer simulation model. This is coherent with the constructionist point of view of learning.

Modeling and Simulation: Lab-based Theory Building

The basic purpose of using the SD methodology in the instruction is to precisely emphasize a model-based approach in the learning theories. A model diagram is visual, and is extremely effective to see 'what fits where', and how various factors and issues are interrelated. That is, students learn to inquire about system structure, and how structure drives behavior. Furthermore, the hands-on experience of model building is very much akin to children playing with 'Lego' building blocks, the fun of which cannot be compared to a conventional style of delivery where the instructor shows model after model and theory after theory.

Examples

In the geography classroom example, a simple stock and flow model (Figure 3) of the population issue is introduced after the brainstorming session. Students are asked build the model on their terminal. The population is modelled as a stock whereas the birth rate and death rate is modelled as an inflow and outflow to the population as shown in Figure 1. Two additional convertors namely "Fraction of population giving birth" and "Lifespan" are also defined in this model. Other possible variables defined may be "Infant mortality", "Diseases" or "Healthcare" services".

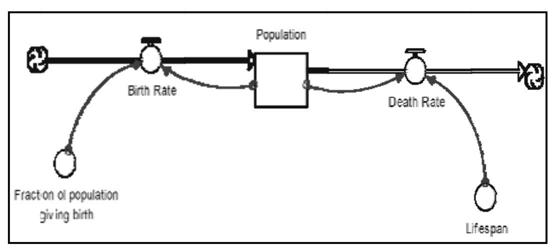

Figure 3: Population Model with Birth and Death Rates

Students are then asked to use the model and simulate different scenarios revolving around birth and death rate and check their predictions made during the Brainstorming phase. This 'learner-driven' learning experience deepens the students understanding of how the relationships of how birth and death rate affects population and the characteristics of developing and developed countries with regards to birth and death rate.

The course will subsequently look into how land resource plays its part in population. To facilitate this, the case story of Easter Island is used. In order to help the protagonists investigate the situation, the students are guided to expand their stock and flow model by including land resource and their influences on fertility and mortalities. As each component is developed the students, the instructor draws their attention also to how agricultural patterns are formed by growing populations etc.

Through this simulation exercise, students observe first hand (through simulation) how land resource limits the growth of population. The students then extend the model to consider non-renewable resources, which are structurally very similar to land, but the difference being that non-renewable resources takes a long time to replenish. Upon simulation, the students learn the possible theories that caused the Easter Island population to be decimated. The final developed system dynamics model is shown in Figure A1 in Appendix A.

In the industrial engineering class, the case story in the earlier section required the development of a production process model and a forecasting model, using the SD software. At each stage, students are introduced to various material and informational delay formulations, and how to incorporate them in business process models.

Analysis and Problem Solving: Harnessing the Power of Systems Thinking

The analysis phase is interwoven with model building and simulation of Section 2.3. As each cut of the simulation model is built, the students are given some exercises to complete. Typically, at the beginning of the course, more guided support is given by the instructor. As the course progresses with growing confidence of the students, more independent exercises may be used. Towards the end of the course, an open-ended design problem can be issued to students as a challenging exercise for them.

Examples

In the geography example, students after building the model are given the following policy design assignment. They were told that as the nation's policy-makers, what measures they would take to grow the population to hit a target value. They then use the computer model to explore and try out different policies in order to achieve the objective. Students will be encouraged not only to hit a target population, but also elaborate on what "policies" they proposed. Through this exercise, the core ideology of systems thinking will be further reinforced as maximizing one factor might not necessary mean hitting the expected target.

If a case-storytelling mode is employed, the session should end by establishing strong conclusions about how the technical content has helped in the problem-solving process. This builds confidence for students about the material learnt. It is also useful to point out further challenges and extensions possible. In the industrial engineering class, the students learn that in the presence of long manufacturing lead times, a good process simulation model is very important and effective in guiding business projections. The process model that they developed in the session with the guidance of the instructor was shown to give much improved forecasts of the customer demands as compared to the initial forecasts. In the course, students are then required to apply these skills in a group project to develop a model for a problem of their choice.

Experimental Studies

As mentioned, two experimental studies have been conducted involving secondary and tertiary students to explore the adaptability of the approach described in Section 2 to both education levels. In this section, we present the experimentalsetups used for each one and discuss the respective results.

Population Dynamics in A-Level Geography

Experimental Setup

The subjects used for this study were student volunteers from a local junior college institution. The students do not read geography in their own chosen program and have no prior knowledge of SD simulation. The experiment was held in a computer laboratory in the authors' research institution. Each student was assigned to a computer desktop with the iThink software installed. There were 10 students involved in this study.

The learning objective for the students is to achieve an understanding of population growth, including relationships between population and development, changes in demographic indices such as life expectancy over time, understanding population-resource relationships, managing population change as well as understanding migration as a component of population change. These are in accordance to the Cambridge International Advanced level curriculum for Geography (University of Cambridge International Examinations, 2011).

Data Collection

The author conducted a session covering the population concepts through the use of the iThink software. The relevant SD tools were taught alongside these concepts. The main form of assessment for this study was through the use of a survey (Appendix B), which was completed by each student at the end of the session. They were asked to give their feedbacks and evaluate the session according to its usefulness, applicability and ability to enhance interest and subject matter retention. Qualitative analysis was then performed for the results of the survey, wherein answers for each criterion were summarized and evaluated by the authors.

Results and Discussions

The survey revealed that all of the students would like their school lessons to be held in a similar manner of exploring a topic together in class instead of the current traditional delivery method. They felt that lessons are more interesting, engaging and interactive which helped them focus better in class compared to a stagnant lecture or tutorial class. The general consensus was that ideas are easier to grasp and understood compared to just reading textbooks. This observation is in line with what Ackermann (2001) states about the process of transmission in learning; wherein knowledge is not merely delivering information at one end with the expectation that students would be able apply it at the other end. Rather, it is an experience that is acquired through interaction with the world, people and thing.

In fact, the students participated actively in the session even when they do not know each other being from different classes. They engage themselves throughout the course from discussions of what they think will affect population and even modeling questions of whether different variables could be modeled in another fashion. When asked whether this session enhanced their interest in Population, all of them gave positive feedback even though they are not Geography students. For instance, one of the students who attended the course commented: "Yes this session enhanced my interest in Population. It was interesting to see how various factors can affect each other and ultimately, the population over a long period of time."

In addition, the students showed no problems understanding the basic concepts of stock and flow diagrams despite the fact that this is the first time the students are exposed to this complex methodology of SD. Most of them even went on the next level and brainstorm other modeling possibilities other than Population. This reveals that even though system dynamics is regarded as a high level thinking skill, there is a great potential in introducing this useful thinking skill into junior colleges at least as students can relate to its ideas well. Some comments of the students are as follows: "I could use it for planning cities in Space and maybe energy management of spacecrafts. My interest is in Astronomy and Engineering."

Although the course lasted for about two hours, one of the students even feel that the course should be longer. This is indeed a huge encouragement as it is not the usual case of which students cannot wait to get out of their lessons and impatiently waiting for it to end. The following feedback was given by another student: "It would be better if the duration of the course were to be extended so that we can go deeper into the understanding of the topic."

Harel & Papert (1991) introduced the idea that students "learn by making". Indeed, this has been observed from the study. As an example, a few students even stayed back and continued exploring the software even after the course ended. They built models of their interest and attempt to draw lessons out of it as if they have already known the software. An example of a SD model built by one of the participant students is shown in Figure 4 below. He is concerned over the issues of overcrowding trains in Singapore and was curious whether building more trains or stations will help the situation. He came up with this model himself with no help at all and proceeds on to discuss his model with me on the validity of the model. All these comments and interest shown from the students greatly shows the potential of incorporating SD into today's educational system. It shows how technology can provide new ways to learn. With the addition of a new medium (i.e. SD computer simulation), students were able to extract new realizations about topics that they may had already been familiar with.

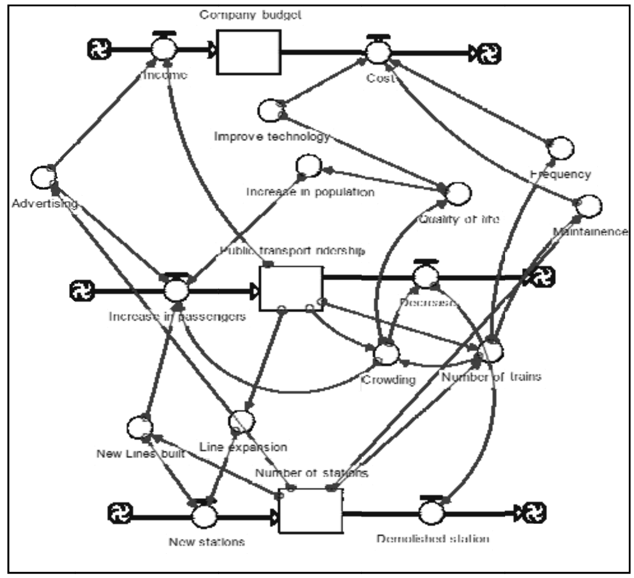

Figure 4: A Student's Attempt to Model the Mass Rapid Transit Situation in Singapore.

Industrial Engineering Modeling

Experimental Setup

In the second experimental study, the course used was IEXXX at the authors' academic institution. The learning objective of IEXXX is to introduce to students at second-year under-graduate level the basic end-to-end process of problem-solving in industrial and systems engineering domains. The problems can include process improvement studies in everyday life situations such as queuing, competition for resources or other systemic issues. A major assessment component in the course is a semester-long project that requires students to work in groups to solve an industrial and systems engineering problem. The students are expected to apply the concepts learned in class and demonstrate an organized and methodical approach to engineering problem-solving. The other assessment component is a midterm quiz. The lecture content consists of project management concepts, frameworks of industrial problem-solving and process improvement such as Six Sigma and systems thinking, SD simulation modelling techniques and concepts.

Two lecture sessions of three hours each were used in this study and delivered with case-storytelling with SD. The topics involved process modelling techniques and their applications in business process improvement. The remaining lectures were used as control sessions and delivered using conventional lecture approach. The size of the class reading course was 80 students.

Data Collection

The effectiveness of the proposed case-storytelling SD delivery is evaluated using the following criteria: retention of material, student's ability to apply learned material in problem-solving, and other qualitative feedback (students' reactions, preferences, comments). The following modes of evaluation used.

i. A one-hour closed book graded assessment was given to the students towards the end of the course. One question was posed each for the material covered using conventional approach and the case-story approach. Each question was allocated 20 marks and consisted of several short-answer questions. The short-answer questions were mainly factual in nature and were directed to evaluate the material retention and knowledge acquisition of the students.
ii. Project Report and Presentation. Students were required to submit a thirty-page report of their project, and perform a twenty-minute oral presentation of their project at the end of the course, followed by a 10 minute Q&A session. The purpose of the Q&A is directed to ask students regarding whether they were able to sufficiently apply concepts and methods delivered in class to problem-solving (in particular modeling) in the project, and also if the students were able to execute the project in an organized and methodical manner. These had direct relevance with the achievement of the course objectives, which is for the students to develop a methodological approach based on systems thinking and modeling to engineering systems problem-solving.
iii. An online survey (www.surveymonkey.com) was set up to collect anonymous feedback from the students taking the course during the semester. This was used to solicit qualitative comments with regards to the general administration and the styles of delivery of the course. The results of the student feedback exercise performed by the university at the end of the semester were also used in this evaluation.

We employed the use of both quantitative and qualitative analyses for this study. Specifically, we used the Student's paired t-test to compare the scores from the graded assessment of the previous cohort that did not use the case-storytelling SD approach and the cohort that did use the said approach. This allowed us to determine if the differences between the scores were significant or not. Meanwhile, we also summarized the students' feedback from this course, which we discuss further in the following subsection.

Results and Discussions

The results for the graded assessment were as follows. The class participation in the quiz was 74. The results were analyzed only for responses that attempted both the questions. Question 1 (Q1) was related to material taught without the case-storytelling method, while Question 2(Q2) was telling related to material delivered using case-storytelling.

Table 1: Quiz Grades Comparison

	Sample mean difference	Sample standard deviation difference	Sample size
Q2-Q1 score	2.6	1.9	74

Although the sample mean of the score in Q2 was marginally higher than that of Q1, this difference was not statistically significant at the 95 percent confidence level. Thus, it is inconclusive if the new delivery intervention improved material retention of the students.

A rubric template based on (Pickett & Dodge, 2007) shown in Table A1 (Appendix C) was used in the student evaluation during the oral presentation and project report assessment. A total of 18 project groups were assessed. For the purpose of comparison, the same number of project reports from the previous cohort was also re-assessed using the same rubric. The course material for the previous cohort was delivered using conventional lecture approach.

In terms of the ability to adopt a Methodical Problem-solving Approach, the current cohort scored 3.4, while the previous cohort scored 3.1. In the Systems Thinking and Modelling objective, the current cohort scored 3.5, while the previous cohort scored 2.7. Finally, for performance of Analysis and Insights, the current cohort scored 3.2, while the previous cohort scored 2.8. Overall, the results from the cohort under the current treatment were marginally better than the previous, and more markedly so for the learning objective of Systems thinking and Modelling. Although it is not immediately conclusive that the use of the case-storytelling resulted in significant improvement in the achievement of the learning objectives, it was observed that generally students put in their projects substantial considerations in the aspects of systems thinking and modelling. Their reports and presentations were also highly suggestive that the case-storytelling provided them with the inspiration and motivation to apply the classroom materials in interesting manners to their own projects.

Ackermann (2001) mentions that expressing ideas makes them tangible and shareable which, in turn, informs and helps us communicate with others. The case-storytelling approach has given the students an alternative way of looking at engineering problems. It has allowed for self-directed learning wherein the students explore and evaluate concepts beyond what was covered in the classroom sessions. This also reinforces what Sterman (2007) stipulated regarding the SD methodology being learner-centric. The instructor becomes merely the facilitator, with the studentsgenerally responsible for creating their own insights on the subject matter.

Finally, some of the comments extracted from the student feedback and online survey are presented in Table A2, where the left column lists comments from the cohort with the proposed treatment implemented, and the right column from the previous cohort without inductive teaching treatment. Most comments saw positive reception of the new delivery method. Students found the case-story learning experience interesting, engaging, entertaining, relevant to real-life and useful in helping them understand the concepts better.

A minority of students felt however that the pace of the lecture was fast to follow, and were not as effective as they expected. In contrast, the past year feedback showed generally that lectures delivered in traditional approach were un-engaging, dry and of little value-adding to their learning. It is clear from these feedbacks that the new approach was very much welcomed by the students. The students also felt that the instructor put in much effort to try to improve the quality of instruction and learning experience. This generally was very well-received by them.

Conclusion

This study proposed a case-storytelling instruction approach with SD computer simulation. This builds upon the inductive learning process, allowing students relate classroom knowledge to real world contexts. The approach involves clarifying causal connections through brainstorming, engaging learner participation through case-story telling and identifying and solving problems through model building and simulations.

This approach was carried out using two experimental studies. The first study involved a single-session instruction on GCE A-level geography for high school students while the second one involved a semester course on an industrial engineering subject for tertiary students. It was seen in both studies that the use of the approach engaged the students and created a collaborative classroom environment. These showed that by allowing students to build, process and analyze their own mental models, they were able to closely identify with the topics being covered in the respective subjects. Furthermore, it was found that the approach encouraged students to extend what they have learned inside the classroom into their own individual interests and projects.

A future direction of this research includes widening the scope of the studies to more schools in Singapore. This will further justify the advantages of adopting the approach into the context of Singapore's education system. Another direction is to develop strategies that would facilitate the transition to this approach from current teaching modes. This underscores the need to train and orient teachers and students alike.

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Appendices

A. Teaching Population with System Dynamics

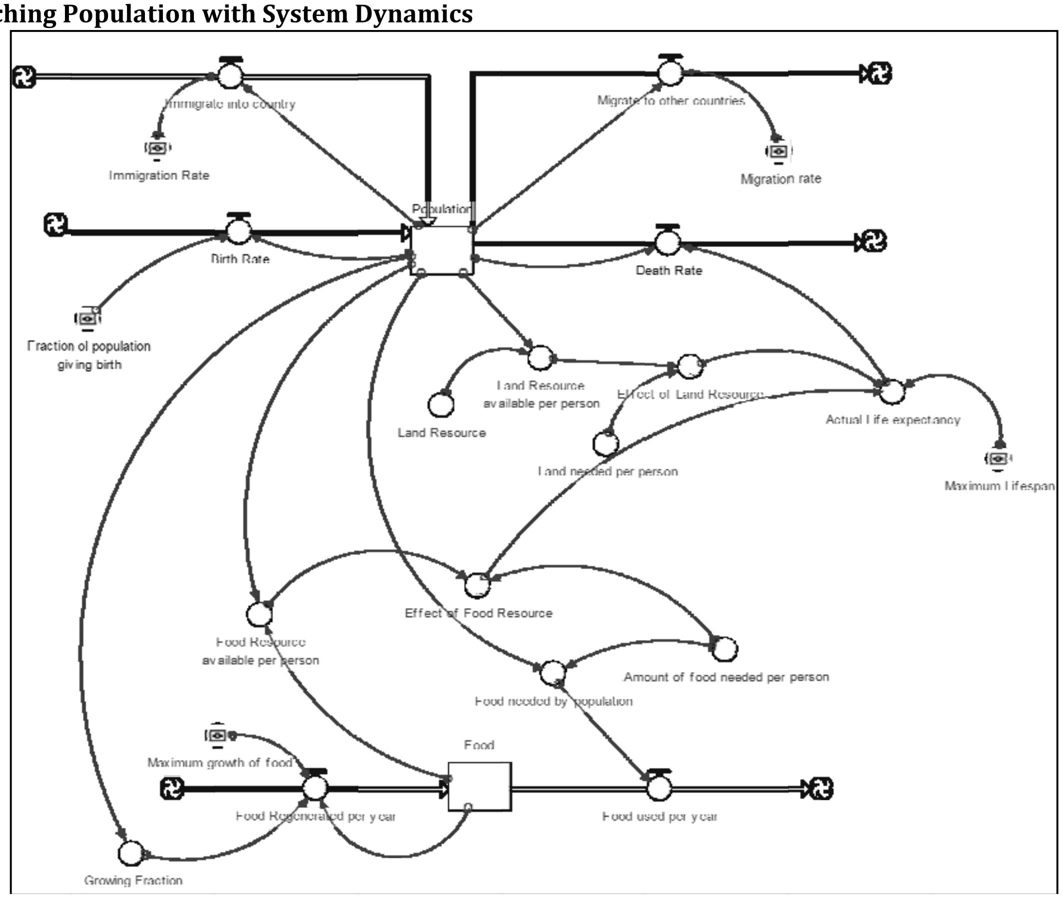

Figure A1: The Complete Population Model

B. Evaluation Survey for Geography Class

1. Would you like your school lessons to be held in a similar way? (i.e. Project and research based and exploring a subject/topic together in class). Please indicate reasons for your choice for question 1.
2. Do you think that this session enhance your interest in Population?
3. Do you think Systems Thinking is useful for your future? If yes, please give examples on how you could apply this thinking skill in future. If no, please state reasons why.
4. Please provide any feedback/improvements that would better aid this learning process?

C. Evaluation of Industrial Engineering Undergraduates

Table A1: Evaluation Rubric for IEXXXX Student Project

Learning Objective / Score	Beginning 1	Developing 2	Accomplished 3	Exemplary 4
Methodical Problem-Solving Approach	Minimal display of clear project management and organization	Demonstrate sufficient emphasis on problem definition and motivation.	Demonstrate coherence and integration of problem-solving stages from start to end of project.	Demonstrate pro-active approach in adapting methodology to challenging situations.
Systems Thinking and Modelling	Minimal display of systems thinking concepts	Demonstrate basic correct application of systems tools to problem-solving	Demonstrate organized approach to understand problem structure, model abstraction and data collection	Demonstrate maturity in thinking of complex problems and systems at high-levels
Analysis and Insights	Minimal effort placed of discussion of results	Basic presentation and explanation of simulation results in quantitative manner	Detailed analysis on system model outputs, including what-if analysis and sensitivity analysis	Demonstrate ability to derive mature insights beyond quantitative conclusions and suggest strategies to resolve issues.

Table A2: Student Feedback from Present and Previous IEXXX Cohort

Cohort with Case-Story Telling	Previous Cohort (No Case-Story Telling)
Has been an enjoyable course so far. Particularly like the part on giving us a case study to learn from. Gives us a more real world example to whilst learning.	Bring more interesting and easy examples. Make it more detailed... We like the examples!
Inductive learning is quite interesting. Lecturer can be more engaging instead of reading off slides. Delivery of lecture can be improved.	Tell us more examples and make the structure clearer to us.
I think the way that lectures are conducted is quite interesting, and insightful.	Make the lecture more interesting
As a whole I feel the module is delivered well. Case studies are good. They show how applications of concepts are done.	Teaching style should be improved. Maybe some examples and illustrations will make the teaching more interesting and understandable.
I like the teaching style but the content is still a little abstract.	Consider modifying the PowerPoint for teaching, it is too wordy.
Lectures have been very interesting and interactive, keep up the good work!	The module is not organized properly. Students hardly understand the contents taught in the lecture.
Lectures are very entertaining and engaging. This was one module I thoroughly enjoyed, also because of the practical significance it has in real world application. The subject matter covered was very relevant, and was done so in a very relevant way.	We didn't learn much. A waste of time.
Very good in engaging students. Has a very effective teaching style.	Difficult to understand as an introduction
Interesting means of conducting lectures. Well at inducing furthering thinking and discussion.	I suggest having a seminar style teaching method instead of a lecture style one.