Transforming Mathematical Model into Agent-Oriented Model and Simulation Through Requirement Engineering: A Preliminary Result

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ABSTRACT

Many of the mathematical models developed in the past have served as a vast repository of knowledge that is rigid and difficult to repurpose and transfer to different stakeholders or modelling technique due to the high learning curves. Even if a mathematical model can be understood, converting the understanding of the mathematical model into agent based modelling and simulation (ABMS) is not straightforward as it is difficult to describe clearly and succinctly due to more data are required and significant software engineering expertise is needed to develop ABMS. We adopt requirement engineering technique to bridge the gap across the modelling techniques. The requirement engineering technique is used to understand the mathematical model and turn into agent context for agent modelling and simulation. This paper presents the preliminary result in adopting the proposed requirement engineering techniques for model transformation. From the results, the agent oriented requirement engineering known as eHOMER is able to transform the mathematical model into ABMS. Hence, the agent modeller can reuse the mathematical model without reinventing the wheel.

Keywords: Requirement engineering, agent modelling and simulation, mathematical model.

I INTRODUCTION

The discipline of modeling and simulation is well-recognized among scientific community due to its importance for understanding a complex system or real world problem. To date, mathematical modeling is among the popular techniques for modeling and simulation. Mathematical modeling utilizes differential equation, discrete mathematics, statistics, linear algebra and etc to model a problem domain. On the other hand, Agent based Modeling and Simulation (ABMS) has emerged as the alternative technique for modeling and simulation of complex systems. ABMS is a modeling approach that concerns with simulation of heterogeneous population of interacting agents in an environment, in which they can reason, learn and adapt. The ability to exhibit emergent behavior from individual level and the ease to model it makes ABMS the choice in modeling and simulation technique among researchers.

However, how to transform the mathematical models into ABMS? This paper presents the preliminary result in adopting the proposed requirement engineering techniques for model transformation. From the results, the agent oriented requirement engineering known as eHOMER is able to transform the mathematical model into ABMS. Hence, the agent modeller can reuse the mathematical model without reinventing the wheel.

Section 2 presents the related works on validating the model transformation. Section 3 briefly describe the model transformation techniques from mathematical model into agent models and simulation. Section 3 present the experiment setup to validate the eHOMER. Section 4 presents the results of the analysis. The paper is conclude in Section 5.

II RELATED WORK

Mathematical models are adopted as a basis for developing ABMS (Mustapha et al., 2016). The idea is to validate the usage of ABMS in a complex problem where mathematical modeling has been applied before.

In these works, the mathematical models are studied and mechanisms are introduced to transform mathematical model into ABMS. Based on the review, the development of ABMS begins with a presentation of a set of mathematical equations to describe a specific complex problem. From these equations, possible agents are identified. Afterwards, agent behaviors are decided by translating mathematical equations into rules. Finally, agents and their behaviors are implemented in algorithm of agent programming language, i.e. agent rule is written as if-else function in the simulation coding.

Although it is possible to reuse the mathematical models for developing ABMS, these current practices are found lacking in systematic way for guiding modelers in translating mathematical models into agents. In this case, there is an ambiguity in the development process for clearly identify which elements in a specific mathematical model such as variables can or should be considered as the agent type, behavior or rule. For instance, which part of equation did these agent behaviors and rules came from? Were these agent rules formulated from the equation itself or based on some model assumption that is not explicitly shown in the equation? Where, in the equation, did the sequence of agent behaviors came from? Often, these ABMS that are developed in ad-hoc manner are not inclusive and not well communicated (Grimm et al., 2010; Schmolke et al., 2010). Therefore, it would be sensible to explore the use of a systematic approach to clarify the process of transferring the knowledge from mathematical models into the development process of ABMS.

III A HYBRID REQUIREMENT ENGINEERING TECHNIQUE FOR MODEL TRANSFORMATION

Requirement engineering is used to understand the user requirements. Hence, we adopt the requirement engineering technique to understand the modeller knowledge for model transformation. The requirement engineering technique is used to bridge the communication gaps between the mathematical modeller and software modeller.

It is sensible to start the model transformation with sketching the final output by both modellers. The final output of the modelling is the visualization or simulation model. Here, picture based requirement engineering is adopted as the first step for model transformation. This is followed by agent oriented requirement engineering to elicitate the requirement into agent context. From the elicitation answers, the modeller will transform it into agent models and simulation model.

We briefly present the agent oriented requirement engineering in the following description.

The extended HOMER (or eHOMER) is introduced as a requirements elicitation technique to comprehend requirements from domain experts or mathematicians. HOMER is introduced for requirement engineering during agent development (Wilmann, Sterling, 2005). The HOMER is shown successful in agent development in ICT4D (WaiShiang C. et al., 2016) , video surveillance (WaiShiang et. al, 2016), games (Wyai, et al., 2017), environmental study (WaiShiang et al., 2016).

In this paper, the elicitation is focused on understanding mathematical model structures (i.e. variables and mathematical notations, and understand their meanings) and the assumptions of the model, and in turn, the elicitation answers are represented as agent contexts (i.e. as roles, tasks and rules).

There are two activities involved in eHOMER. First, interview session is conducted to elicit requirements through picture based requirement engineering and eHOMER questionnaires. Then, agent modeler will relate which answer in eHOMER as requirement is pertaining to specific agent oriented models.

Generally, agent modelers attempt to seek the following answers from the interview through eHOMER questionnaire as partially shown in Table 1.

- Problem statement of the model – the overview about this model and why it was needed.
- Agent characteristics like role name, interaction protocol, task description and rules derived from part of equation body that explicitly or implicitly describe them. – Does this variable specify some type of agent (or agent states) or simply an attribute (knowledge) belong to certain individual agent? Are these two equations implicitly describing some form of interaction between two or more agents?
- Hidden dependencies – is there any assumption like (behavioral or mathematical) rules that is essential but not explicitly shown in this equation body?

Table 1. eHOMER Questionnaires.

1 **What concern is being addressed behind the study?**
   a) If you were to solve the problem of ……., which role(s) do you require?

2. **For each role in the above, we need to collect a task description**
   a) What is the **purpose** of this role?
   b) What **tasks** will commonly be required?
   For **each task**,
      i. What **subtasks** make up this task?
      ii. What **constraints** are for this task?
   c) Which *other roles* in the environment does this role rely upon?
   d) Which *other role* rely upon this role?
   e) What knowledge about this role's *attributes* is required for this study?
   f) What *resources* required by this role in fulfilling its role?
   g) Are there any changes in this role's *task list, knowledge attribute* and *resource* when not interacting with others? If so, what are the outcomes?
   h) Are there any changes in this *role's task, knowledge attribute* and *resource* when *interacting with other roles*? If so, what are the outcomes?

3. **Does this issue lead to the need for environmental requirement? If Yes, please continue below; otherwise, move on to Question 4**
   Which environmental *artifact*(*s*) do you require for this study?
   For each artifact, we need to collect an environmental description
   a) What is the *purpose* of this artifact?

b) What *constraints* are there for this artifact to fulfill its purpose?
c) What *resource*(s) is required by this artifact to fulfill its purpose above?
d) What knowledge about this artifact's *attributes* is required for this study?

4. We need to collect description of codes of behavior required for each role

a) What code of behavior must be observed by **all roles?**
b) Are there any *specific* codes of behavior for **certain role**?
c) What is the sequence for all tasks to be completed by each role?

5. Are there any other rules that must be adhered to in this study?

IV EXPERIMENT SETUP

The aim of the study is to evaluate usability aspect of requirement engineering for transform mathematical models and into agent based modelling and simulation. Malaria transmission model from (Kon, C. and Labadin, J., 2013) is used for this usability study. Work is done to validate the model transformation through software testing (Kuster et.al., 2006). It has been indicated that proving correctness of model transformations formally is difficult and requires formal verification techniques. Hence, software testing is applied to validate the model transformation. From the test case, it can identify the errors by testing the output of the model transformation or model transformation development. We adopt the testing approach in which usability study are conducted to test the adoption of the proposed requirement engineering techniques for model transformation.

The case study presents the partial differential equations proposed by Kon and Labadin (2013) to formulate transmission behavior for mosquito-borne infectious disease, notably malaria. The Malaria transmission model is used to understand the behavior of malaria transmission based on the interaction between humans and mosquitoes.

Malaria transmission model partitions the populations into categories depending on whether they are carrying the disease or not. In this case, the categories (also known as the compartments) are Susceptible and Infectious. Susceptible represents the state of humans and mosquitoes that are not yet infected but vulnerable to infections. Infectious represents the state of humans and mosquitoes being infected with mosquito-borne disease and are capable of spreading the disease to susceptible group. The details of the case study can refere to (WaiShiang et. al, 2017).

To answer these research questions, the usability study was designed according to the following characteristics:

Participants' background: There were 30 undergraduate students who voluntarily participating in this usability test. These students are from Faculty of Computer Science and Information Technology in UNIMAS and have varied in study majors such as Software Engineering, Computational Science, Network Computing, Multimedia and Information System and have range of study year (from 1st year until 4th year students). These students have no prior knowledge or experience in ABMS and epidemiological study. Nevertheless, they do have familiarity or experience in basics of programming and knowledge of classical software development life cycle, obtained at some point of their past IT studies (i.e. from college or some training courses).

Usability study duration: Originally, usability study was intended to be performed within a day with all students who were invited earlier on. Due to their participation approach in voluntary basis, the study must be conducted in more than one day. As a result from this constraint, the usability study was conducted in three batches to facilitate the minimum of 30 students. Initially, eight students came as first batch. In the following month, another 11 students came as the second batch and finally in third batch, 11 students have attended in the following week.

Usability study plan and data collection method: The usability study is performed in three sequential sessions. First session dealt with Experiment 1 which evaluates the perception of students in understanding mathematical models. Then, second session dealt with Experiment 2 which evaluates the competency of students in producing complete and accurate simulation. Finally, third session concludes usability study by surveying student feedbacks.

Both Experiment 1 and Experiment 2 employ Pre-Test and Post-Test as data collection method.

Test moderator: This role was enacted by the author of this thesis. His roles are to coordinate usability study, to develop Pre-Test and Post-Test questions in each experiment, to introduce the testing plans to students, to monitor, train and support students in the tests and to collect student test results and feedbacks.

Experiment 1. This experiment aims to evaluate students' performances in answering malaria mathematical model before and after introduction of requirements elicitation technique, eHOMER. This experiment is conducted in two phases – Pre AOM and Post AOM.

In Pre AOM phase, all students are required to answer a list of questions. This Pre-Test consists of equations for malaria transmission model, the diagram that shows connection between mosquito and human equations, the parameter definition of the malaria transmission model's equations and five questions about malaria transmission model. These students were asked to complete Pre-Test within 1 hour. Pre-Test ends when all students have already submitted their answer sheets to the moderator.

In Post AOM phase, a short tutorial session was conducted by the moderator on eHOMER. These students are instructed on how to use eHOMER to collect information about mathematical models. This tutorial session ran for 20 minutes. At the end of tutorial session, requirements elicitation session was conducted with these students. In this case, these students were given the opportunity to role-play as interviewer. These students were asked to interview the moderator (acting as so-called domain expert) by using eHOMER questionnaire in order to elicit malaria mathematical model. This interview session has lasted for an hour.

Upon completion of requirements elicitation session, students were asked to do Post-Test. Post-Test ends when all students have submitted their answer sheets to the moderator.

V RESULT

Time and scores were collected during Pre-Test and Post-Test. Time measures the duration to complete Pre-Test and Post-Test in minutes. Score refers to the correctness of students in answering the questions in Pre-Test and Post-Test. For each question, a correct answer is measured as 20 marks and incorrect answer is measured as 0 marks. The maximum score for these tests is 100 marks.

The following section presents the findings from the evaluation of student Pre-Test and Post-Test results.

The means and standard deviations calculated from students' test scores and time take to complete Pre-Test and Post-Test are shown in Table 2.

Table 2. The mean and Standard Deviation Values from Students' Pre-Test and Post-Test Results in Experiment 1

	Mean score (μ)	**Standard deviation of score (σ)**	**Mean time (μ)**	**Standard deviation of time (σ)**
Pre-Test	14	12	29	10
Post-Test	46	15	7	4

From Table 2, it can be concluded that a) students' scores in Post-Test (after using AOM) are larger than their Pre-Test score (not using AOM) and b) time taken to complete test questions by students in Post-Test is smaller than in Pre-Test. Hence, the use of extended AOM has led to improvement of test scores and reduction of time taken to complete test questions.

Mean and standard deviation values from Table 2 are then translated into normal distribution graphs to illustrate how spread out these Pre-Test and Post-Test scores and time are.

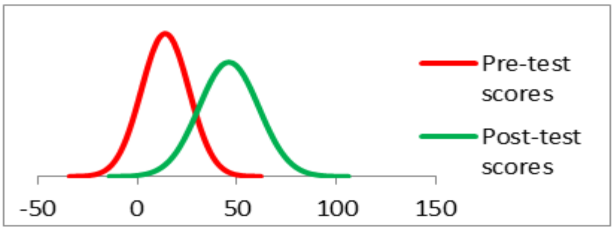

Figure 1. Normal Distributions of Pre-Test and Post-Test Scores.

Figure 1 presents the plots of normal distributions (the bell curves) based on means and standard deviations of Pre-Test and Post-Test scores. Red graph describes the curve for Pre-Test that has the mean of scores, μ = 14 and standard deviation, σ = 12 whereas green graph describes the curve for Post-Test that has μ = 46 and σ = 15. Mean value show where the peak is at (x- axis) whereas standard deviation value shows the width of the curve – the bigger the standard deviation value, the wider it becomes (data become spread out over wider range of values). According to the distributions shown in Figure 1, it appears that nearly all students in Pre-Test have same low scores. On the other hand, Post-Test shows sign of improvement in students' test scores where test scores are much diverse. Some of these students have achieved very high scores.

Figure 2 presents the plots of normal distributions based on means and standard deviations of Pre-Test and Post-Test times. Red graph describes the curve for Pre-Test that has the mean of time, μ = 29 and standard deviation, σ = 10 whereas green graph describes the curve for Post-Test that has μ = 7 and σ = 4. According to the distributions shown in Figure 2, it appears that students' Pre-Test time is highly varied. Some students have spent shorter time to complete the test while others have been reported taking longer time to complete the test. On the other hand, there is improvement in their Post-Test where all students have completed their tests at short span of time.

Step 2: Hypothesis Testing

In this step, the hypotheses for Experiment 1 are a) Post-Test score is larger than Pre-Test score (as Hypothesis 1) and b) Post-Test time is smaller than Pre-Test time (as Hypothesis 2).

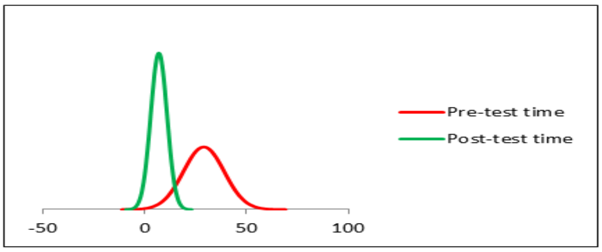

Figure 2. Normal Distributions of Pre-Test and Post-Test Time.

The test statistic, t, falls in the critical region, as displayed in Figure 3, so null hypothesis was rejected. Hence, the sample data do support the claim that Post-Test score is larger than Pre-Test score when students participate in Pre-Test and Post-Test of Experiment 1.

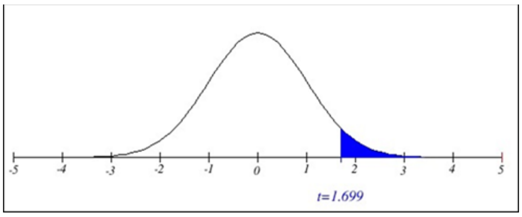

Figure 3. Hypothesis Test For Scores With Dependent Samples.

On the other hand, the test statistic, t, falls in the critical region, as displayed in Figure 4, so null hypothesis was rejected. Hence, the sample data do support the claim that the Post-Test time is smaller than the Pre-Test time when students participate in Pre-Test and Post-Test of Experiment 1.

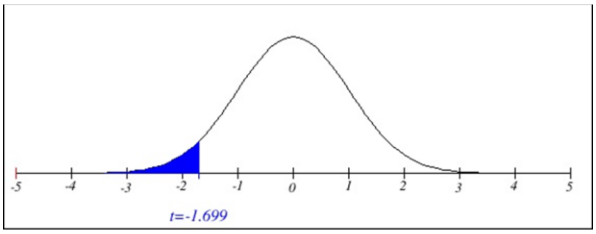

Figure 4. Hypothesis Test For Time Taken To Complete Test With Dependent Samples.

Discussion of Experiment 1. In summary, the findings above confirm that students' performances were significantly improved when adopting extended AOM to comprehend malaria transmission mathematical model. In Pre-Test, the problem statement described as mathematical model was still vaguely perceived by these students, even with these "support documents" to explain what each variable in these equations mean. After eHOMER was introduced, these students were able to obtain a clearer picture about the actual problem statement from this malaria transmission mathematical model. As a result, their scores are much higher in Post-Test than Pre-Test as well as time taken to complete Post-Test becomes lesser than Pre-Test.

In summary, these findings have shown that eHOMER is useful to support students in understanding and comprehending mathematical models.

Experiment 2. Experiment 2 is conducted to evaluate students' ability in rapid prototyping agent based malaria transmission model and simulation based on the knowledge gain during the requirement elicitation. Ideally, the answers from the eHOMER can map into agent design model and then simulator model. To what extend it is valid is experimented in the experiment 2. This experiment is also conducted in two phases – Pre AOM and Post AOM.

Data for evaluation in Experiment 2

Data about students' time and competency in producing NetLogo malaria transmission model were collected. Time refers to both tests in Pre and Post AOM-NetLogo mapping phases being timed, measuring how long it takes these students to complete their simulations. Competency refers to how correct was the simulation behavior being produced which was not depended on any metrics. Competency of students is indicated by the states of their simulations: Correct, partially correct or failed. In this sense, these are the indication to whether their simulations have been produced correctly, or at least, partially correct or have failed to exhibit any desired behavior at all (i.e. unable to execute simulation due to error in codes). "Partially correct" assumes that the simulation created by student is executable, can exhibit interactions but still showing incomplete model behavior due to small programming mistake like allowing some agents to exhibit wrong rule of behavior due to misunderstanding of disease transmission mechanics (i.e. allowing susceptible mosquitoes to infect humans which is not consistent with the requirement found in their eHOMER elicitation answers).

Findings. This section presents the findings of Experiment 2 upon evaluation of extended AOM based on students' Pre-Test and Post-Test simulations.

Due to small sample size in Experiment 2, the hypothesis test statistic was not performed for evaluation. Therefore, results in this experiment are indicated by report of simulations that are in the state of correctly produced, partially correct or failed to run as the findings of Pre-Test and Post-Test.

In Figure 5, there was no student able to produce malaria transmission simulation correctly. The data in Figure 6.5 shows that before AOM-NetLogo mapping was introduced, 90% of students have failed to produce simulations correctly whereas 10% of students did manage to produce partially correct transmission behavior.

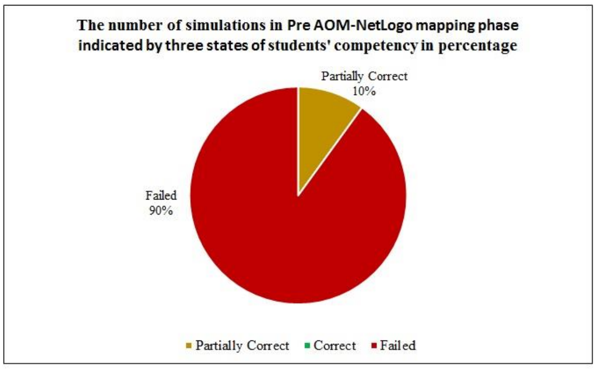

Figure 5: Percentages Of Student Simulations In Pre AOM-Netlogo Mapping Phase Indicated By State Of Competency In Producing Correct Simulation

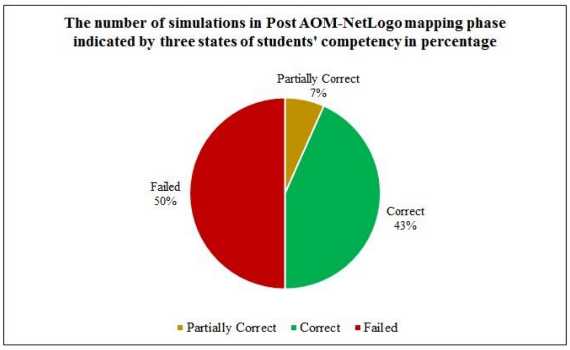

Figure 6: Percentages Of Student Simulations In Post AOM-Netlogo Mapping Phase Indicated By State Of Competency In Producing Correct Simulation

Meanwhile, in Figure 6, result has revealed signs of improvement in producing simulations after these students were taught in rapid prototyping of malaria transmission behavior simulation via AOM-NetLogo mapping framework. The data in Figure 6 shows that after the conduct of lecture about extended AOM, 43% of students did able to produce simulation accurately whereas 7% of students did manage to produce partially correct simulation while 50% of students have failed to produce desirable simulations.

Discussion of Experiment 2

These findings confirm that the competency of students in producing malaria transmission simulation has fairly improved when using extended AOM. In Pre-Test, all of these students were struggled to convert their understanding of malaria transmission into coding and as a result, none were able to produce malaria transmission simulation appropriately. In Post-Test, extended AOM did able to aid some of these students in creating simulations correctly through mapping guideline, and hence, number of simulations with correct malaria transmission behavior in Post-Test is greater than in Pre-Test. However, there were some students who failed to produce simulations correctly in Pre-Test are also incapable to produce Post-Test simulation correctly, even after being taught in how to map knowledge model and behavior model into NetLogo.

VI CONCLUSION

eHOMER was helpful in discovering knowledge about malaria transmission model in terms of agent contexts that these students can familiarize with, such as human and mosquito as roles, transmit disease as task performed by human and mosquito roles and rules that state how malaria transmission must be fulfilled, and so on. This concludes that eHOMER is useful for model transformation from mathematical model into agent oriented modelling and simulation. In future, more works are needed to recruit more sample in conducting the validation.

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