Teaching Computer Science in Universities: Replicating Social Simulations for Interdisciplinary Learning in the Classroom

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Abstract. This paper draws attention to the importance of replication as a pedagogical driving force in university courses. We discuss some of the overall concepts relating to replication and make the bridge between teaching computational science and experimentation in social simulation. The academic advantages that students obtain from replication are discussed and a case study in a computer engineering course is reported. We conclude with some thoughts on the role of experimentation in the context of interdisciplinary learning in computer science courses.

Keywords: Social Simulation, Replication, Experimentation, Verification, Validation, Scientific Method, Education, Pedagogic Goals, Computer Science and Engineering.

1 Introduction

One of the factors that can really make replication appealing is the connection that it establishes between the academic and scientific worlds. This paper focuses on the importance of this connection and demonstrates how replication can be a driving pedagogical force and a facilitator of many interesting synergies between interdisciplinary scientific areas. Replication helps the student to open his mind to the scientific method and develop a critical and dynamic attitude towards research that contributes to the community. In particular, in computer science-related degrees, replication promotes student contact with other programming languages and algorithms, other frameworks and the discussion of ideas with other researchers from different fields, mainly from the computer and social sciences, in a way that allows the students to deepen and apply many of the concepts acquired throughout their academic training.

This paper reports the experiences of the authors in using replication as an instrumental tool for teaching social systems simulation in a computer engineering class. In the first part of this paper we carry out an analysis of the overall concepts of replication in a broad sense, and also when applied to the computer and the social sciences. The concepts of verification and validation of software programs, as well as of conceptual models, are discussed in the context of typical approaches and also with respect to more formal and critical approaches used in high-risk engineering. We discuss some of the overall concepts and make a connection between teaching computational science and conducting experiments in social simulation. The academic advantages that students obtain from replicating social simulations are discussed and an example is reported. The case study describes a replication of the model published in the Journal of Artificial Societies and Social Simulation, “It Pays to Be Popular” [3], carried out by two computer science students in a semester class of the first year of an MSc Computer Engineering degree which has recently been adapted to the Bologna standards[1].

A discussion of the results obtained and the options taken during replication is provided, based on students’ reports and their own perception of the benefits of replication for their academic training. Based on these results, we present replication as a pedagogical driving force, with special emphasis on its role in introducing students to the scientific method and contributing to interdisciplinary learning in the classroom.

2 Replication: From Computer to the Social Sciences

The concept of replication is one of the foundations of experimental science. For example, Karl Popper has argued that only through systematic replication can one conclude that the obtained results are not the product of an isolated event. However, we should always be aware that, regardless of the number of replications conducted, we will never be able to prove that a model is truly valid and that all its replicas are exactly the same. The principal purpose of replication is to increase confidence in the model through refinement and verification of its specification and implementation. In its simplest form a result that is reproduced many times by different modelers, re-implemented on several platforms in different places, should be more reliable [7]. In addition, the very exercise of verifying programs promotes the assessment of the model as a validated representation of the subject being modeled. In this sense, while verification concerns the evaluation of the computerised implementation of the model in terms of the researchers’ intentions, validation refers to an evaluation of the credibility of the model as a representation of the subject modelled. At any rate, the very idea of verification and validation involves comparing models with observations and descriptions of the problem modelled, and this may include other models that have been verified and validated to some level. This truism poses a methodological attitude familiar to any mature scientist or engineer. However, transmitting this attitude to young computer science students and, in general, to any student enrolled in empirical sciences, is not so straightforward.

In social simulation, we should think of replication as an essential part of the model creation process. Only in this way will we be able to assure that unexpected results are either a direct consequence of an unintended implementation (the actual computerized model) or a consequence of the intended model itself (the conceptual model). From a computer science perspective, verification strives to guarantee that the implementation matches the conceptual model defined – in other words, that the

[1] The Bologna process is a European agreement whose objective is to reform European higher education area by making degree standards more comparable throughout Europe.

functional requirements are appropriately implemented. Again in computer science, this process is usually less complex, more obvious and more systematic than verification in social science simulation. Many of these benefits are due to the traditional methods of software engineering, which often assume that the outputs of any known program are known *a priori* and its functional requirements can thus be defined. There are some exceptions to the former presumptions though – for example, in fields such as high-level risk engineering. After each one of the project phases (e.g. implementing a waterfall model), a very strict, severe and formal revision takes place, in order to assure confidence in the elaborated models. For instance, in aeronautical engineering there is a team responsible for the analysis, conception and design of the system controls model. The formal revision that takes place between the design and the implementation phase will have to assure total confidence in the model. Otherwise, the company responsible for the design will most likely see its reputation at risk and possibly collapse.

To mitigate risk and increase quality, the implementation is carried out by several teams (usually more than three) that conduct parallel developments with different languages, frameworks and approaches – a strategy that allows for easier identification of the source of an error. It is interesting that such an approach resembles replication in social simulation: If only one team encounters an error in the system, there is a high probability that the error is their fault, but if all teams encounter an error, the probability will point to an error in the model. Only when all teams finish implementation without a single error will the system advance to the next phase.

Social science models and simulations, due to their complex and exploratory nature, do not possess many of the much appreciated functional requirements of computer science, and their value resides to a great extent in the exploration of emergent properties. The software development process does not follow the classic philosophy of computer science, but instead is quite close to the one described in high-level risk engineering. However, there are still significant differences. Whereas in high-level risk engineering the replication is an *a priori* process that aims to validate and verify the model before it is released for consumption, in social science simulation the replication is carried out as an independent and a *posteriori* process that questions and tries to confirm or disconfirm models according to different criteria, such as the ones proposed in Axtell's seminal alignment [4]: numerical identity, distributional equivalence and relational alignment.

At any rate, we should always be aware that no matter how many times the results of experiments agree with a theory, one can never be sure that the next time the results will not contradict the theory. If a replicated model produces results different from the original one, we may start questioning some of the results of the original model itself. At this level, verification and validation tend to conflate. However, validation seems much harder to assess than verification, insofar as it is more straightforward to assess correspondence between conceptual and computerized models than between conceptual models and the intended targets of modeling.

In effect, the problem of model verification and validation leads us directly to the crux of the scientific method. With the arrival of computational models into the social sciences, one obvious benefit resides in the pedagogic utility of replication methodologies. They are simple to use in the class and instrumental in the introduction of students to the logic of the scientific method. They are useful, as we have observed, both in computer and social sciences. In the era of interdisciplinary work, and the tendency under the Bologna process (in Europe) to compact courses within short periods of time (with less time for teaching integrating subjects) replication emerges as a powerful and a novel tool in the computational and social sciences. If students are enticed to replicate already existing models, we will achieve great revenues at the pedagogical level through a first contact with the scientific method and an approximation to multidisciplinary environments.

3 Replication and Education

It would not be untrue to say that in some cases different fields of sciences walk in different directions and may not converge and produce interesting synergies from their union. With this thought in mind, we should try to bring the concepts of social simulation to students with a computer science background as this would contribute to the software development process itself as well as to the students' learning process. The reverse should happen also, and we should develop the tools necessary for scholars in the social sciences to become more experienced in programming and developing their own experiments. This may be an important goal insofar as the specification of conceptual models – usually created by social science researchers – can be misinterpreted by developers responsible for their implementation.

As far as computer science is concerned it is becoming crucial to highlight the importance of students' contact with the underlying philosophy of the scientific method. Accustomed to a very organized and technical mode of thinking, students are not always aware that at the base of all the good practices and software methodologies there are an important set of scientific and empirical principles. They are not familiar, moreover, with the very dynamic nature of the scientific process, and how different fields of science use rather different methodologies. Whether a practice is appropriate or not is always to some extent subjective and the result of community-wide acceptance. In social simulation, these kinds of emerging consensus introduce dynamics in research, as we begin to question, evaluate and discuss the choices of the creators of models. Often, to eliminate doubts it is recommended that contact be made with the authors of the original model in order to disentangle subjective and ambiguous details in a specification.

Many authors advocate that in replication it is important to develop the replica with different programming languages and toolkits, rather than the ones applied in the implementation of the original model. This kind of attitude exposes the student to a higher diversity of programming languages and toolkits, thereby providing new insights that result in critical judgments on each one of the model dimensions. One interesting definition of a model dimension is proposed by [1], who identify the following dimensions for a model: time, hardware, programming language, toolkit, algorithms and authors. Further on in the process of replication, students are confronted with further educational processes, such as algorithm analysis, source code depuration and design patterns; all of which will contribute to training students in software engineering skills. From a learning outcome perspective, students may also have the opportunity to apply some of the concepts and methodologies learned throughout their academic courses, such as object oriented Programming, distributed programming, agent-based systems, statistics and data Analysis, software engineering, artificial intelligence, etc.

Indeed, the diversity of skills and technologies that one has to deal with in the development and replication of social simulations is quite diverse, and together they create an intimate connection to the idea of critical thinking and the nature of the scientific method. It is a simple recipe available to academics and students that may benefit the teaching process in a motivated, simple and effective way.

3.1 Replicating in the class

Our case study involves work carried out in a semester class, called Social Systems Simulation, in the 1st year of a Computer Engineering MSc course in ISCTE. Students at this level have a considerable technical expertise in programming languages and software engineering, but they had not dealt previously with computer science applied to the social sciences. They were divided into groups of two or three. Two groups were encouraged to implement the same model independently, and to check and compare its results at the end of the semester. The model was the well-known Axelrod's culture dissemination model [5], a widely replicated model and one which is straightforward to implement. The outcome was that both implementations were able to reproduce the original model with sufficient accuracy, and even to implement some further extensions. Besides the verification perspective, a very interesting debate emerged among the students about the value of the model as a representation of social reality (the validation dimension).

Another group, composed of two students, was encouraged to investigate the literature of social simulation and find a model which they would like to present to their fellow students in the class and to further replicate. The choice selected by the students was a model published in the paper "It Pays to Be Popular" [3]. The object of this study is the interaction between several kinds of agents in a war scenario, namely the benefits obtained from the cooperation of civilians with peacekeepers when the geographical area where they are located has a war threat or is at war. However, the difficulties encountered by the students in reproducing and even understanding the specification of the model were obvious, and the students themselves were able to conclude that the model was under-specified. The short report given below is based on their written report and their own perception of the usefulness of replication as a driving pedagogical force in the class.[2]

3.1.1 Model Analysis

The simulation model "It Pays to Be Popular" focuses on the interaction between civilians and peacekeepers in a warfare scenario, namely the benefits of civilian assistance to peacekeepers. It recreates a war scenario taking into account the terrain topology and the intervenient agents. The topology of the terrain represents high and low ground, as well as eyesight restrictions. An agent in a higher position has a

[2] The tentative replica of the model implemented can be found here: http://sss.dcti.iscte.pt/pays_to_be_popular. The original implementation of the model is not available on-line, as far as we know.

certain advantage over another agent in a lower position. Also, grounds with higher vegetation will be preferred by terrorists as it makes it harder for the peacekeepers to locate them. On the other hand, lower-vegetation grounds will entail higher risks. The model also comprises small villages where the civilians live. They are safer zones where the eyesight restriction is at its maximum. Civilians will search actively for insurgents according to their predisposition, which are specified by the model's variable Pscan.

The description of the current model is structurally divided into two major parts: terrain and agents. Further details of the model specification are not relevant for the purpose of this paper and are not discussed in depth. Furthermore, given the controversial character of these types of scenarios, the denomination given by the original authors for the type of agents used – such as the roles and the actions of "peacemakers", "insurgents" and "civilians" in a warfare scenario – is susceptible to discussion from a validation perspective. This issue is, however, beyond the scope of this paper and we will focus exclusively on the verification perspective according to the terms and specification of the original authors. The two components of the model are as follows:

Terrain. The terrain is the first of the two fundamental components of the model. The terrain has a specific topology, which is represented by a two-dimensional board that uses color gradients for the simulation of various levels of vegetation. The standard dimension of this board is 500x500 units, divided into small squares of 10 units in width (see figure below).

Vegetation can assume values from 0 to 100, identifiable by the change of green tonality of the board squares. The higher the vegetation value the darker is the color of the square. The maximum vegetation of the model corresponds to the darker green square on the board. The other entity of the terrain is urban construction. Constructions represent real world civilian areas, such as villages and small cities. The number of urban constructions, Nb, is one of the model parameters.

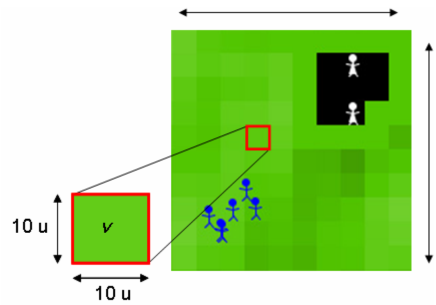

Fig. 1. Board example with a square (*left*) and a small board with 100x100 units, i.e. 10x10 squares (*right*).

Agents. In the original conceptual model three types of agents existed: peacekeepers, insurgents and civilians. Three of the parameters of the model are Np, Ni and Nc, which represent respectively the number of agents in the simulation of each type. The Peacekeepers (Np) are represented by the blue color and their role is to locate and eradicate any threat that they might encounter, as well as to lower the number of "blue" casualties while protecting the civilians. The Insurgents (Ni), are represented by the red color and their role is to avoid detection for as long as possible and kill the "blues" (peacekeepers) whenever they have the chance. The Civilians (Nc) are represented by the white color and can usually be found inside urban constructions. Their purpose in life is to warn the peacekeepers of any known threats that arise during the simulation and they do not actively pursue insurgents. Each agent has four basic behaviors: detection, movement, communication and engagement. Each one of these behaviors has distinct actions with regard to each type of agent. All agents have the same amount of simulation time for their behaviors and only one can be simulated at any given moment in time (threading is not available). The simulation ends when all of the peacekeepers or all of the insurgents are dead. Further details of each behavior and the simulation itself can be found in the original publication of the model.

3.1.2 Model Implementation

The model was implemented using the Repast Toolkit, in contrast to the original implementation which used NetLogo. Many questions on the replication process previously referred, such as the criteria used for comparing results between models, were taken into account by the students. In this case, a relational alignment was attempted. Regardless of the complex mathematical details of the original model, almost every functionality and feature described in the original model was implemented in the replica. Even so, despite the fact that some results obtained were similar, and that distributional equivalence tests were not actually carried out, the results obtained were sufficient for the students to identify that the published description of the original model was highly under-specified.

One of the first obstacles that a replicator will find on its first contact with a model will be the natural language, in which the original conceptual model is specified. In the model studied, the lack of objectivity and omission of a few hidden parameters was severely felt. There were some cases in which we had no idea of how to replicate the model such as the flocking algorithm implemented in the original model, which was responsible for the movement patterns of the peacekeepers on the board. Without any knowledge of the hidden parameters, we could not decide on an exact way to implement the model. A possible solution would have been to attempt an approximation to the model implementation by reengineering, through direct observation of the original simulation at execution. Another solution would be to contact the authors in order to disambiguate several aspects of the model. Given the limited time available in a semester class, the adopted solution was to align the hidden parameters according to the expected results, which is far from an ideal solution for the problem that we had at hand.

There are other details that would be appealing for a deeper analysis and which were the subject of intense discussion with regard to the interpretation and the alignment process of the model. E.g. the absence of communication between the insurgents was, at a validation level, questionable. Nevertheless, to convey the message of replication as a valuable pedagogical driving force, we will not spend additional time and space in this paper criticizing all the points of the original model in which the replication appears to have failed. The principal point of this thesis is to illustrate the students' attitude and position in the face of the scientific method and the experimentation process. Experimenting, questioning choices taken, criticizing, sharpening students' scientific sensibility and finding justifications through investigation and experimentation can and should be a powerful motivation for replication in academic environments. In the end, the results of the replica were not entirely conclusive but we were able to re-specify the model and achieve a reasonable similarity, which suggests a valid relational alignment.

3.1.3 Results

In order to achieve the relational alignment criteria, we conducted (with respect to the inputs) a graphical representation of outputs from both the original model and the replica. In fact, after the alignment and despite the divergences found, we could still recognize a fairly similar appearance between the representations. Divergence can result from innumerable causes, many of which have already been mentioned, such as the ones encountered with the replication of the flocking algorithm. The following example compares the first test results of both models, which consisted of evaluating the impact of the parameters Nc and Pscan in relation to the number of deaths of peacekeepers. The first parameter (Nc) represents the number of civilians and the second (Pscan) refers to the degree to which the civilians actively search for insurgents.

We conducted 20 independent simulations for each of the values of Nc ranging between 2 and 20 (in increments of 2) and for each of the values of Pscan ranging between 0% and 100% (in increments of 10%). Although 20 simulation runs for each data point are clearly insufficient to infer input-output functions (see e.g. [6]), this was the number of simulations carried out in Wheeler's original analysis. The results are shown in table 1 and the representation is presented in figure 2.

	Pscan										
Nc	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
2	5	5	5	4	5	5	6	3	4	5	3
4	4	5	6	6	6	6	5	4	6	5	3
6	4	4	3	6	5	3	5	3	4	3	5
8	3	3	4	4	5	5	3	3	5	2	3
10	3	3	5	4	2	2	3	2	3	0	4
12	4	3	1	3	2	2	3	4	2	4	2
14	3	4	5	4	2	3	2	2	2	3	2
16	4	5	3	3	3	4	2	2	1	3	2
18	6	5	2	3	2	4	2	2	3	2	1
20	3	5	2	2	2	2	2	2	1	2	0

Table 1. Replica results.

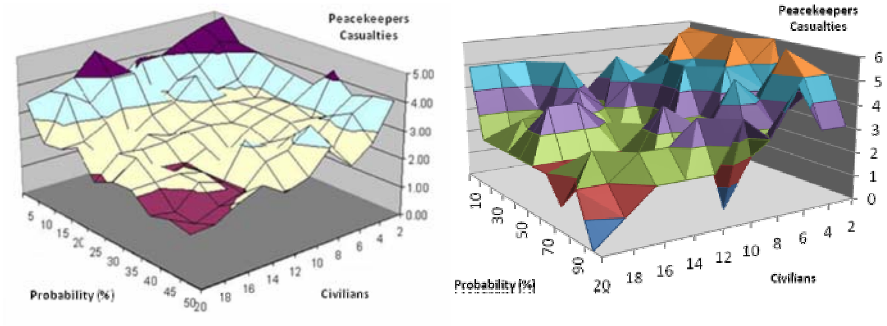

Fig. 2. Original model results[3] (*left*) and replica results (*right*).

As civilians inform peacekeepers of insurgents' positions the number of peacemakers casualties decreases. However, the results obtained with the original and the replicated models appear somewhat different, although this could possibly be assessed with distributional equivalence tests. At any rate, the reasons for the apparent differences between the two graphics are diverse, and a number of possible reasons were reported by the students: a lack of clarity and the existence of subjectivity in some parts of the original model description led to misinterpretation, and thus to different implementations; the omission of hidden parameters, the lack of descriptions for the algorithms used and the over-simplification of the model; the original implementation of the model itself may differ from its specification; and, even if highly improbable, it may happen that different authors, using different frameworks and distinct implementation approaches, might replicate exactly the same errors.

4 Discussion

Replication is a complex process and it requires careful analysis by the model authors and replicators. In the vast majority of cases, replication processes are mostly reactive and not proactive, i.e. the creator of the model may publish the model with a weak effort at verification and in the future someone else will replicate it. However, we should not take this lightly and see it as something that will possibly be done in the future. Instead, we should see this as a scientific assessment of our models that allows us to verify and help validate our research. It is of the utmost importance to adopt a good set of best practices and patterns for replication as this may allow us to establish canonical replication processes for the agent-based simulation community of practice.

The main purpose of this paper was not to dissect the present case study and find solutions for all of its problems, but instead to make a sound argument for the role of replication as a powerful pedagogical driving force in universities and academic environments. In addition to arguments that favor replication, there is one that we would like to highlight: the sharpening of the students' critical thinking skills and the development of a sensitive attitude towards results, whereby confrontation with the scientific method results in an immediate learning outcome. It is relevant to highlight

[3] The figure presented in the left is a copy of the original article by Wheeler [3] and it has an error on the probability scale. It should range from 0% to 100% in increments of 10%.

that such an outcome was achieved in the scope of only a semester class and not in the context of the development of an MSc or PhD thesis.

With respect to the interdisciplinary argument, there are several arrangements between the world of social simulation and computational science that would result in very attractive synergies. The advent of social simulation classes in computer engineering courses, open to both computer and social science students, is certainly one. In addition to our attempt to build a bridge between teaching in computer engineering classes and experimentation through replication of social simulations, other approaches, in which social science students replicate social simulations should also be attempted and reported.

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