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STUDENT MODELING & SIMULATION PROJECTS IN HEALTHCARE: EXPERIENCES WITH HILLINGDON HOSPITAL

Simon J. E. Taylor
Pamela Abbott
Terry Young

Modelling & Simulation Group
Department of Computer Science
Brunel University London
Uxbridge, UB8 3PH, UK

Richard Grocott-Mason

The Hillingdon Hospitals NHS Foundation Trust
Pied Heath Road
Uxbridge, Middlesex UB8 3NN, UK

ABSTRACT

This paper describes experiences in the first year of running final year Modeling & Simulation (M&S) undergraduate projects with The Hillingdon Hospitals, a large UK National Health Service (NHS) Hospital Trust. Our approach used project- and problem-based learning in a group context with emphasis on the student's responsibility for the execution of their project. As part of their B.Sc. (HONS) Business Computing course, the students had taken a module on Business Process Modeling and Simulation during their second year. The student group was supported by two facilitators with help from two simulation researchers. Each student worked with a stakeholder in a variety of clinical service settings to create conceptual models, business process models and discrete-event simulations. The projects helped stakeholders to reflect on how their services might be improved, highlighted new areas of investigation, raised awareness of M&S at Hillingdon Hospital and equipped students with real-world M&S skills and experience.

1 INTRODUCTION

Located in West London, The Hillingdon Hospitals National Health Service (NHS) Foundation Trust (www.thh.nhs.uk) consists of two hospitals: Hillingdon Hospital and Mount Vernon. Hillingdon Hospital provides a wide range of services including Accident and Emergency (64,000 patients annually), In-patients, Day Surgery and Outpatient Clinics. The Cumberland Initiative (CI) is a large-scale collaboration between healthcare providers, industry and academia that aims to transform the quality and cost of NHS care delivery through M&S and Systems Thinking. Last year the CI began to encourage universities to explore the potential of undergraduate and postgraduate student projects in healthcare.

Brunel University (BU), a member of the CI, is sited around a mile away from Hillingdon Hospital and hosts the Modelling & Simulation Group (MSG) in the Department of Computer Science. The MSG investigates a wide range of M&S methodologies, technologies and domains and supports teaching & learning activities in M&S. With support from the MSG, seven students from the B.Sc. (HONS) Business Computing undergraduate degree studied M&S in healthcare with Hillingdon Hospital. This paper reports on the extremely positive experiences from the first year of these challenging and exciting student projects. The paper is structured as follows. Section 2 outlines how the projects were set up and the process that the students followed. Section 3 gives an overview of some of the projects and their outcomes. Section 4 discusses the challenges and improvisations made during the projects. Finally, section 5 concludes the paper.

2 STUDENT PROJECT SETUP AND PROCESS

All students in their final year of their undergraduate degree at BU undertake a six month Final Year Project (FYP) (October-March) which represents a substantial element of their final degree classification. The M&S projects were initiated with a set of brainstorming meetings between Hillingdon Hospital and BU to identify potential student projects, resulting in a very long list. A further shorter list of possible student projects was created on the basis of M&S "fit", scope, risk and willing stakeholder participation. Project outlines were then developed that described the problem, its context and supporting literature. The project outlines were meant to provide students with a framework to pursue excellence in M&S and to show Hillingdon Hospital the value of M&S in healthcare and the potential of undergraduate student projects in this area.

In parallel with this activity, a general "M&S in Healthcare" project was advertised to students entering the final year of the undergraduate B.Sc. (HONS) Business Computing. Business Computing students were selected as they all had taken a module in Business Process Modeling and Simulation during their second year. This module covered the basics of business analysis, static modeling approaches using Business Process Modeling Notation (BPMN) and discrete-event simulation using the COTS Simulation Package SIMUL8 (www.simul8.com). The core literature on the module included Paul, Yeates and Cadle's (2010) text on business analysis, White and Miers' (2008) and Briol's (2010) guides to BPMN, Robinson's (2004) text on discrete-event simulation, Shalliker's (2009) guide to SIMUL8 and indicated papers from the Winter Simulation Conference archive (informs-sim.org). Other relevant readings were also recommended.

The aim of the module is to equip students with the skills to specify the business logic of a system and then to evaluate it in terms of resource requirements with discrete-event simulation. To give the students the opportunity to understand how difficult an M&S FYP in healthcare might be, they were given a complex case study to investigate and report on over summer. In the end seven students agreed to study M&S in healthcare and specific projects were assigned (one other worked with the team and studied an online ordering system with a large UK retailer).

There were several challenges to these student projects. These could be separated into M&S pedagogy and M&S project issues. Although students had taken a relevant M&S course there were still many M&S issues that needed further tuition, including some advanced aspects of SIMUL8 such as user interface design. Furthermore, FYPs also follow a particular process and include aspects of research methods, which need careful project management irrespective of the topic being studied Modeling issues were similar to those encountered on any simulation project and included conceptual modeling, model development, data and access to stakeholders and project management. The pedagogical issues were addressed during regular weekly group supervision meetings that lasted around two hours (sometimes longer). Different topics were covered each week and students were encouraged to present their on-going results and experiences, as well as leading discussions on different topics. A project schedule was drawn up that reflected FYP project deadlines and deliverables with M&S requirements. This did not include meetings with stakeholders due to the complexity of scheduling each set of meetings. Students were supported by two project facilitators (supervisors) – one with substantial M&S experience and one with substantial experience in Information Systems – who ran the weekly meetings and provided further support via email and individual meetings. Two researchers also assisted with ad-hoc queries that related to model development in SIMUL8. User support and online resources from SIMUL8 also proved to be invaluable. Our approach used project- and problem-based learning in a group context with emphasis the student's responsibility to pursue their project.

It is important to note that ensuring the students adhered to the project schedule was no easy task, since, the schedule itself deviated significantly from the "normal" FYP process by taking a "hands-on" bottom-up approach rather than a top-down linear approach. Traditionally, the FYP process would begin with a task definition, proceed with a background literature review followed by research design and ethical approval after which the project's research-oriented activities would begin. At this point, the student would usually be midway through their six-month period, i.e. perhaps at the start of the second term. Once the research is done, analyzed and written up, the design, (implementation and testing, if necessary) activities would start, be written up, analyzed and evaluated. After the evaluation then the whole dissertation write-up would be completed. In the case of these projects, it was necessary to turn this process on its head. Students were expected to start modeling from the beginning. They were "prepped" by the summer "homework" and were very enthusiastic. Thus, a considerable amount of time in the first term was spent doing several iterations of modeling and information gathering, and liaising with the project stakeholders. The second reason for the bottom-up schedule was actually to give the stakeholders reasonable timeframes in which to meet the students. The supervisors were acutely aware of the extremely busy schedules of the stakeholders and did not want to expose the students to the risk of not being able to engage with them. With this in mind, the supervisors also mediated the meetings with the stakeholders to ensure they were kept focused on the refinement of the problem, explanations of the process and clarifications of the issues at hand.

As noted above, students were working in a M&S framework designed to mitigate the impact of M&S project issues, enabling projects to be developed at a distance from the stakeholders. Initial meetings were held with stakeholders to help the students get a "flavor" of the work. The supervisors then acted as the stakeholders to give students definite guidance on system issues. Students then used their advice with information and data derived from literature to build their models. Later in the process students presented the results of their work back to their "real" stakeholders. Students then continued with a mix of stakeholder and supervisor support. In most cases the level of the "real-world" support increased towards the end of their work and reflected the interest and energy that the student's enthusiasm and professionalism generated. By starting the students with this "bottom-up" problem-oriented approach, they were forced to engage immediately with their problem context, to progressively build up a layered and complex picture of the problem and to use their supervisors as facilitators and mediators not as instructors or project managers. Their own creativity was stimulated in order to arrive at solutions. Working within a group with shared access to documents and each other's work helped to cross-fertilize ideas and create shared knowledge as well.

The next section gives an overview of the projects pursued by the students.

3 THE PROJECTS

The seven projects could be broadly categorized into three main areas: projects looking at improving specific healthcare pathways (Deep Vein Thrombosis (DVT) and Menorrhagia), those concerning the comparison of models by which Accident & Emergence (A&E) attendance could be improved, one concerning a hospital service (Phlebotomy) and one concerning improving decision making around estimated discharge dates. Students selected those topics with which they were most comfortable and which had the most scope for developing.

The students were encouraged to approach their projects using a fairly generic process which is now described. Each given problem was to be approached as a process improvement problem to which they would apply process M&S techniques using mainly BPMN and discrete-event simulation (with SIMUL8) as they had been taught in their second year undergraduate module. Alongside the process improvement activities of the project itself, they were to investigate the research question of the suitability of these tools to healthcare process improvement. This was phrased generically as the objective: "to evaluate the use of business process modeling and discrete-event simulation to investigate problem X in system Y". As a "bonus", or extra challenge for the students, they were also asked to "to design and/or implement a decision support tool for problem X in system Y for stakeholders Z", if this was appropriate to their project. It was up to the students to interpret this set of generic expectations and tailor them to best suit their projects. In most cases, this meant analyzing the AS-IS situation of the process outlined in the problem and then to propose a TO-BE solution. In the lexicon of business process modeling the "AS-IS" situation is considered the current status of a system and the "TO-BE" is a hypothetical best state that, if implemented, would resolve issues analyzed for the AS-IS situation. Figure 1 illustrates the generic process.

The department's FYPs must also adhere to the accreditation criteria of the British Computer Society (BCS). In our department this has been generally interpreted as work which requires an Information System (IS) solution, therefore the students had to find a way to reflect that they had built or designed an information system as a result of their work. This was accomplished in a combination of ways which included coding Visual Logic routines into the SIMUL8 models in order to better capture some complex real-world behavior, interfacing the models with spreadsheet data input /output and building GUI front-ends that could manipulate the data of the underlying models.

In the following sub-sections three of the student projects are discussed in more detail, explaining the main approach, the student's tailored process and the results of the project.

3.1 Pathway Improvement Project – Deep Vein Thrombosis

The problem involved improving the Deep Vein Thrombosis (DVT) pathway so as to make it more efficient and reduce the referrals to Hillingdon Hospital's Emergency Assessment Unit (EAU).

Two students attempted this project, each tasked with looking at various entry points into the EAU from the DVT pathway, one from the General Practitioner (GP)'s surgery and the other from the Accident and Emergency (A&E) department. The students were provided with the pathway documentation and supporting information about the pathway from Hillingdon Hospital and engaged in two lots of interviews with the doctors in the EAU mediated through their supervisors. In addition to this they followed up their interviews with emails addressing specific queries and their own individual research into the process and general information about DVT. Representative data were obtained from the EAU from a third doctor who was responsible for the data management role in the EAU.

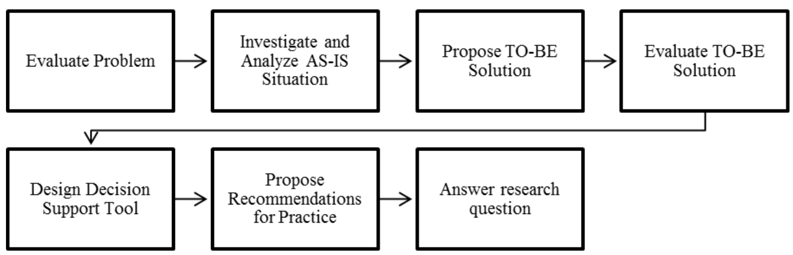

Figure 1: A Generic Process for Student Projects in Modeling and Simulation

Both students took a similar approach to the project by concentrating first on static modeling of the process through BPMN followed by dynamic modeling through SIMUL8. They then sought ways in which to improve the referral rates to the EAU through both a process-change approach (i.e. removing or altering the static process) and through dynamic modeling (determining whether the process changes made a difference to pre-selected Key Performance Indicators (KPIs)). The students' tailored process is shown in Figure 2 (using the student's language).

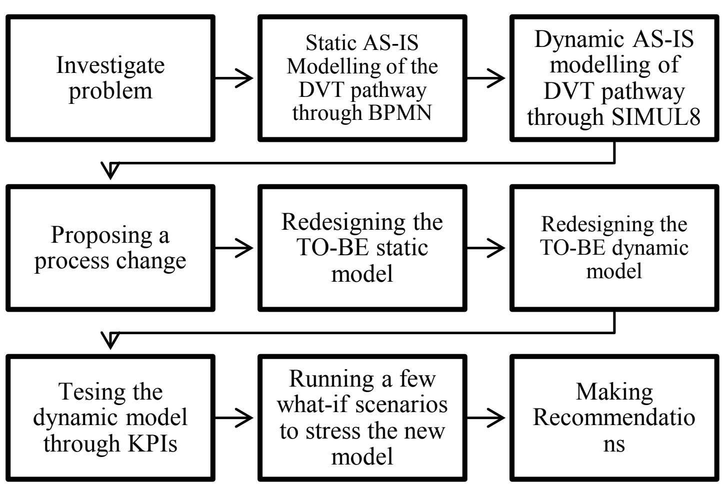

Figure 2: Students' Tailored Approach to the DVT Pathway Problem

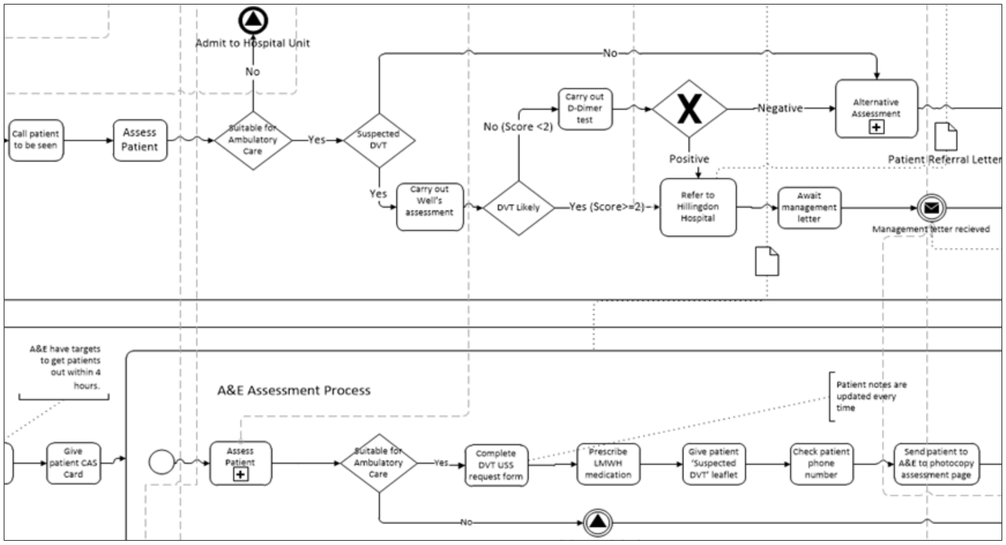

Figure 3: A segment of the BPMN diagram representing the DVT pathway from the GP's surgery to the EAU (AS-IS)

In the process of completing this project, the students produced quite a few artefacts demonstrating specific points in the progress of their work. In Figure 3, for example, a segment of a very advanced version of a student's BPMN AS-IS process model details some of the steps expected in the process between the GP's surgery and the Hillingdon A&E department. The diagram is quite detailed incorporating a variety of flow objects, reflecting the student's in-depth understanding of the entire process.

The static model acts as a conceptual model for developing the dynamic model. In Figure 4 the direct mapping from the AS-IS BPMN model to the AS-IS simulation model is evident. The three main entities (GP, A&E and EAU have been explicitly partitioned (like swimlanes in a BPMN diagram), the collaboration points (message flows in BPMN) are translated into queues and workcenters and work entry/exit points mimic start and end events in the BPMN diagram.

The students were able to demonstrate process improvements from the AS-IS situation to the TO-BE situation by comparing the results of the TO-BE simulation models with those of the AS-IS. They also did what-if analyses of the TO-BE models by changing resource allocations, referral rates and operating times, showing that even with a modest improvement in the process the model could still be further improved by considering staff reallocations and increased working hours. Although such a result may be thought of as a common-sense recommendation, the ability to prove it via an evidence-based method, rather than guesswork, was one of the contributions that the students could make with their project.

3.2 Improving Decision-Making Project – Estimated Discharge Dates (EDDs)

This problem was broadly scoped out initially as finding a way in which to better predict estimated discharge dates for patients. When a patient enters the hospital, they are assessed and an estimated discharge date (EDD) is assigned. This date is very often inaccurate and is based not only on the patient's current condition but also on a number of interacting and complex parameters such as complicating secondary conditions e.g. diabetes, the patient's home environment, the availability of ancillary home care packages, the consultant's own experience and so on. Failure to discharge a patient on time also has potential consequences for the admittance of new patients since there may simply not be available capacity and it is unknown when that capacity would be made available. Additionally, if the conditions are not favorable for discharge and the patient *is* discharged this can cause an unwanted and unnecessary re-admittance.

The student took an iterative approach to this problem. Three iterations of this cycle were executed, each time refining and redesigning the problem itself. It became evident during these iterations that the problem could probably not be solved by using only discrete-event simulation, hence a reconfiguration of the problem was necessary. Thus, instead of trying to predict better EDDs and model patients arriving at the hospital, the student considered modeling bed capacity, the resource that would be most affected by the delayed discharges. The student's process is illustrated in Figure 5.

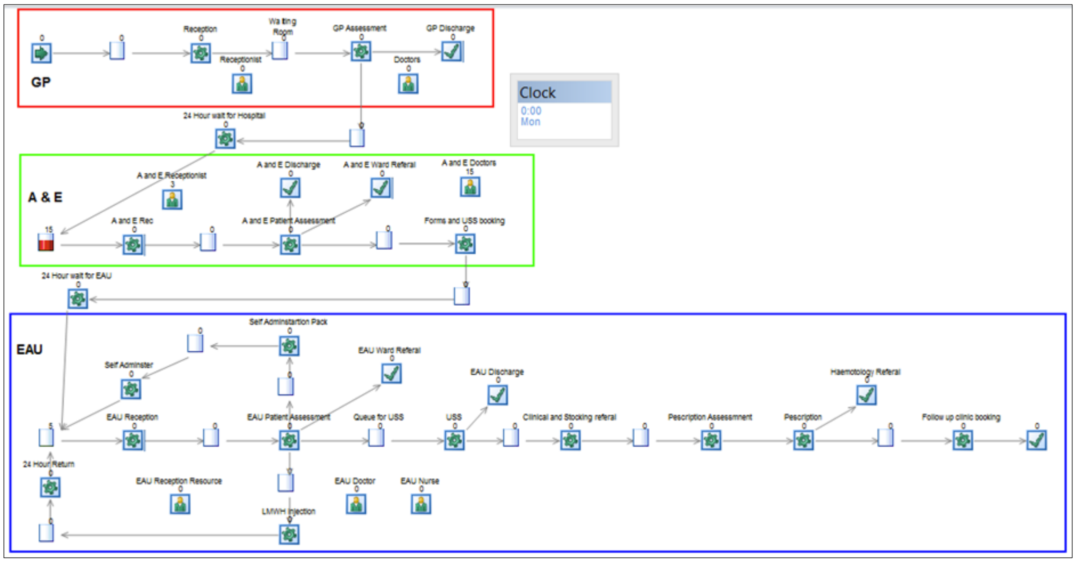

Figure 4: The SIMUL8 model representing the DVT pathway from the GP's surgery to the EAU (AS-IS)

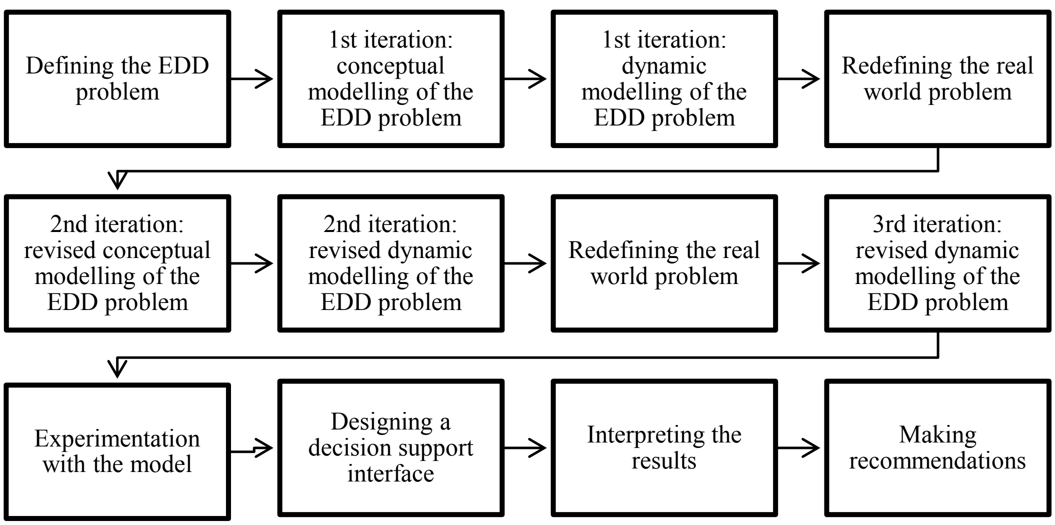

Figure 5: Student's Tailored Approach to the EDD Problem

The following are examples of are some artefacts of this process which demonstrate the iterative nature of the student's search to find a better definition of the problem. The initial conceptual model is represented in Figure 6. This is a very simplified version of the problem identifying key activities, using a simple flow chart diagram. Figure 7 illustrates a final conceptual model of the EDD process after 2 iterations with modeling and refining the understanding of the problem. The BPMN diagram illustrates a higher level of understanding of the process, the actors involved and the interactions between entities.

The student underwent a similar process of problem refinement with the dynamic modeling aspect of the work. The iterative process of redefining the problem through modeling and reflecting this back to the real world produced a final simulation model as shown in Figure 8. A considerable amount of the functionality of this model representing the underlying complex decision making processes had to be incorporated through the use of Visual Logic. The student then used the final model to perform experiments to determine the optimum shift patterns and resourcing necessary to ensure reliable bed availability and better planning for EDDs.

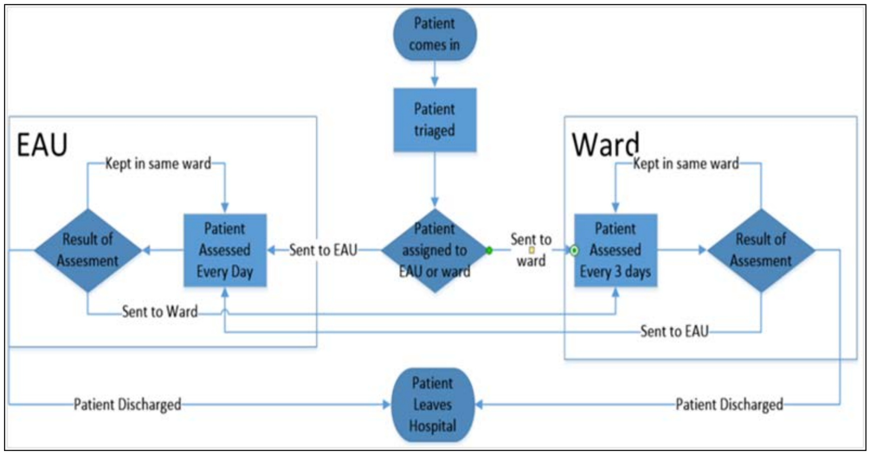

Figure 6: Student's initial conceptual model for the EDD problem

The strength of this project lay in the various experiments that were run on the final model to determine an optimal configuration of bed capacity, consultant shifts and ward admissions. It was found that the recommended configuration for the hospital was a 60% discharge rate, with 1 day EDD routing and the use of a Saturday shift for consultants. Weekend shift working is a proposal that has been suggested from time to time by the NHS to solve care quality problems that occur on the weekends in hospitals. The student's ability to demonstrate this using systems thinking and statistical evidence offers an objective means by which to consider this proposal.

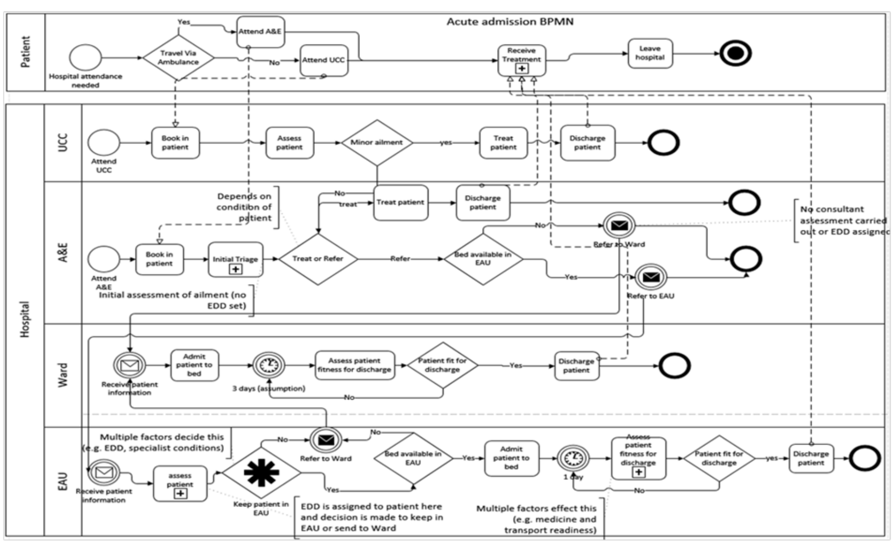

Figure 7: Final conceptual model in BPMN for the EDD problem

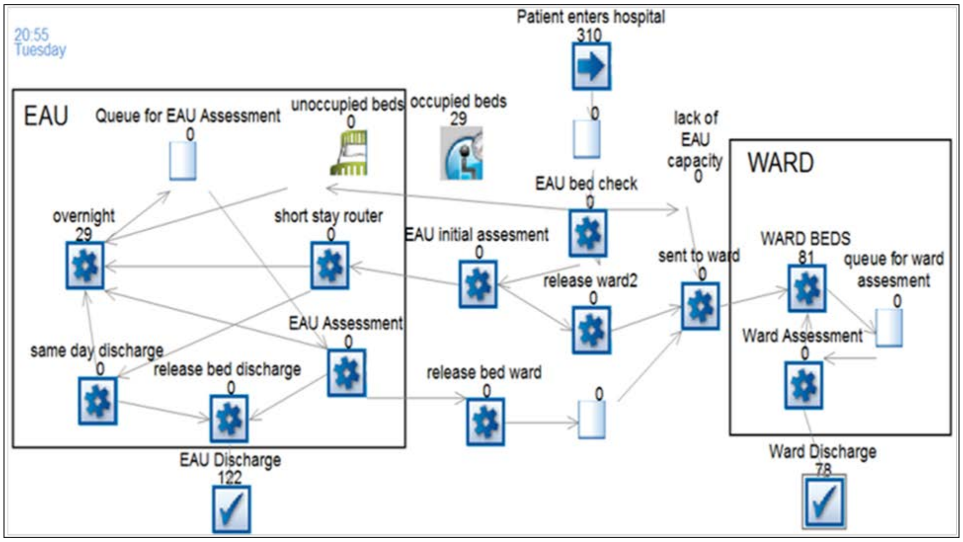

Figure 8: Final SIMUL8 model of the EDD problem

3.3 Service improvement Project - Phlebotomy

This project investigated the reduction of queuing times in a hospital's phlebotomy unit. The problem itself is a straightforward simulation problem. However the student's approach to this problem was unique and inspired. The analysis of the problem revealed opportunities to both improve the workflow (static modeling) and the queuing problem (dynamic modeling).

Conceptual modeling was done using both workflow notation and BPMN. The workflow model is shown in figure 9. This was found to be a simple communication tool for negotiating the problem definition between the student and the stakeholder.

The student developed two simulations to allow stakeholders to investigate their system. The first allowed the stakeholder to actively engage with what-if scenarios (through a decision support tool) that dynamically changed the number of available phlebotomists and their shift patterns. The stakeholder could choose an option that was financially viable, reduced variation in both resource availability and utilization, and also had a positive impact on the patient queuing times. The second model implemented a process change by introducing a prioritization of certain types of patients in the queue and an extra resource. Trials were run on this model and it was concluded that, though it resulted in less patients leaving the system without completing, there was still an unacceptable waiting time in the queue. The final recommendation of a suitable model was left to the stakeholder, who could assess different scenarios and their impacts through the decision support tool.

4 DISCUSSION – CHALLENGES AND IMPROVISATIONS

This combined project- and problem-based approach to student learning in the FYP process was trialed for the first time in this department with a set of stakeholder-led projects mediated by the supervisors of these students. It enabled us to capture experiences with the process that could be incorporated in the next iteration of such projects as points for improvement. The supervisors observed that students faced many challenges with this approach, but at the same time also innovated with improvisations of their own. The challenges faced by the students can be categorized into two broad areas: issues associated with the given problems and issues associated with the project process. These will now be discussed.

4.1 Problem Challenges and Improvisations

Some of the issues in this category were easily addressed and some not. For example, issues related to the new terminology of both the healthcare domain and the simulation modeling package were resolved by students' independent research. Less easy to dispel was the challenge of (a) either reducing the complexity of a problem so that it could be addressed with modeling and simulation techniques or (b) introducing complexity into a simple problem so as to demonstrate sufficient mastery of the methods that would be reflected in performance. The EDD and the Phlebotomy cases described in section 3 were examples of (a) and (b) respectively. In the case of the EDD problem, the doctors' discussions seemed to always introduce additional complexities and the student's challenge was to try to produce something that, although realistic, could (a) model some usable aspect of that problem and (b) produce results that would be understandable and useful to the stakeholders. With the Phlebotomy problem, the student constantly improvised her approach to introducing complexity into a simple problem, until she resolved this dilemma by moving the complexity away from the problem and introducing it within an innovative solution. Thus, the solution to the problem became not just improving a queuing problem but providing a stakeholder with the ability interface with, and make decisions on the basis of, a model of her real-world reality.

For those students who had different aspects of a similar problem (as described in the DVT case in section 3), the challenge was how to substantially differentiate themselves from each other so as to demonstrate independent learning. These students' improvisation was to model the problem from different perspectives and then to ensure that the emerging issues allowed them to model different problems. Due to the real-world nature of the problems and experience with ethical hurdles to data acquisition, most students constructed hypothetical data sets by doing independent research and complemented these with some real data from the doctors' own sources.

4.2 Process Challenges and Improvisations

As stated in section 2, students were presented with a generic process which they needed to tailor to their own individual projects based on their own experiences and research findings. Students related some of the challenges associated with this approach. One main issue seemed to be the effort of translating and/or representing a real world problem as a static model and then communicating the model to their stakeholders and other audiences (e.g. supervisors/markers). Aspects of the resulting models were either too detailed, not detailed enough or too complex for a lay-person to understand. Some of the students addressed this challenge by using simplified versions of their conceptual models (i.e. Not BPM) as demonstrated earlier in Figure 9. Once the basic conceptual model had been used to negotiate the problem definition with the stakeholder, a more complex understanding of the process could be gained by the student through the BPMN techniques. Related to this, the students also had difficulty understanding the role of dynamic modeling in this process. Some interpreted it as simply re-representing the static model of the scenario (see Figure 4). As their familiarity with using the two methods complementarily grew, they adopted various approaches such as: (a) only representing that part of the static process that provided a viable simulation problem; or (b) building the dynamic model to optimize what-if experimentation rather than demonstrating process flow. Similarly, they also had to learn to identify the utility of decision-support tools so that instead of bolting on an interface to their underlying model regardless of suitability to the problem, that interface would actually demonstrate the predictive power of the underlying model.

Where students had technical difficulties in understanding the SIMUL8 software Visual Logic elements, expertise was sought from departmental resources and from the software producers themselves. The mediation of the supervisors also mitigated the challenges related to dealing with real-world stakeholders with busy schedules and conflicting priorities.

5 REFLECTION AND CONCLUSIONS

The contributions of this paper are two-fold. The first is to show how, with appropriate support and management, undergraduate students can pursue successful M&S projects in healthcare and the second is that healthcare stakeholders can also benefit from these projects by being exposed to M&S

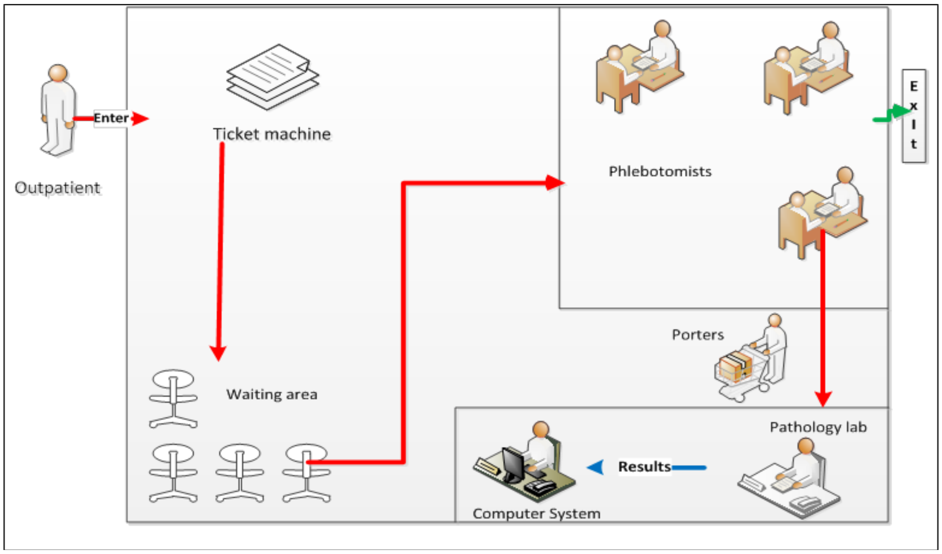

Figure 9: Conceptual model of the Phlebotomy problem

with a balanced level of commitment. However, the "journeys" that the students and stakeholders followed was extremely valuable. Their learning was structured around a substantial final year project where they had to develop practical and academic project management skills (project-based learning) against a real world problem (problem-based learning). This was supported by a "normal" simulation course that they attended in their second year where they were exposed to M&S theory and practice issues.

To put our work in context, Grasas, Ramalhinho and Juan (2013) look at how M&S is used across an educational sector, in this case Spanish Masters degrees and note that the use of a professionally-oriented approach is highly recommended in most OR/Simulation courses. Extending this, a professionally approached M&S project within the context of a computing-based undergraduate degree gave our students the opportunity to learn more about M&S in practice but also to consolidate many themes developed during their degree. Several authors note how students can learn through using simulation and gaming, or Serious Games, to explore problems through structured "play" (de Fretias and Oliver 2006). For example, Deshpande and Huang (2011) review approaches in engineering education, Cleophas (2012) develops a framework for the design of serious games in the area of revenue management, Chwif and Barretto (2003) discuss the use of simulation games in Operations Management, Tobail, Crowe and Arisha present their experiences in supply chain games, and Constantino, et al (2012) use a simulation based game approach for teaching operational management topics in production planning. Saltzman and Roeder (2013) discuss perspectives on teaching M&S in a College of Business and reflect on the differences between teaching approaches between engineering and business. Ezz, Loureiro-Koechlin, and Stergioulas (2012) review of the benefits that simulation tools offer in different educational fields. All support the view that M&S can be used successfully to effectively learn more about a given subject but must be supported by formal instructional methods. These experiences reflect either how M&S is used to support education of a particular topic or how M&S is taught to students. We suggest that it is extremely valuable to present opportunities for students to pursue substantial projects in the real world built on the above by allowing students to use simulation in practice, and, with stakeholders, to use simulation to understand subtle issues in healthcare.

For example, the process of learning was not just restricted to these students but was evident with the supervisors and the stakeholders as well. For the supervisors, our learning pertained to pedagogy in two ways: (a) how to co-construct an experiential student-led learning process that incorporated an appropriate level of challenge without exposing students to too much risk; and (b) how to assess the resulting learning outcomes within the constraints of a pre-defined marking scheme. The marking scheme could not adequately reflect a student's growth in awareness and ability to apply these skills to similar tasks, but only the skill of communicating their outputs in written and diagrammatic format, constrained by a fixed communication genre (a Word template). For the stakeholders, their learning pertained to the ability to reflect on their practice and on the complexity of the processes which they perform every day with regard to process performance metrics (e.g. the 4-hour targets of the A&E department or prescriptive but untested pathways). This space for reflection facilitated by their engagement with independent and naïve external observers of their process, allowed them to appreciate the value of systems thinking approaches to problem-solving in a challenging environment. The students' projects allowed the stakeholders to identify more clearly what aspects of a process they could highlight and control and what aspects were better left to experience and know-how.

The SIMUL8 simulation software enabled students to start at a fairly simplistic level of modeling and allowed them to build in as much complexity as they wished. It enabled stakeholders to engage with the modeling process. The Visual Logic language facilitated the modeling of system aspects and the development of user interfaces. The support that the package provides for understanding the number of trials to run in each experiment was also highly useful. Other simulation packages could have been used as well as other simulation approaches. SIMUL8 presented a good fit with the students' skills during their course and was therefore a natural choice for their projects. In future other packages and approaches may be considered.

Overall, this paper adds another example of how M&S can present the opportunity for students to study a range of exciting and challenging projects in a fascinating area. We have discussed experiences in the first year of running these undergraduate projects in collaboration with The Hillingdon Hospitals. At the end of the projects the students formally presented their work to their stakeholders at Hillingdon Hospital in an open event. This was well attended with over 20 clinicians and generated significant interest for the next year. Hillingdon Hospital also awarded a prize for the best student project and the runner up. Overall, although the specific results of each project was based on qualitative or literature-based data and, arguable, models could have been more detailed, the experiences of the "journey" that everyone took during these projects has raised significantly the awareness of the potential impact of M&S in healthcare and has helped stakeholders at Hillingdon to reflect on how their services might be improved, highlighted new areas of investigation, raised awareness of M&S at Hillingdon Hospital and equipped students with real-world M&S skills and experience. It must be noted that during the presentation of outcomes it was also made clear that these demonstrated the potential of M&S and would not be the same as outcomes from a M&S project conducted by a M&S professional. Another set of projects will run with Hillingdon Hospital in the new academic year. A similar programme of activities will be pursued. The main difference will be that students will have access to this year's project reports and will have volunteer support from this year's students.

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AUTHOR BIOGRAPHIES

SIMON J E TAYLOR is a Reader in the Department of Computer Science and leads the Modelling & Simulation Group (http://tinyurl.com/os98k8y). His email address is simon.taylor@brunel.ac.uk.

PAMELA ABBOTT is a lecturer in business analysis and process modeling, business intelligence and ERP theory and practice in the Department of Computer Science, Brunel University. Her email address is pamela.abbott@brunel.ac.uk.

TERRY YOUNG joined Brunel University as Professor of Healthcare Systems in 2001 after 16½ in industrial research and technology. Terry is also a leader of the Cumberland Initiative; a unique collaboration between health, industry and academia, committed to building a national center in services and systems excellence. His email address is Terry.Young@brunel.ac.uk.

RICHARD GROCOTT-MASON is a Consultant Cardiologist and Joint Medical Director of The Hillingdon Hospitals NHS FT. His e-mail address is richard.grocottmason@nhs.net