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BROADENING PARTICIPATION IN MODELLING

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ABSTRACT

During Summer 2018, the first author spent a summer in Exeter. This summer-long experience was funded in part by a Leverhulme Trust Visiting Professor grant award obtained the year before. During the time spent, there were several trips hosted by other UK institutions, a public lecture on modelling, and interaction with faculty at the University of Exeter, which was the host institution for the grant. Broadening participation in modelling was a key theme of this visit. The awardee found that he was spending significant time spanning normally distinct departments and faculty in a quest to better understand the diverse nature of modelling. We summarize the key milestones of the visit, and project how the summer experience might inform the discipline of modelling. Further, we provide a roadmap for other researchers who may wish to collaborate in applying for similar grant awards.

1 THE LEVERHULME TRUST SABBATICAL EXPERIENCE

The Leverhulme Trust is a UK-based grant awarding body. The Trust funds schemes such as, Research Project Grants, Early Career Fellowships, Emeritus Fellowships, Leverhulme Research Centres, Research Leadership Awards and Visiting Professorships. The Visiting Professorship allows a UK institution to invite an eminent researcher from overseas for a period of 3-12 months, with the overriding criteria for selection being, (a) the academic standing and achievements of the visitor in terms of research and/or teaching, (b) the visitor's potential for making a substantial contribution to the skills in the host institution, and (c) the systematic nature of the proposed UK program (Leverhulme Trust 2019). The purpose of the Visiting Professorship at the University of Exeter was to encourage broadening participation in modelling by exploring modelling as a means for interdisciplinary engagement and collaboration across the university and Exeter's cultural centres such as libraries, museums, and historical sites. Models are used widely in diverse areas from business and engineering to art and the humanities. And yet, we tend not to teach modelling "in the large." Instead, specific types of models are covered within disciplines. One of the objectives of the visit was to suggests forming a broader framework for model education that can serve to link various disciplines, and indeed form new bridges connecting science and culture.

Fishwick's collaboration with the Dallas Museum of Art (DMA) had previously explored the idea of using models (Fishwick 2016) as a way to explore applied mathematical relationships in the art, especially those from computer and information science. For example, a 500-year old Incan tunic was connected to dynamic state and information-flow models explaining technique and fabrication. Models familiar to operations researchers and computer scientists were presented within a cultural setting. The result was to introduce modelling, and information processing, within a cultural centre—the DMA, thus, significantly expanding the reach of modelling education (broadening participation) to large groups of museum visitors.

How can this research potentially inform the rich cultural landscape within Exeter? Consider the following - two local attractions in Exeter are the Royal Albert Memorial Museum & Art Gallery (RAMM) and the Exeter Cathedral. The 15th century astronomical clock, part of the Cathedral, serves as an excellent example of an object that ties together culture, science, and engineering. Modelling the clock begins with conceptual modelling of the components, followed by modelling the geometry, shape, and dynamics. Historically, all clocks are computers since they model time and space (e.g., the apparent motions of the sun and moon in the Cathedral clock). By exploring the clock, one can learn about history, craft, mathematics, and information processing (e.g., data flow). These interdisciplinary insights are surfaced through an interdisciplinary approach to modelling. Modelling, if taken broadly to include knowledge, process, and behaviour, provides a pathway to interdisciplinary connection-making. Models become interpretations linking disciplines to our daily experiences with scenes and their collective objects.

The goal of the Visiting Professorship application was therefore to develop an interdisciplinary perspective and framework for modelling with the objective of broadening participation. This extended stay of three months was intended to create new connections and strengthen existing links between cultural artefacts, usually studied within the humanities, and scientific artefacts, usually studied in business, science, and engineering. Modelling serves as the logical glue to make these interdisciplinary connections.

2 WHAT IS BROADENING PARTICIPATION?

For the last few decades, the National Science Foundation (NSF) in the US has required that all proposals that are submitted to the agency contain the sections *Broader Impact* and *Broadening Participation*. What do these mean, and how are these sections relevant to modelling? As to the meaning, Broadening Participation refers *to increasing the diversity, depth, and number of individuals, geographic regions, types of institutions, and disciplines participating in Science, Technology, Engineering and Mathematics (STEM)*. For modelling, this implies that one of our community efforts should be to align discussions and education on modelling to a much wider audience than is generally targeted. To broaden participation it is necessary 1) to position models within various contexts, and 2) to create translational links from concepts to more formal model structures.

For the visiting position, the goals were to engage a diverse collection of people with the subject of modelling. The idea behind the goals were to: 1) meet with university faculty that had the word "model" in their professional vocabulary, and 2) explore how some activities not normally considered "modelling" could be framed as models (e.g. writing or drawing as modelling). This diversity of people and institutional units is outlined, and further detailed in Table 1.

Table 1: Prevalence of Models in Other Disciplines.

Disciplines	**Examples of the use of models**
Anthropology	Explanatory models (Bollig and Finke 2014), moral models (D'andrade 1995).
Archelogy	System models to understand prehistoric societies (Bell 1987), phenomenological model and scaffolding model (Wylie 2017).
Computer Science	Specifications are models of problems and programs are models of possible solutions; high-level programming languages are models of abstract machines, whereas low-level languages function as models of physical machines (Fetzer 1999). In Software Engineering, the Unified Modelling Language (UML) .
Digital Humanities	Semiotics and DH modelling (Ciula and Eide 2016)
Education	Conceptual models and interactive demonstration models (NSF 2019), use of LEGO modelling (Danahy et al. 2014; Peabody and Noyes 2017)
Mathematics	Didactical use of models for maths education (Van Den Heuvel-Panhuizen 2003), Mathematical modelling, game theoretic models.
Sociology	Sociological models (Pabjan 2004).

3 BROADENING PARTICIPATION THROUGH USE OF HYBRID MODELLING

M&S is generally acknowledged as a sub-field of Operations Research (OR), particularly when simulation techniques such as Discrete-event Simulation, System Dynamics, Monte Carlo and Agent-based simulation are used as tools to help decision makers make better and more informed decisions. OR is an applied field of research, and therefore, the advances in M&S research are frequently developed as software artefacts by commercial software vendors. Practitioners generally use M&S software for model building, scenario development and experimentation. Traditionally, M&S research largely took place in research silos. For example, consider the expansive SD, DES and ABS communities, each with their international societies (*System Dynamics Society, The Society For Modeling and Simulation International, European Social Simulation Association*), world leading conferences (*International Conference of the System Dynamics Society*, *Winter Simulation Conference, Social Simulation Conference*) and journals (*System Dynamics Review, Journal of Simulation, JASSS - The Journal of Artificial Societies and Social Simulation*). These communities have continued to thrive without much engagement with the peer M&S communities, but arguably, this has resulted in lost opportunities to further the M&S discipline as a whole.

Increasingly, researchers and practitioners have valued the benefits that could be accrued through the representation of the system of interest using multiple M&S methods. This has led to a growing body of research in *Hybrid Simulation (HS).* Brailsford et al. (2018) present a comprehensive review of HS. However, this was also limited in its scope, this HS continued to look ‘inwards’ to the simulation community, rather than to explore diverse methods and techniques that have been used in disciplines like Computer Science/Applied Computing, Data Science, Econometrics and Problem Structuring/Soft Operations Research, that could be combined with conventional one-technique simulation (e.g., a model developed in DES) or with HS (e.g., a model using more than one simulation technique) in one or more stages of a simulation study. Powell and Mustafee (2017) introduced the term as *Hybrid Systems Modelling* (HSM) for such multi-disciplinary studies, wherein simulation is one of several techniques that are used in conjunction in a hybrid study. Mustafee and Powell (2018) introduced a classification of HS and HSM.

Although HSM proposes an inter-disciplinary approach for the best possible representation of a system, thereby leveraging the strengths of individual techniques and methods to achieve synergy in systems’ modelling, its target audience continues to be the researchers and practitioners. How do we broaden participation in modelling activities, such that it extends beyond the realms of simulation/HS/HSM communities? What is the learning that could be derived from the engagement of general users (as distinct from researchers and practitioners) in the activity of modelling, and from which the simulation/HS/HSM communities could benefit? We see Hybrid Modelling (HM) as offering the potential to engage with a diverse range of users from both Arts and Sciences and from which the communities of simulation/HS/HSM communities will learn; similarly, the users will further appreciate the concepts of modelling in their everyday lives. Thus, *HM will encourage broadening participation in modelling*. Figure 1 frames HM within the more general context of conventional modelling and simulation.

4 SCALE MODELLING

One aspect of broadening participation is in cultivating the experience of communicating the task of modelling to different groups. Most people have heard of *fashion models*, and they engaged in play with *scale models*, especially when of a young age, but often not stopping there. Rather than dismissing these models as irrelevant to the field of modelling and simulation (M&S), our goal included the task of determining how to create an effective communication channel. For example, in several trips to the Exeter Cathedral, we noted a concerted effort to engage the public in the construction of a Lego model of the cathedral. The model in progress is shown in Figure 2.

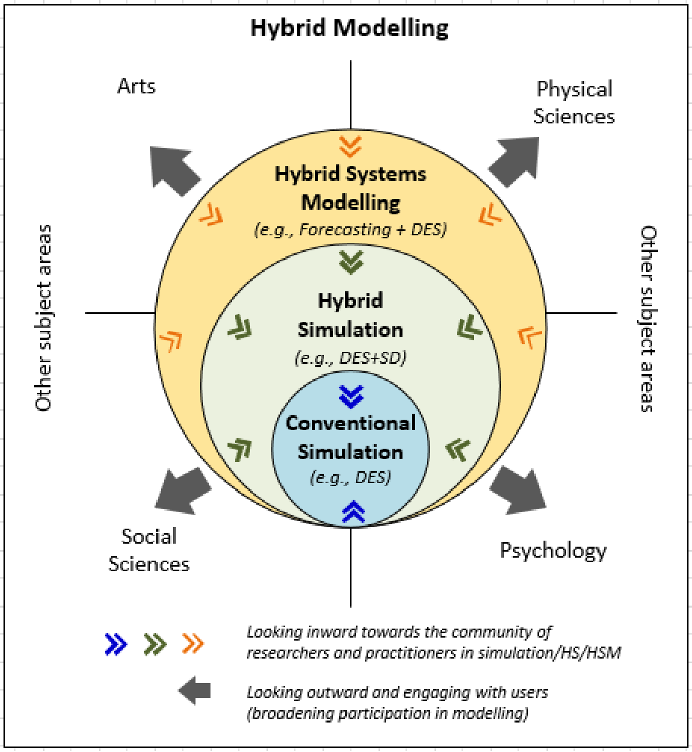

Figure 1: Hybrid Modelling extends the reach of the community of researchers and practitioners engaged in simulation/HS/HSM through engagement of diverse range of users from various fields. Unlike simulation/HS/HSM which have traditionally looked inward, hybrid modelling encourages broadening participation in modelling by reaching out.

Figure 2: Left: A partially constructed Lego cathedral model at the front entrance of the Exeter Cathedral. Right: The first author's three bricks being added to a section of the chapter house.

This scale model uses one of the smallest Lego bricks, increasing the spatial accuracy of the geometric representation. The interaction with the public consists of a person paying one English pound per brick. This money goes toward the upkeep of the cathedral, and its other expenses.

How does Figure 2 connect or relate to models of M&S? The first observation is that most models present in industrial vendors, selling M&S software, have virtual scale models in their software. Sometimes, these models show an overhead representation, and in others, a 3D representation is included to provide the simulation user with familiar visual cues and context. Examples are found in Simul8 (2019) which offers a top-down 2D model of the shapes and geometry of the simulated behaviors. Siemens PLM Software (2019) shows entire 3d spaces complete with simulated people performing tasks within the space. These are scale models where the geometry is simulated via computer graphics.

We need to return to physical scale models like the cathedral. Could they be used to encourage conversations about discrete event or continuous time processes? Past research in integrative modelling (Fishwick 2004; Quarles et al. 2009; Quarles et al. 2010; Ezzell and Fishwick 2017) shows that this is possible. An *integrative model* is defined as combining and contextualizing one model with another, such as a finite state machine within the human-interact context of a medical device 3D geometry (scale) model. For example walking through the cathedral by starting at the west entrance is a task done by many visitors. Creating a resource/queue model would allow adding knowledge of visitor behavior into the scene. This can be as simple as post-it notes attached to the cathedral, or the use of augmented reality as a means to join different model types within a single interface.

Connecting disparate model types (scale vs. discrete event) becomes a human interface question. How can a visitor see the connections? Allowing these connections in our models, gives the visitor or user more information. For the case of Lego-based models, there is a natural tie-in with the extensive use of Lego blocks throughout K-12 levels.

In line with a need to broaden participation in M&S is starting with familiar models. The Lego model is a good place to start because (1) Most people have constructed similar construction-kit models in the past, and (2) Scale models visually resemble their targets, thus not requiring abstract reasoning to understand them.

The cathedral model not only extends the usual M&S modelling frameworks but also is evidence of the *informal learning* movement (Tal and Dierking 2014) and *object-based learning* that dominates museum-based educational activities (Chatterjee and Hannan 2015). These learning theories and methods involve learning that is outside of the traditional classroom environment.

Other sorts of models that fall into the category of scale models were found across the UK during our travels. For example, (1) a doll house, (2) models in museums (e.g. Egyptian funerary models), model-based theme parks such as the "model within a model" of Bourton-on-the-Water (model village), and (3) model shops. Figure 3 shows two such models. On the left we see a model of "the house that moved" (a medieval house in Exeter originally at the corner of Frog Street and Exe Bridge. The house was then moved in its entirety a short distance away. On the right, a photo of Bourton-on-the-Water inside its model village.

5 MODELLING FOR THE MASSES

On July 12, 2018, the first author gave a talk, entitled The Giraffe and the Harpsichord: Modelling the Museum" that was about modelling in the large—an attempt to connect models of different sorts. The target audience was the public since tickets for the lecture were advertised locally within Exeter periodicals. The purpose was to introduce modelling "to the masses." In that effort, scale models, drawing and writing were highlighted as first steps in making models.

The talk title stemmed from an observation that, as in mathematical abstraction, it is possible to find a single model that models both the Giraffe and the harpsichord on display in Figure 4. Figure 4 also shows (on the right) a simple diagrammatic model to show that each has four legs and a body.

Figure 3: Left: The (medieval) house that moved. Right: Inside the model village at Bourton-on-the-Water.

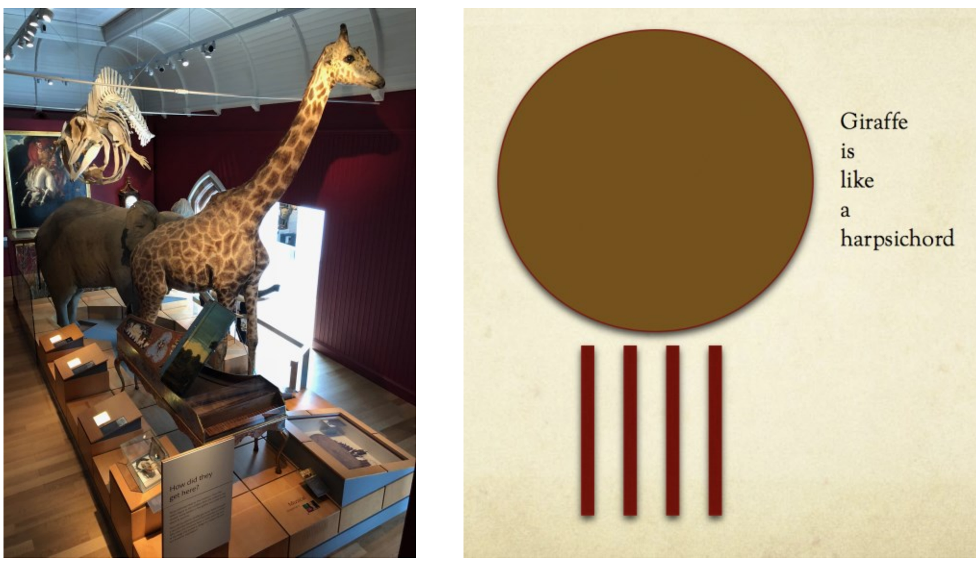

Figure 4: Left: The harpsichord near the bottom of the photo and Gerald the Giraffe towering over the harpsichord. Right: an abstract diagrammatic model of the giraffe and the harpsichord. Courtesy of the Royal Albert Memorial Museum, Exeter.

Behavioral/dynamic models were introduced in a similar fashion. They were first abstracted into a linear sequence of visual events (like a comic book or storyboard). These were then shown to the audience to emphasize that since modelling captures only a subset of the total attributes of a target object or scene, sometimes we wish to model the knowledge of something (i.e., as in concept maps or semantic networks) or the behavior of something (i.e., the sorts of models that tend to be defined within the academic M&S community.

6 SOME MODELS ARE HIDDEN

There are different sorts of models, each at a different level of abstraction or aggregation. This can make modelling a cornucopia of styles, methods, and objects. However, there are many things that are not normally viewed as modelling, but play that role. Mathematics, and its extensions, is an area where one is creating a model if the mathematics describe or represent something else. In a simple instance, imagine that someone claps both hands together. The mathematical expression of "1+1=2" is a model of this activity, where the numbers 1 and 2 represent the left and right hand, and "+" modelling the act of clapping. Here is a partial list of "hidden modelling languages":

- Mathematical structure – the structure is deemed modelling via "mathematical modelling" when the model components are depicted in canonical mathematical notation. This suggests that all of mathematics can be construed as modelling.
- Diagrams that visually depict structure – still mathematical in meaning, this is a visual front-end to mathematical structure. This can be everything from Boolean circuits and Venn diagrams to visual logic and visual equation networks used in systems modelling.
- Information structure—such as a computer program, pseudocode, or a data structure.
- Writing in a natural language – natural language as a starting point for broader participation in modelling, and represents early phases of model design.
- Drawing – capturing a system through purely visual constructs. This is a good beginning to the act of *paying attention* to an observed scene, with drawing facilitating attention.

The first bullet point is captured in the practices of mathematical modelling. Usually, the term "mathematical" refers to the use of traditional typographic mathematical symbols within formulaic or algebra based structures. The "1+1=2" is an example, but a simpler example is the use of a number to model something. A person can be modeled by the number "4" on the argument that the person has two legs and two arms, when added together makes 4. But, this also means that "4" can model cows, horses, and dining room tables.

The second bullet point is centered around the use of diagrams to create models. This very common in the M&S and Software Engineering communities to name two. In the latter, UML, BPMN, and SysML are all Object Management Group (OMG 2019) diagrammatic standards for modelling. These standards are used widely in industry and taught in academia.

The third bullet is really an extension of "mathematics" for modelling. Basic data structures, extending number, can be models for real-world phenomena. The windows on a side of a building or the Roman Wall in Exeter can be modeled with a variety of data, information, or knowledge structures.

The fourth bullet point requires some explanation if we are to believe that writing is modelling. Similar to drawing, but in the cultural processes of written language, most phenomena to be modeled are best described in writing first. Only then, can the writing be analyzed and cross-checked against the sorts of components in a model. Forrester's System Dynamics (Forrester 2013) represents one such approach, where the first step is creating a vocabulary around the system to be modeled. The causal graph, captured as a network diagram of natural language concepts is a beginning of the incremental translation from natural language to the formal language of ordinary differential equations. Checkland and Scholes (1999) present another approach that values drawing and writing as pre-steps toward more detailed models.

Regarding the fifth bullet point, the first author spent some time discussing the relation of modelling to drawing with Gemma Anderson (Anderson 2018). The discussion began by learning about the set of drawings. Some of the drawings were resemblance-type representations, similar to a scale model. Other drawings folded in conceptual and abstract aspects of biological processes such as mitosis. Drawing is something we naturally do, especially in the early ages. However the act of drawing represents a solid first step toward understanding a phenomenon. A factory floor is best drawn first before attempting to translate this layout to a discrete-event resource network model. An activity that is modeled ultimately as a finite state machine or Markov model is best sketched-out before abstracting behaviors into system states and transitions.

7 LESSONS LEARNED

There are numerous lessons learned during the visit. Some of these lessons are specified in an enumerated list:

1. *Different cultures* – Modelling is an activity that takes place in many different university units. For instance, the Business School might use a business process modelling language, whereas the sculptor will make models of initial versions of their artwork. Computer Science uses software engineering models as well as models of formal automata. To be able to converse with others, it is necessary to learn their language: the words used, the vocabulary, and the context. This inter-cultural situation is similar to that of relating different countries, each with their own natural languages and norms. If an effort is not sufficient and crossing linguistic barriers, modelers will have a difficult time seeing what they do in a broader context.
2. *Experiential learning* – the sort of approach used during the trip relied heavily on learning through direct experience on scenes, objects, and places. This type of learning is standard practice in areas such as art education, museum culture (where they have lots of objects in an object-based learning methodology). However, in many areas, the idea of seeing a process model as relating to a Tudor house is peculiar. That an object is in one sort of building can affect our interpretations of that object. A good example is in museums. If a museum is dedicated to art then one may not find computational thinking, to pick an example, in the art museum since that subject lies outside of their mission statement. In theory, any object can be interpreted across multiple dimensions regardless of where that object is located. In practice, though, the physical context biases and limits the interpretation.
3. *Silos* – A silo is a place where the discipline-specific culture is dominant. For example, in Computer Science, a model might be of software and yet, in the Business School, a model may be of an organizational (human-related) process. At a higher level, these models are similar because they involve the flow of information regardless of whether or not people are involved in defining the model. But the silos that exist in the academy are challenging to dissolve. With discipline-specific fragmentation and ever-increasing specialization, comes communities that cannot talk to each other.
4. *Vocationalism* – As modelers, we have to ask ourselves at which abstraction level, we are willing to operate. The process as network of computer vs. humans is just one of these examples. If we abstract to a higher levels, the models are identical or at least, very similar in structure. Preparing students specifically for one kind of job, with that job's technologies and domain-specific practices is something universities need to do. At the same time, there should be a need to stress how a model can cross boundaries. Noting that part of the Medieval Bridge in Exeter can be modeled by an array in computer programming provides an example. Having Computer Science or Business students going to the Medieval Bridge to learn data structures may seem counterproductive, but in actuality, if the goal is to deliver an abstract understanding of models or to reach many more people in educating them on modelling, the Bridge experience may be worthwhile. It doesn't matter if visiting the Bridge does not specifically prepare them for a job; it is about crossing boundaries, learning to think more abstractly, and being able to communicate among diverse populations.

8 SUMMARY FROM THE LOCAL HOST

Fishwick visited The University of Exeter Business School on a project that looked at developing an interdisciplinary perspective and framework for modelling. During his stay he was based at the *Centre for Simulation, Analytics and Modelling (CSAM)*, which is one of the five research centers under the Department of Science, Innovation, Technology and Entrepreneurship (SITE). The local host and Fishwick had active research collaboration for several years (e.g., Mustafee et al. 2012; Mustafee et al. 2014a;

Mustafee et al. 2014b; Mustafee et al. 2015; Mustafee and Fishwick 2017), and the Leverhulme Trust Visiting Professorship afforded this opportunity to carry forward this engagement.

8.1 Engagement within the University

Fishwick attended research seminars and mentored our post-graduate researchers (PGRs). The faculty and the post-doctoral research fellows especially benefitted from his experience as an internationally recognised researcher in M&S, getting to understand how simulation expertise could be tied with knowledge from other disciplines and offered as a service (this comes from Fishwick's personal experience where he set-up a company for model auditing and compliance in relation to hurricane loss modelling - Metaphorz, LLC), the importance of using standards in such initiatives, funding opportunities for STEM and interdisciplinary work in the US (Fishwick contributes to a National Science Foundation's STEM + Computing [STEM+C] program which tests a novel approach for teaching Physics to high school students). Parallels could be drawn to the UK Office for Students-funded Institute of Coding (of which Exeter is a part) which seeks to create new ways to develop digital skills that are needed at work and in life (https://instituteofcoding.org/). Fishwick's visit was also an opportunity for us to have a common understanding of the US system (with its academic tenure, research funding disbursement for universities, private and State universities and tuition fees) and the UK Higher Education, with its REF, TEF, league table rankings, NSS, Office for Students (OfS), etc. Fishwick engaged with colleagues from the different University of Exeter (UOE) Colleges and Departments, included, Mathematics, Computer Science, Archaeology, Sociology, Philosophy and Anthropology, Digital Humanities, the Graduate School of Education. Further exchange of interest included meetings with the UOE IIB's Arts and Culture team.

8.2 Engagement with the Wider UK Simulation Community

Fishwick delivered talks at several universities, including presentations at *The UK Operational Research Society's (ORS) Simulation Special Interest Group (SIG)* events - https://www.theorsociety.com/, and a joint *Leverhulme Trust–ORS–CSAM* event at Exeter (Table 2). The table also lists the local organisers for these events. This follows our original LT proposal, which was supported by several of the academics listed in Table 2 (last column). Thus, it is fair to say that Fishwick's visit galvanized the UK simulation community, with prominent UK academics in M&S hosting and organizing local events at their respective universities (with overall co-ordination from the host). The series of academic talks culminated at Exeter with the *"One-day Workshop on Transdisciplinary Modelling and Simulation using Hybrid System Models"*. The event was attended by over 25 academics and practitioners. It included two key note presentations (including a keynote), six other presentations and a final panel discussion.

Table 2: External Engagements in Summer 2018.

Event	Date	Event City	Location	Local Hosts
1	30th May	Manchester	Manchester Business School	Nathan Proudlove (The University of Manchester) and Stephan Onggo (Trinity College Dublin)
2	8th June	London	Brunel University London	Simon Taylor and Anastasia Anagnostou
3	12th June	Loughborough	Loughborough Business School	Antuela Tako and Stewart Robinson
4	18th June	Southampton	Southampton Business School	Sally Brailsford and Christine Currie
5	4th July	Surrey	Surrey Business School	Lampros Stergioulas and Masoud Fakhimi

6	6th July	Warwick	Warwick Business School (ORMS Seminar)	Martin Kunc
7	17th July	Exeter	Exeter Business School	Nav Mustafee and Andi Smart

8.3 The Leverhulme Trust Public Lecture

As part of the Leuverhulme Trust award, the Trust expects a public lecture to be delivered by the Visiting Professor to mark their residence in the UK. Fishwick's *Leuverhulme Trust Public Lecture* was organized at *the* Royal Albert Memorial Museum (RAMM), Exeter. The title of the lecture was "The Giraffe and the Harpsichord: Modelling the Museum" (refer to Section 5). The giraffe and the harpsichord are two exhibits at the RAMM museum; in the lecture, Fishwick gave an overview of modelling and explained how Gerald (the giraffe) and the harpsichord are connected. The lecture provided an opportunity for the audience to explore modelling as a means to connect ideas and objects. The lecture event was attended by almost 50 people, the vast majority being members of the public (Figure 5).

Figure 5: The Giraffe and the Harpsichord: Modelling the Museum - The Leverhulme Trust Public Lecture.

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