Modelling the complexity of technology adoption in higher education teaching practice

The study reported in this paper examines the inter-relationships between organisational roles during the process of sustaining the diffusion of e-learning innovations in higher education teaching practice. Through this process, new ways of teaching and learning with digital technologies become adopted by a mainstream group of academics in similar university teaching roles. Unlike top-down implementations of enterprise-wide e-learning management systems that succeed because they are mandated by university policies, e-learning innovations that originate in higher education teaching practice are generally bottom-up initiatives that mostly fail to achieve mainstream adoption. Previous studies have viewed technology adoption in teaching practice as a simple linear process. These studies have relied on traditional case study and survey research methods to identify individual and institutional actors and causal factors in this process. The methods used in these studies do not explain the inter-relationships of actors and factors in what is a dynamic, non-linear, complex process. This study is the first to investigate this problem from a complexity perspective. The study uses computer modelling to simulate and explore the inter-relationships between organisational roles within university systems that enable and inhibit mainstream bottom-up adoption of e-learning innovations that originate in higher education teaching practice.

Introduction

The continuing lag in adoption of e-learning innovations into mainstream higher education teaching practice is emerging as a growing concern amongst universities (Bates & Sangrà, 2011; Laurillard, Oliver, Wasson & Ulrich, 2009; Selwyn, 2013). The 2017 New Media Consortium Horizon Report Higher Education Edition warns that "if institutions do not already have robust strategies for integrating these now pervasive approaches, then they simply will not survive" (Adams Becker et al., 2017, p. 2). This concern is particularly evident where large investments are being made by universities in technology infrastructures. These investments are occurring in an effort to remain competitive in a growing global education marketplace, fuelled by expectations of an increasingly digitally literate population of students (Johnson et al., 2016). To meet the demands of this highly leveraged, competitive and emerging digital education landscape, government policy recommendations are directing universities to find more scalable solutions to the adoption of e-learning innovations (U.S. Department of Education, Office of Educational Technology, 2017, p. 74). How to scale up university adoption of e-learning innovations continues to present challenges for educational researchers, as noted by Sabelli and Harris (2015):

> Getting innovations to scale is an increasingly important mandate for educational research, yet also a vexing challenge for researchers who have attempted to take this on. A common perspective on scaling considers it fundamentally as an issue of how to take interventions that have been shown to work in a small number of settings and transfer them to a larger number of settings (Sabelli & Harris, 2015, p. 13).

The process of scaling up the adoption of new interventions is commonly referred to in the research literature as the diffusion of innovations (DoI) (Rogers, Medina, Rivera, & Wiley, 2005; White, 2010). This term has been popularised through Everett Rogers' seminal model of diffusion of innovations (Elgort, 2005) and DoI theory (Rogers, 2003). In his final published paper, Rogers et al., (2005) defines the sustainable diffusion of an innovation as occurring when "critical mass is reached at the point where there are enough adopters that further diffusion becomes self-sustaining" (p. 7). Most e-learning innovations that originate in higher education teaching practice fail to reach this critical mass point which Markus (1987**)** describes simply as "the way we do things around here" (p. 506) and Pacansky-Brock (2015) portrays as achieving mainstream adoption. Just as in the early pioneering years of e-learning, during the 1960s, e-learning innovations are still failing to be adopted by the mainstream of academics in teaching roles in the universities where these innovations originate (Nicholson, 2007; Reid, 2012). This is occurring even when the innovations are proven, through rigorous evaluation studies, to be effective in teaching and learning. The failure to achieve mainstream adoption of proven e-learning innovations in universities has been recognised for over 20 years in the research literature as a global problem (Nichols, 2008). This has led to numerous research studies. However, these studies have continued to view DoI from a traditional linear perspective based on scaling up from small to large implementations. It is a view that contrasts with the

proposal by Rogers et al., (2005) for a hybrid theory of DoI and Complex Adaptive Systems (CAS). This study addresses the limitations of previous studies by adopting an interpretive complexity perspective that applies and extends Rogers et al., (2005) hybrid DoI CAS hybrid theory by using computer modelling (Levin, 2015) within an interpretive interactionism (Denzin, 2001) research design.

From causality to complexity

Over the past two decades, educational researchers around the world have focussed on the individual and institutional actors and the factors in the diffusion of e-learning. The actors represent the various e-learning stakeholders in universities. The factors represent both the drivers for success and the challenges or barriers that respectively enable and inhibit the DoI process. These previous studies have reported a range of diverse findings and conclusions about the causes and effects of both top-down management-driven implementations of e-learning systems and bottom-up adoption of e-learning innovations that originate in higher education teaching practice. The majority of these investigations have been conducted as case studies, ranging from one-off single cases in one or several universities to 43 cases in a 2006 to 2012 longitudinal study in one university (Csete & Evans, 2013). In addition to citing case studies, published articles on the subject of technology adoption in universities also report results of surveys and interviews and, in some cases, provide no more than a few examples and anecdotes to support their findings and discussions. The causal factors reported in these articles derive from experiences and influences that have been found to play a part in technology adoption decision making by university teaching staff. Previous studies range from exploring the perceptions, beliefs and attitudes of individuals in university teaching roles towards the adoption of new technologies in their teaching practice (Alexander, 2006; Smigiel, 2013) to examining the roles of institutional structures, systems, policies and practices in implementing technology adoption (Gunn, 2010; Salmon & Angood, 2013; Csete & Evans, 2013). Some studies combine an investigation of the roles of both individual and institutional actors (Elgort, 2005; Sharpe, Benfield & Francis, 2006; Birch & Burnett, 2009; Gunn & Herrick, 2012; Henderson, 2015). Causal factors examined in these studies include the role and perceptions of students (Smigiel, 2013, Henderson, 2015), the pedagogical impact of teaching and learning processes (Elgort, 2005; Birch & Burnett, 2009), funding availability (Gunn & Herrick, 2012) and the features of e-learning products (Alexander, 2006; Gunn & Herrick, 2012). This focus on isolating the causal factors and actors in the DoI process "has been criticised for over-simplifying what is often a complex organisational change process" (Nutley, Davies & Walter, 2002, p. 13). In an extensive review of published literature from around the world, Casanovas (2010) concludes that previous studies "focus on factors and prescribed practices, but not on the human interactions during the transition from individual adoption until institutionalization" (p. 73). The limitations of viewing DoI as a simple linear process of scaling up from small to larger numbers based on cause and effects studies has led to recommendations for further research to examine the process of technology adoption from a complexity perspective (Rogers et al., 2005). From this perspective, understanding the "relationships among members of a system" (Rogers et al., 2005, p. 3) in which DoI is viewed as a non-linear "complex emergent phenomena" (Kiesling, Günther, Stummer & Wakolbinger, 2012, p. 1) provides a new and challenging opportunity for further investigation.

The research questions addressed in this study emerge from a view of several layers of complexity that depicts universities as complex educational systems (Jacobsen, 2015) made up of "diverse but interconnected elements" (Rossiter, 2006, p. 261) in which DoI is viewed as a complex process that operates within a complex adaptive system (Rogers et al., 2005). Rossiter (2006) adds to this view by also suggesting that complexity is "an integral dimension of e-learning" (p. 245). Snyder (2013) suggests that questions about complexity "take the viewpoint of individual (or institutional) actors' effect on the wider system rather than the reverse" (p. 9). The five guiding questions in this study apply this multi-perspective viewpoint by examining: (1) university actors as diverse elements in a complex educational system; (2) the critical success factors in the sustainable diffusion of innovations as diverse elements in a complex emergent process; (3) the association between factors, in a complex process, with the roles of actors, in a complex system; (4) the interactions in the inter-relationships between factors and actors as diverse interconnected elements in a complex system and process; (5) implications for organisational change suggested by the interaction of factors and actors in a complex process within a complex system. These questions inform the main research question which seeks to identify actionable insights rather than the causal factors found in previous studies of technology adoption in higher education teaching practice. Cooper (2012) defines the term *actionable insights* as having the "potential for practical action rather than either theoretical description or mere reporting" (p. 4) and concludes that "too frequently, management reports fail to provide this level of clarity and leave actionable insights as missed opportunities" (Cooper, 2012, p. 4). There is

some debate about how complexity theory can provide these insights. Castellani (2014) argues that "complexity theory is not so much a substantive theory, as much as it is an epistemologically explicit attempt to model social life in complex systems terms" (p. 10). The main research question in this study adopts this complexity system perspective by exploring how modelling the inter-relationships between organisational actors and factors in technology adoption within higher education teaching practice can elicit actionable insights. In proposing a modelling approach to studying education as a complex system, Levin and Jacobson (2017) argue that existing quantitative and qualitative methodologies used in educational research are insufficient for understanding the nonlinear dynamics of education when viewed as a complex system. By seeking to model interactions that are nonlinear and dynamic in the relationships between critical success factors and university system actors, the questions guiding this research reflect a complex systems perspective while building on the results of previous studies.

Connecting the actors and the factors

Recommendations from educational researchers and policy makers suggest the need to investigate both the relationships between the DoI actors in a university system and the DoI factors identified in previous studies. For example, Stepanyan, Littlejohn and Margaryan (2010) propose that "a deeper understanding of the factors of sustainability and, most importantly, their inter-relationship" (p. 30) is necessary for future studies of DoI. They add, three years later, that an "insight into multiple stakeholder perspectives, could provide better pointers toward future e-learning sustainability" (Stepanyan, Littlejohn & Margaryan, 2013, p. 98) from both an individual and institutional level. The view of these researchers is also supported in the 2014 report of an investigation by the European Commission Directorate for Education and Training study on innovation in higher education. This report recommends further research is needed about "the roles of the key stakeholders in implementing innovation" (Brennan et al., 2014, p. 1) and concludes with a policy recommendation to "clarify the roles of the different actors" (Brennan et al., p. 7) in this process. An Australasian Council on Open, Distance and E-learning (ACODE) research study concludes its investigation of 15 case studies of bottom-up adoption of e-learning products in Australian and New Zealand universities by observing:

> It seems possible that if the universities concerned had a clearer understanding of their role in the development and support of elearning innovations, some of the challenges around sustainability might be discussed and addressed at a strategic level throughout the process from development to product maturity (Gunn & Herrick, 2012, p. 15).

Furthermore, Gunn and Herrick (2012) recommend that "universities consider and clarify the roles of key individuals, practitioners and departments in the support, evaluation and adoption of new elearning products" (p. 2). They suggest the need to investigate questions "around the institutional structures and processes where the innovators work" (Gunn & Herrick, 2012, p. 16). This view is supported by Kiesling et al., (2012) who suggest that "more research is also needed on the structure of social systems, which plays a key role in diffusion processes" (p. 43). This reflects similar calls for this type of research to be conducted around the world (Bui, 2015; Singh & Hardaker, 2014).

There are only a few available published case studies of bottom-up adoption of e-learning innovations in Australian and New Zealand universities. Of these, the largest study was conducted by Gunn and Herrick (2012) for a project funded by ACODE. Other smaller studies have been conducted by the Office for Learning and Teaching (OLT) http://www.olt.gov.au/ and its predecessor bodies between 2004 and 2016 when funding for new OLT projects ceased. The OLT projects investigated case studies of mostly top-down technology adoption in Australian universities and were concerned largely with the describing the dissemination rather than the diffusion of e-learning innovations. These case studies describe the organisational structure within a university system as being made up of both individual and institutional actors. The individual actors in this study represent the innovators and adopters who are in academic teaching roles and the institutional actors represent management and professional development and/or technical support roles with responsibilities for e-learning within their university. Staff in institutional management roles and support services together with individual lecturers who are innovators and adopters of new ways of teaching and learning with digital technologies, each play a part in the sustainable diffusion of e-learning innovations. Roberston (2008) describes the diffusion of e-learning innovations in universities as occurring across three systems: macro, meso and micro. Within higher education these three systems are respectively described as "the organisational activity system – largely represented by management … the technological activity system – largely represented by information technology specialists … [and] the

pedagogic activity system – represented by those with primary responsibility for teaching and learning" (Roberston, 2008, p. 821). Within universities each these three activity levels within a university system plays a different role in the collaboration required for the diffusion of innovations in education (White, 2010). Pacansky-Brock (2015) suggests that a new way is needed to connect these diverse roles in the DoI process:

> Our models of faculty support are out-dated remnants of machine-age thinking and we are missing rich opportunities for collaborative solutions. We must begin to understand each higher education institutions [sic] as members of a complex ecosystem. Each is an organic system that is in a continuous state of change (Pacansky-Brock, 2015, para 5).

There appear to be no previous studies that have investigated the DoI process from the perspective of this complex and constantly changing higher education technology landscape. This may be largely because the skills and resources required to visualise this complex ecosystem have previously required a highly specialised knowledge of mathematical equations and computational modelling tools (Levin & Jacobson, 2017; Rogers et al., 2005). Over the past decade, computer simulation modelling applications have become more freely available and provide user interfaces that make it possible to more easily build models that explore non-linear interactions within, for example, institutional structures (Levin & Jacobson, 2017). The aim of this study is to provide further evidence that computer simulation models can be used to visualise and interpret the interactions and inter-relationships between actors and factors in complex systems with complex problems and thus lead to actionable insights.

Using Multi-Mediator Modelling

The multi-mediator modelling (MMM) computer simulation used in this study builds on the results of proof-of-concept research reported in Levin and Datnow (2012) and most recently in Levin and Jacobson (2017). The coding and concepts in the MMM tool and framework were developed by Professor James Levin at the University of California San Diego **(**UCSD**)** La Jolla Department of Education Studies. The MMM tool uses code from NetLogo, "a free multi-platform agent-based model-building environment developed by Wilensky (1999) and his colleagues at Northwestern University" (Levin, 2015, p. 3). More information about NetLogo can be found at http://ccl.northwestern.edu/netlogo/.

MMM originates from agent based modelling (ABM) which has been described by Axelrod (2005), an American political scientist, as a "third way of doing science" (p. 1). Tubaro and Casilli (2010**)** define the features of ABM in the following terms:

> ABM uses computational techniques to simulate dynamic interactions between individual entities in a given social context. Emphasis is not on variables as in statistical models, but on 'agents' (Smith and Conrey, 2007) that are endowed with attributes and behavioral [sic] rules, and act on the basis of some decision-making criterion or heuristic – an epistemological posture sometimes illustrated by the catchy slogan 'from factors to actors' (Tubaro & Casilli, 2010, p. 61).

As a research method, ABM is derived from the complexity sciences. Jacobson (2015) suggests that "the use of computer modelling, particularly ABMs, can provide research and policy insights about complex educational systems" (p. 310). The application of MMM extends traditional social science research methods, such as case studies and surveys that are commonly used in educational research, by providing "analytics and information that goes beyond traditional quantitative and qualitative educational research approaches" (Jacobson, 2015, p. 310). Agent based models have increasingly been adopted in diffusion research "as intuition aids that facilitate theory-building and as tools to analyze real world scenarios, support management decisions and obtain policy recommendations" (Kiesling et al., 2012, p. 1). In a similar way, the MMM tool developed by Levin (2015) is applied in this study to build on emerging theories of DoI and complexity (Rogers et al., 2005). In this study, the MMM tool has been modified for modelling real and possible scenarios of sustainable diffusion of e-learning innovations to inform university change management strategies.

Levin (2015) describes the functions and features of the MMM computer simulation tool as providing a framework in which

> the concepts in the domain being modeled are represented by labeled circles, each of which has an activity level that is partially determined by impact from other concepts within the model and partially determined by outside context, represented by globe icons … the activity level of each concept and context node is indicated visually by its size (Levin, 2015, p. 3).

In this study, the creation of connections between these MMM nodes occurs during interviews with volunteer participants who apply scenarios from their experience of technology adoption in their university to the model. Running the model, once these connections are made, allows an interpretation of changes to the size of the factors and levels of influence associated with different actor roles. A completed model that illustrates this effect is shown in Figure 1. This example is from one of five pilot interviews for this study conducted in 2016. The findings from these interviews will not contribute to the final research data collected for this study which received ethics approval following the pilot phase.

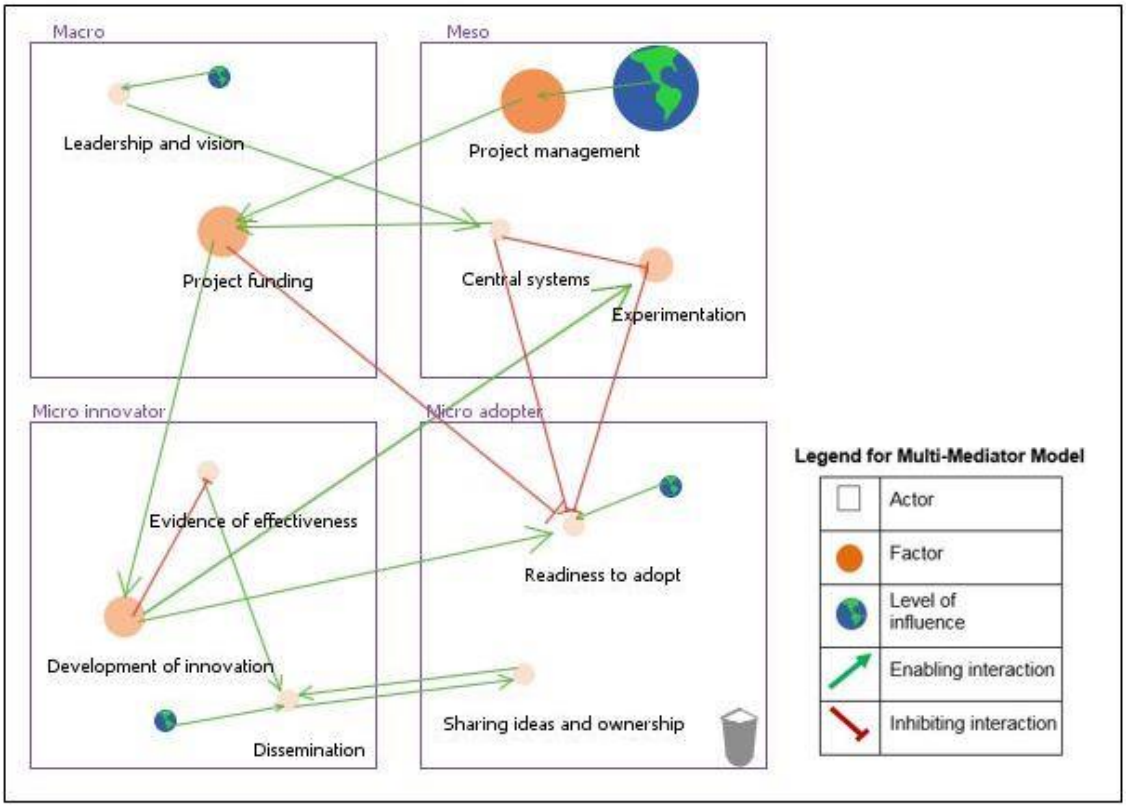

Figure 1. **A Multi-Mediator Model showing connected actors, factors and levels of influence**

In Figure 1, the concepts being modelled are shown as labelled dots that represent critical success factors in the sustainable diffusion of an e-learning innovations. Please note that the factors in the model appear the same size before the connections between them are made and the model is run. The factors that appear in the model in Figure 1 were drawn from a preliminary analysis of 15 Australasian university case studies conducted by Gunn and Herrick (2012). Each factor relates to one of four actors in the model, defined by the quadrants. The actor labels for each quadrant represent two levels within the organisational structure of a university: the individual level (micro innovators and micro adopters) in the lower two quadrants and institutional level (macro management roles and meso professional and/or technical support services) in the upper two quadrants. Each actor and factor in the model plays a role in the complex process of technology adoption. These factors and actors provide the starting point for completing each model. During an interview the factors in the model are connected and levels of influence are applied to reflect a scenario from a lived experience of technology adoption provided by the interview participant. The factors connected by arrows indicate the direction of enabling interactions in the scenario and the factors connected by barred lines indicate inhibiting interactions. The levels of influence of specific factors within an interviewee's scenario are indicated by attaching and adjusting the size of the globe icons before the model

is run. The levels of influence act as the context nodes in the model. Figure 1 shows the resulting size of the factors and associated levels of influence after the model is run. The relative size of factors and levels of influence indicates their activity level in the inter-relationships between actors: the greater the size the more a factor and influence plays a role in the scenario.

The process of creating the model framework shown in Figure 1, started with the researcher's analysis of themes in published reports of case studies. The outcome of this analysis was then applied to create the common framework in the model used at the start of each interview which showed the factors as even sized dots within each of the actor quadrants. As Levin and Datnow (2012) suggest, this first step in the data modelling process is useful for drawing "themes out of qualitative case studies of educational change" (p. 199). In their own research, Levin and Datnow (2012) applied data from a case study using a prototype of the MMM tool to demonstrate that case studies can inform the development of dynamic models of complex interactions in educational change processes. During the interviews conducted for the pilot phase of this study, the placement of some of the factors in the initial model were changed by interviewees as they directed the development of the model to reflect scenarios from their own experience and explored alternative possibilities. In some cases, additional factors were also added as the modelling process unfolded.

Viewed on their own, ABM models can appear simplistic and limited in interpreting social complexity (Tubaro & Casilli, 2010). However, when used as part of an interactive interpretive interview process, these models can provide a dynamic diagrammatic representation that acts as a graphic elicitation stimulus for gaining deeper insights about complex systems and problems. The advantages of using this graphic elicitation method are described by Crilly, Blackwell and Clarkson (2006) as follows:

> Diagrams are effective instruments of thought and a valuable tool in conveying those thoughts to others. As such, they can be usefully employed as representations of a research domain and act as stimulus materials in interviews. This process of graphic elicitation may encourage contributions from interviewees that are difficult to obtain by other means (Crilly et al., 2006, p. 3).

Jacobson (2015) suggests that using an agent-based computer simulation modelling tool like MMM, provides a "simplicity-complexity epistemic view" (p. 311) of complex systems that leads to insights based on simple rules rather than producing complex causal explanations. In this study, the insights revealed by interviewees, after modelling a scenario from their own lived experience, are applied in exploring and testing possible alternative connections in the model to depict an ideal scenario of bottom-up adoption of e-learning innovations in their university. Used in this way, MMM becomes "an effective tool for discovering surprising consequences of simple assumptions" (Axelrod, 2005, p. 1). In the pilots conducted for this study many surprising insights were revealed by interviewees about inter-relationships between the roles of university actors in the adoption of e-learning innovations. These revelations occurred throughout the modelling process which provided a dynamic "helicopter" view of the university system as "a whole which is more than the sum of its parts" (Tubaro & Casilli, 2010, p. 61), a popular catch phrase, attributed to Aristotle, in describing social complexity. During interviews for the pilot study, the consequences of changing the relationships in the model could be seen immediately as new enabling and inhibiting connections between the factors were applied and levels of influence were adjusted.

An interpretive complexity research design

The research design used in this study follows five phases in the interpretive interactionism methodology proposed by Denzin (2001): deconstruction, capture, bracketing, construction and contextualisation. The first four of these phases informs the development of the model and the final phase locates the context for the model in the lived experiences of the interview participants. These phases also reflect the five guiding questions in this study. This approach brings an interpretive complexity perspective to modelling and investigating the phenomenon of sustainable diffusion of e-learning innovations. In the *deconstruction* phase, prior conceptions of the phenomenon are examined in the research literature to identify the system elements (the actors). The *capture* phase identifies the process elements (the factors) in the phenomenon which are drawn from extant case studies. The *bracketing* phase reduces the system and process elements (the actors and factors) to uncover "essential structures and features" (Denzin, 2001, p. 70). In the *construction* phase the essential elements (the critical success factors and four system actors) are brought together to build the model framework.

The *contextualisation* phase relocates the "the phenomenon back in the natural social world" (Denzin, 2001, p. 70). This last phase occurs during individual interviews with participants who have a current or recent experience of the phenomenon in their own university and who represent the roles of actors in the model.

The four steps in this contextualisation phase are

1. Obtaining and presenting personal experience stories and self-stories that embody, in full detail, the essential features of the phenomenon as constituted in the bracketing and construction phases
2. Presenting contrasting stories that will illuminate variations on the stages and forms of the process
3. Indicating how lived experiences alter and shape the essential features of the process
4. Comparing and synthesizing the main themes of these stories so that their differences may be brought together into a reformulated statement of the process
(Denzin, 2011, p. 79).

The interpretive complexity research design developed for this study challenges traditional research methods found in previous studies that have adopted a linear view of scaling up e-learning innovations.

Conclusions

The outcomes of the pilot study reported in this paper, demonstrate that the development and interrogation of a computer simulation that models the complexity of technology adoption in higher education teaching practice can be used to reveal actionable insights for informing university change management and teaching strategies. In seeking to elicit actionable insights through modelling the complexity of technology adoption, this study applies a research design that looks beyond the purely linear and causal explanations found in previous quantitative and qualitative studies. While agent-based modelling is a proven methodology that has been used in other studies of the diffusion of innovations, its application as an interactive visual artefact for eliciting data collection during interviews is a new approach in educational research. The data gathered in this pilot study demonstrate the value of agent-based modelling in researching the sustainable diffusion of e-learning innovations. As well as leading to actionable insights, this new approach also has the potential for further applications in investigating complex problems and systems in other areas of educational and social research.

This is the first study to apply an agent-based modelling methodology to examine technology adoption processes within a university from a whole system perspective that presents a view that is more than the sum of its parts. This is in contrast to previous studies that have drawn primarily on data from individual case studies to identify lists of common success factors and barriers to the sustainable diffusion of e-learning innovations. The application in this study of agent-based modelling through an interpretive interactive process offers a new way of exploring and understanding the increasingly dynamic, complex and changing demands faced by universities in adopting new technologies in teaching and learning. By applying this method during interviews to examine the relationships between key stakeholders and critical success factors in e-learning adoption from an interpretive complexity perspective, this study aims to contribute towards furthering the application of agent-based modelling in organisational transformation. At a practical level, the research methods applied in this study are also aimed at informing educational change management policies, strategies and processes that can support the wider adoption of proven innovations in teaching and learning with digital technologies and move university teaching practice into the 21st century.

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