A Complex Adaptive Systems Approach to Personality and Social Psychology through Design Sciences

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March, 2019

A thesis submitted for the degree of Doctor of Philosophy at The Australian National University, 2019.

I declare that this thesis reports my original work, no part of this thesis has been accepted previously and presented for the award of any degree or diploma from any university, and to the best of my knowledge no material published or written by another individual is included in this thesis, except where due acknowledgement is given.

Paper 1
Title: A complex adaptive systems approach to the relationship between personality and social division
Authors: Andrew Reilly, Dirk Van Rooy, Simon Angus
Publication: Systems Research and Behavioral Science via World Conference on Complex Systems 2019
Status: Under Review

Paper 2
Title: Belief persistence, stress, and shared reality: An agent-based model
Authors: Andrew Reilly, Dirk Van Rooy, Simon Angus
Publication: Journal of Artificial Societies and Social Simulation via Social Simulation Conference 2019
Status: Submitted

Paper 3
Title: Design sciences in social psychological research: Using computational models and serious games to complement existing methods
Authors: Andrew Reilly, Dirk Van Rooy, Simon Angus
Publication: Behavior Research Methods
Status: Submitted

Paper 4
Title: Exploring the relationship between personality and strategy formation using Market Farmer: A pilot study on the use of a bespoke computer game in behavioural research
Authors: Andrew Reilly, Dirk Van Rooy, Simon Angus
Publication: The Journal of Occupational and Organizational Psychology
Status: Submitted

I declare that I was the main author of the four papers presented above and that the roles of the co-authors were to review drafts and provide guidance.

Word count: 32,650

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Dr Dirk Van Rooy

Also signing on behalf of Simon Angus

Acknowledgements

I would like to thank Dr Dirk Van Rooy for his encouragement and support of my PhD study and for his patience in dealing with my various dead ends. I would also like to thank Dr Simon Angus for his patience and technical rigour in providing help and support for the different projects undertaken. I would also like to thank panel members at the ANU for their advice, particularly Dr Mike Smithson who always seemed to have a moment. Finally, I would also like to thank my wife for supporting me over these years and for family and friends who have shown an interest in my work.

Editorial services were provided by Andrea Watts according to Standards D and E of the Australian Standards for Editing Practice.

Abstract

Conventional approaches to personality and social psychology focus on identifying statistical regularities between variables, resulting in a limited understanding of how these relationships are generated. A complex adaptive systems (CAS) approach offers a theoretical lens through which existing approaches can be understood from a generative perspective, in which relationships between variables emerge from interactions between biological, cognitive and social actors. Although this approach is often explored through computational modelling, computer games also offer a means of examining generative processes in personality and social psychology, and both methodologies can be grouped under a design sciences approach. This thesis demonstrates the utility of CAS and design sciences by applying the CAS perspective to the relationship between personality and social change, and arguing for the use of design sciences to complement existing approaches by improving external validity in conventional experiments and examining behaviour over time. The utility of CAS and design sciences is demonstrated through two studies: an agent-based model examining the role of negative affect in belief persistence, and a computer game examining the relationship between personality and strategic cognition. It is concluded that the CAS and design sciences approaches offer significant potential that can be realised through a comprehensive endeavour focused on building research teams with diverse skills, and creating a broad platform on which to run studies.

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A Complex Adaptive Systems Approach to Personality and Social Psychology through Design Sciences

Introduction

There is a longstanding view in the behavioural sciences that a clearer understanding of individuals, groups, and societies can be gained by examining relationships as dynamic, non-linear processes (Eidelson, 1997). From this perspective, once a statistical relationship between phenomena has been established, the mechanism for generating the relationship should be identified (Smith & Conrey, 2007). However, social psychological research still largely focuses on identifying linear relationships between variables (Smaldino, Calanchini, & Pickett, 2015; Smith & Conrey, 2007), even while acknowledging that causation is likely due to multiple interactions between them. This may in part be due to a methodological preference for controlled laboratory experiments, which constrains the scope of theory in addressing reciprocal causality and process-based explanations (Cook & Groom, 2008). Nonetheless, the past decade has seen further calls for more integrated approaches that examine bidirectional relationships between individuals and social contexts through interactionism (Reynolds et al., 2010), socioecological approaches (Oishi & Graham, 2010), and computational modelling (Jackson, Rand, Lewis, Norton, & Gray, 2017; Smith & Conrey, 2007). This has been particularly relevant to political psychology, where relationships between common social structures such as ideologies are thought to emerge out of interactions between motivated individuals (Bou Zeineddine & Pratto, 2017). However, little work has been done to examine bidirectional relationships between individual differences, such as personality, and shared social phenomena such as shared beliefs and values (Jost, Federico, & Napier, 2009). The aim of the thesis is to apply complex adaptive systems theory (CAS) to the explanation of existing evidence and to extend current explanations through the application of methodologies associated with *design sciences*, and in doing so, to address the lack of research into bidirectional relationships and process-based explanations of phenomena in personality and social psychology (Smaldino, Calanchini, & Pickett, 2015; Smith & Conrey, 2007).

A CAS is a collection of interconnected individual entities whose actions collectively result in an emergent order without a centralised or external form of control (Eidelson, 1997). This emergent order is often interpreted as a stable property of the system, or a continuous

pattern of behaviour (Carmichael & Hadzikadic, 2019). In social systems, people aim to meet their interests through interactions with others, such that the social organisation enters into stable states, where there is no benefit for individuals to change the balance struck between pursuing their own self-interest and reducing interpersonal friction (Heylighen, 2008). In this way, dyads form stable pattens of interaction that can be identified as relationships, and these combine to form larger stable social groups (Ramos-Villagrasa, Marques-Quinteiro, Navarro & Rico, 2017). These relatively stable, emergent states exert bidirectional influence between the individuals whose actions they result from, and the emergent order itself, which constrains the actions of the individuals, with the effect of prolonging its own existence (Haken, 2006). An example of this is the bidirectional relationship between the bottom-up motivations of individuals from which social structures emerge that recursively shape individual preferences in a top-down manner (Jost et al., 2009). For instance, religious doctrine emerges from the sustained beliefs of individuals and their interactions with each other, while regulating behaviour (Sosis, 2019)

One advantage to the CAS perspective is the ability to account for change through adaptation. Adaptation occurs when system structures change to fit a new situation, both at the individual and societal level (Tzafestas, 2018). When individuals find that interactions with others no longer produce the benefits they once did, relationships with others change or break down, resulting in the dissolution of large-scale social structures. The process of establishing new relationships and ways of interacting occurs as individuals identify beneficial behaviours, which results in the widespread reorganisation of social structures at the societal level (Carmichael & Hadzikadic, 2019). A clear and dramatic example of this is the fall of the Soviet Union, where economic pressures eventually led to a simultaneous breakdown of political relationships and the ideologies that supported them, eventually replaced by a different, but more adaptive system (Holling, 2001). Another advantage of the CAS perspective is the ability to reconcile apparent contradictions present in conventional approaches, such as the person-situation debate in personality psychology (Lucas & Donnellan, 2009), which seeks resolution through interactionism (Webster, 2009). Rather than reifying personality traits as latent variables (Boag, 2011; Borsboom, Mellenbergh, & van Heerden, 2003), a CAS approach perceives traits as stable, reccurring relationships between emotion, motivation, cognition, and behaviour that represent adaptive solutions to environmental conditions through processes of system stability and plasticity (DeYoung, 2015).

The CAS perspective allows for rigorous empirical testing, and *design sciences* (Klabbers, 2006) is one of many associated methodologies. Design sciences involve the construction of artefacts, such as computer games and simulations, for the purposes of solving a practical problem faced by scientists. In contrast to conventional empirical approaches in psychology, which tend to focus on the direct observation of behaviour, design sciences can include computational artefacts that do not include human participants, and follows on from the tradition of building experimental apparatus in the physical sciences. Unlike the physical sciences, however, where observed relationships between inputs and outputs tend to be fairly stable over time and across contexts, the social sciences examine phenomena where this relationship is more dynamic and contingent on the historical context of a given situation, making it more difficult to establish stable cause-effect relations (Klabbers, 2006). One example of an increasingly common artefact type is that of computational models, such as agent-based models (ABMs) (Jackson et al., 2017; Smith & Conrey, 2007). ABMs consist of simulations of artificial agents that interact with their environment and with each other according to programmed rules. In simpler models, these rules may be fixed, but in more complex models the rules concern the construction of rules by the agents themselves, thus allowing modellers to examine contingent input-output relationships and adaptive processes occurring across time. Computer games are another artefact increasingly used as a research tool in the social sciences (Noy, Raban, & Ravid, 2006). Similar to ABMs, games create a simplified environment in which behaviour can be examined, but agents include human participants who are motivated by the system of rules and mechanics of the game. However, much of the research conducted in personality and social psychology using games relies on gathering data on users of commercially available games (Ivory, 2013), and to my knowledge there are very few, if any, studies to date on the development of bespoke, highly engaging games as research tools in social psychology.

Stability and plasticity are fundamental concepts in CAS that can be examined through a design sciences approach that are also relevant to personality and social psychology, particularly in regard to the relationship between individual and social change. Stability refers to the capacity for a system to retain structures, while plasticity refers to the ability of the system to acquire new structures (DeYoung, 2015). In psychological systems, such as memory, stability refers to the capacity for retaining learning gained from past experience, while plasticity refers to the acquisition of new information. While these may occur as a dilemma in some contexts (Abraham, 2005), in others, their combination and complementarity can describe a range of observed phenomena (DeYoung, 2015). For

example, common models of personality traits such as the Five Factor Model can be reinterpreted as ordered categorisations of behaviours expressing stability and plasticity that are related to political positions on conservation and change (Block, 2010). Therefore, when examining the bi-directional relationship between individual differences in stability and plasticity and political ideologies representing conservation and change, the CAS approach offers a theoretical lens through which concepts familiar to political and social psychologists can be reinterpreted as processes of adaptation. Furthermore, the associated artefacts of ABMs and games can be used to examine these processes in a way that complements existing methods by identifying the mechanisms that dynamically generate relationships between variables (Smaldino, Calanchini, & Pickett, 2015; Smith & Conrey, 2007).

This thesis will apply a CAS framework and seek to recast and explore core concepts in social psychology. First, the CAS approach will be applied to investigate the bidirectional relationship between individual differences, such as personality, and social stability. In doing so, a theory of personality as an emergent phenomenon between biological and social systems is presented. Then, an ABM will demonstrate how design sciences can be used to focus on a particular aspect of this relationship in relation to stress and belief persistence. In this instance, it is suggested that stress can account for the persistence of belief in both poorly- and well-connected individuals. The thesis then further extends this approach by exploring the use of games as research artefacts, demonstrating how games can offer a complementary means of validating existing approaches as quasi-experimental methods. A pilot study is then conducted on the use of a bespoke game in examining the relationship between personality and strategy formation through exploration and exploitation behaviours that underpin adaptive processes, with the broader purpose of the study being to gain an understanding of the challenges and consequences of this approach. In doing so however, surprising results are found suggesting that political orientation may be a significant factor in strategic thinking.

Foreword to Paper 1

The first paper contributes to the aims of the thesis by applying the CAS perspective to Jost, Federico and Napier's (2009) theory of elective affinities, in which the relationship between individual differences and socio-political structures is mutually coconstitutive. By applying the CAS approach, the mechanisms by which this relationship is generated can be revealed as processes of adaptation that occur when individual motivations interact to produce phases of structural growth and dissolution in social systems in response to change. Holling's (2001) four-phase model is used to as a basis for describing these structural, adaptive changes, which emerge out of interactions between individuals with diverse motivations. A fundamental concept in this explanation is exploration-exploitation, which underpins many accounts of behaviour across biological and cultural domains (Hills et al., 2015). In this context, exploration is the search for new behaviours and social structures, while exploitation occurs as a feedback effect in which successful behaviours are identified and repeated. A key point made in this paper concerns the role of stress, which initially motivates the exploitation of social structures in order to preserve gains, but biases ingroup relationships. This results in social division and the eventual dissolution of social structures, which leads to greater exploration. Building on this basic mechanism of stasis and change, the paper draws on evidence from multiple disciplines to show how the CAS approach can account for many observed relationships between values, political orientation, and individual differences.

A Complex Adaptive Systems Approach to the Relationship Between Personality and Social Division

Abstract

Psychological differences between individuals appear to play a role in political and social division, but process-based models that can account for how the relationship between personality and political orientation is generated are lacking. Using a complex adaptive systems model, this paper argues that micro-level biological differences and macro-level sociocultural structures exert a bidirectional influence on personality as a meso-level construct. A process-based account of the relationship is provided, suggesting that initial biases at the biological level are accentuated through feedback effects that occur through social interactions. These individual differences drive collective adaptation to changing environments, resulting in the emergence of political values associated with successive phases of the adaptive cycle. Political and social division therefore occurs as an inevitable element in the process of societal adaptation and emerges out of interactions between individuals responding to stress. This flexible model is also able to account for both congruence and incongruence between personality and political orientation.

Introduction

Social division has emerged as an issue facing many countries over the past 20 years. Populations are divided politically between liberals and conservatives, generationally between old and young, and geographically between urban and rural dwellers. These divisions are particularly acute in the United Kingdom at the time of writing, where the Brexit divide crosses political lines, uniting the young against the old and highlighting the stark contrast between dynamic urban centres and impoverished regional towns (O'Reilly et al., 2016). Psychology has a significant role to play in understanding these divisions by identifying relationships between individual differences and social structures. For example, much work has been done to identify needs and motives that predispose individuals to ideologies (Jost, Federico, & Napier, 2009) associated with values like conservatism and egalitarianism (Jost, Nosek, & Gosling, 2008). This work has provided a foundation for theories on social division as a process where individuals no longer identify with a superordinate group due to a shift in self-categorisation with an alternative or lower order group (Reynolds, Jones, O'Brien, & Subasic, 2013), for example when individuals begin to identify more with being English than with being European.

However, the field as a whole is vague on the processes that define relationships between higher order phenomena, such as group formation and dissolution, and lower order phenomena, such as personality traits or cognitive preferences (Cacioppo & Visser, 2003; Jost et al., 2009). For example, system justification theory (SJT) (Jost, 2004) posits an implicit motivation among individuals to justify the existing social order even when it conflicts with personal interests. Psychological preferences related to conservative political positions, such as a need for order, structure, and closure and an aversion to novelty, diversity, and change (Jost & Hunyady, 2005) are thought to trigger negative affect when exposed to views questioning the validity and stability of the current system. This then encourages the cultivation of social connections where these views are less likely to be expressed (Jost, Ledgerwood, & Hardin, 2008), resulting in the formation of groups that place social pressure on members to offer mutual support for the status quo. Jost (2004) claims that system-justifying views may be overturned when the need to maintain a favourable self-image and/or the motivation to support the actions of others in one's social group overwhelm the motivation to continue supporting the status quo. The point at which views change can occur as a 'tipping point': a sudden change that occurs as a result of accumulated instability or pressure (van der Maas, Kolstein & van der Pligt, 2003). However, it is unclear where this tipping point in attitude change lies, how it might differ among individuals and groups, and how it may interact with other factors involved in the formation and dissolution of groups. To address these questions, process-based accounts of social and individual change are required. These accounts should identify mechanisms by which individual differences contribute to the formation of social structures and shared values, alongside accounts of how these social structures and values reflexively shape individual preferences and define group boundaries (Jost et al., 2009).

This paper aims to address these gaps by presenting complex adaptive systems (CAS) theory as a dynamic model of change and stability in individuals and societies, and showing the benefits of this approach in aligning familiar constructs in personality and social psychology along two dimensions associated with change and social relations. Furthermore, we will explain how this approach can provide a process-based account of the role played by individual differences in producing social division and will argue that this forms a necessary and inevitable phase in social transitions. Finally, we will present *design sciences* as methodologies with the potential for furthering our understanding of the interaction between individual differences and social phenomena.

Complex Adaptive Systems Theory

A complex adaptive system (CAS) is a dynamic, evolving network of relationships between entities (Paperin, Green, & Sadedin, 2011) whose actions result in an emergent order without a centralised or external form of control (Eidelson, 1997). Thus, a CAS comprises at least two levels of analysis: a lower order micro-level at which individual network elements can be examined in terms of their behaviour and responses to the behaviours of other elements, and a higher order macro-level at which stable network structures can be observed. In addition to this, a meso-level can be determined as the point at which micro- and macro-levels interact. An example of this is the small world effect in social networks (Watts & Strogatz, 1998), where most nodes, or people, have preferences for local ties, but a small number maintain global connections to people beyond their immediate network. These variations in preferences for local versus global connections at the individual micro-level result in a higher order network structure at the macro-level where a path from any given node can be taken to reach any other node through a small number of interceding nodes. Thus, any two people can theoretically be connected through intermediaries that have long-range connections to other people, a phenomenon commonly known as the *small world effect* (Watts & Strogatz, 1998). These intermediaries exhibit social power by virtue of their network position, not only because they represent a bottleneck through which information passes across the network, but also due to their ability to play a greater role in social division by severing global connections (Fidler, 2015). In this example, meso-level interactions concern the bidirectional relationship between an individual's propensity for global connections and the effect that this network position has on that propensity, as the knowledge that an individual is known to maintain diverse connections may result in further connections being made through feedback effects. For instance, a person with a preference for social interaction may develop a wide circle of social contacts and gain a reputation for being friendly and sociable, which may in turn encourage others to make contact with them, thus encouraging the development of trait extraversion.

Two dimensions can be used to define the actions of micro-level elements and the emergent states of the network: *connectivity* and *plasticity*. Connectivity refers to the tendency of individual elements to form either local (low connectivity) or global (high connectivity) connections, while plasticity refers to the tendency for either making, breaking, or maintaining connections. In social systems, this tends to result in two broad types of social

groups. One group reflects greater connectivity and plasticity, characterised by loose personal networks made up of higher status individuals with more self-oriented goals and liberal values like change and equality. The other group reflects lower connectivity and higher stability, and is characterised by tighter personal networks made up of lower status individuals with more group-oriented goals and conservative values (Markus & Stephens, 2017). Together, these features of social network structure offer greater adaptability through the diffusion of information (Granovetter, 1973) and behaviour (Rogers, 1995). For example, the spread of linguistic innovation depends on the presence of both highly-connected individuals who pass on new features of a language, and more isolated individuals who retain older features (Fagyal, Swarup, Escobar, Gasser & Lakkaraju, 2010). These features also contribute to resilience in social systems when highly-connected individuals serve as a bridge between groups (Doyle, Marsh & Lewis, 2013), thus enabling social systems to adapt to environmental changes by passing on innovative responses across the social network, while retaining information that is still adaptive to more stable feature of the environment.

Order emerges in a CAS as it adapts to environmental conditions. For example, a particular configuration of relationships may be adapted to the environment in such a way that it offers some advantage or *fitness* to the elements involved. When environmental conditions change, individual fitness also changes, as elements find themselves maladapted to the new conditions, resulting in a period of instability as the system readapts by transitioning to a new state. The emergence of a new order confers greater fitness on elements through adaptation to environmental changes. An example of this at the individual level from a more conventional perspective is the change in behaviour that occurs when a person is exposed to particular stimuli, such as the endorsement of conservative political views following exposure to mortality-salient images (Jost, Glaser, Kruglanski, & Sulloway, 2003). The increase in negative affect that occurs as a result of the exposure signals a decline in fitness by reminding a person of their own mortality, triggering a transient, cognitive-affective state that is attracted to conservative political positions as a means of reducing negative affect, thus increasing the perception of overall fitness.

In this context of survival through fitness, the dynamics of connectivity and plasticity play out through a fundamental dilemma in biological systems between *exploration* and *exploitation* (Hills et al., 2015; Stadler, Rajwani, & Karaba, 2014). Exploration allows an organism to try new behaviours that may be more adaptive then current behaviours, such as searching new areas and acquiring knowledge, while the exploitation of these allows the organism to thrive. The challenge of adaptation is to acquire new behaviours without losing

the ability to exploit existing ones, as it is a struggle to survive without successful behaviours, but it is difficult to learn new behaviours when struggling to survive. Systems explore new behaviours by increasing plasticity, which allows elements to break off old relationships and to form new ones, while reducing plasticity allows successful configurations to remain, increasing the capacity to exploit those strategies that have been useful. This is reflected at the meso-level in the social systems discussed previously where people who express more conservative political positions in support of existing institutions and social arrangements tend to also have tighter social groups due to a preference for familiar social contacts. For these people, identifying a stable source of support increases the chances of repeatedly exploiting that social resource to maintain fitness, which encourages the emergence of tightly knit communities of people relying on each other through a shared preference for familiarity, stability, and the reproduction of existing social relationships. In these more isolated local networks, social ties are reinforced over time through feedback effects. For those with greater social ambition, however, there is always the chance of a more fruitful social connection to be gained by exploring networks of social contacts. While this may sometimes lead to a dead end, by increasing opportunities, they gain a broader—if looser—personal network of other well-connected individuals that allows them to exploit this social capital for personal gain. Group boundaries and rigid social structures hamper this process of expanding social connections, and thus explorative strategies tend not to support the reproduction of existing social arrangements.

Complicating matters is the fact that the environment to which a given system is adapting may itself consist of other systems dynamically adapting to their own environments, such that each change in fitness for one system changes the fitness of those around it (Haken, 1993). An example of this "system-of-systems" would be an established team of individuals who have processes in place where material is sent to team-member B to be checked for mistakes. As a complex system of interacting structures and processes (Cervone, 2005; DeYoung, 2015; Shoda, Tiernan, & Mischel, 2002), B's personality exhibits stable patterns of behaviour indicating a high level of Conscientiousness that allows them to perform this task well. If person B is replaced with a new team member with a lower level of Conscientiousness, the error-checking task may then fall back onto individual team members, disrupting their own systems of behaviours, tolerances, and preferences. As each individual system adjusts by forming new attitudes and practices, the super-ordinate system of the team accommodates the new member. Thus, the fitness of both individual members and the team as a whole falls, while time, energy and resources are consumed by explorative actions

undertaken to establish new procedures. Once individual team members have increased their own fitness by adopting alternative behaviours that accommodate features of the new team member, the overall fitness of the team in terms of the quality of work produced increases, and the team, as a social system, can be said to have adapted to the change (Summers, Humphrey, & Ferris, 2012).

This example illustrates the advantage of the CAS approach in accommodating multiple levels of analysis in a single model. This is illustrated in Figure 1, where a changing social system is represented by a landscape across four time periods, which in turn comprises the social environment of an individual person represented by a ball. The hills and valleys of the social environment indicate the existing and potential fitness positions of the person, where descent marks a decrease in fitness and an increase in exploration, while ascent reflects the cumulative effect of exploiting newly explored strategies, resulting in increased fitness.

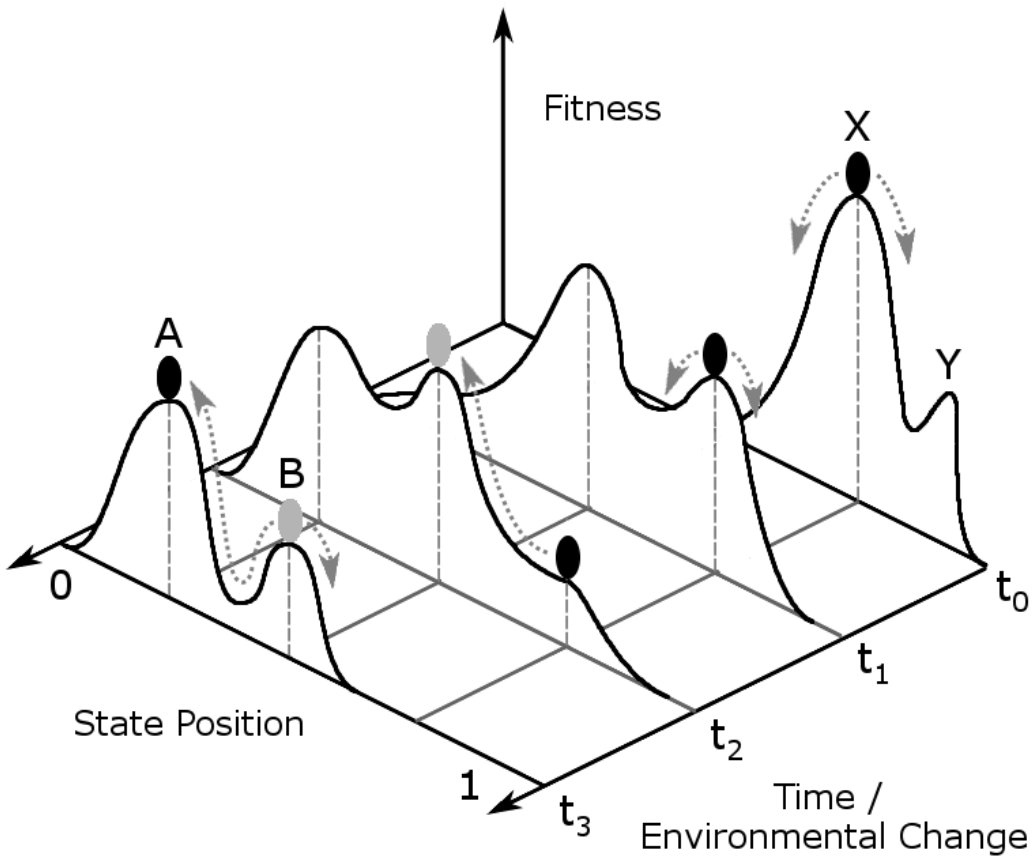

Figure 1. An individual as a CAS, represented by a ball, adapts to a dynamically changing social environment.

Here, an initially adapted individual X at step 1 (t_0) is at a lower level of fitness at step 2 due to changes that have occurred in the environment. Without exploration, X's overall fitness would reduce even more by step 3, but fundamental to a CAS is its *adaptive* character, and so a period of exploration sees the individual abandoning familiar habits, initially reducing fitness as they explore alternative behaviours, and then increasing fitness by step 3. Note that the increase or decrease in fitness of a given individual at the micro-level may contribute to the overall fitness of the macro-level in both positive and negative ways, for example when individuals acting out of self-interest can either advantage or disadvantage their social group. Therefore, a CAS at a given level of analysis is often regarded as being in a constant state of adaptation, with ceaseless environmental change and strategy discovery consistently challenging the system's level of fitness. However, when multiple levels are considered, the complex, dynamic nature of CAS means that distinct phases of exploration and exploitation are rare, and instead, systems undergo multiple adaptive cycles simultaneously in different areas, time scales, and levels of abstraction. This is particularly evident when examining large social groups that are hierarchically composed of smaller groups with loose boundaries, and of individuals, each of whom may also exhibit varying behaviours associated with adaptive cycles in different contexts. For example, the economy of a country may improve by reducing trade barriers, which encourages new industries (increasing national economic fitness) that provide jobs for educated workers (increasing their individual fitness), while those in other industries may lose their jobs and struggle to find another (decreasing their individual fitness).

These dynamic processes evolve out of feedback effects that occur at both the individual and collective level. For example, when one person experiences difficulties in maintaining fitness and embarks on a process of exploration, others in their social group may then be forced to change their behaviour to accommodate this change, which, in turn, results in more widespread instability. Furthermore, when the social group is perceived to be unstable by its members, this may discourage long-term planning, as future goals representing increased fitness may be perceived as transitory or illusory. This spreading of behaviour, whether increasing plasticity or stability, through feedback effects, signals the trajectory of the system in terms of a given phase in the adaptive cycle (Holling, 2001).

It is this ability of the CAS approach to offer a model of interactions between individual and social systems that is of particular value to the study of personality and social psychology. For example, it is broadly accepted that while the enduring patterns of behaviour that comprise personality reflect the motivations of individuals, they are also shaped by social

interactions and varies across situations (Mischel, 2009; Webster, 2009). What is missing is a model of how these stable and malleable features of personality interact to produce individual and social change, and what the role of personality is in generating social outcomes like group formation, division, and political preference. By providing models of change that incorporate multiple levels of analysis, CAS offers researchers the conceptual tools required to form hypotheses and design studies that can examine concurrent processes of individual and social change, particularly when these processes include nonlinear phenomena such as tipping points and feedback loops that are difficult to examine with more conventional approaches.

Applying the CAS Approach

I will now give an example of how the CAS perspective can be applied to addressing a gap in an existing model of political orientation based on the notion of elective affinities. In this model, the epistemic, existential, and relational motivations of individuals hold an affinity with certain political orientations available in a socially constructed superstructure of values and ideologies. However, the mechanisms by which individual differences contribute to the formation of ideologies and values, and how these reflexively shape individual preferences are unclear (Jost et al., 2009). This is due to the nature of the evidence presented in support of the model, which largely consists of statistical regularities derived from cross-sectional research designs, which do not explain the process of how relationships between variables are generated. Therefore, the lack of process-based explanations limits the ability of the model to account for the role of individual differences in political change. Because the CAS perspective offers a process-based model that can accommodate both stability and change at multiple levels, it provides an advantage to researchers seeking clarification of this relationship and also offers a conceptual foundation for examining it further. Therefore, these advantages will be discussed first by presenting the levels of analysis relevant to the model, and then by discussing the process by which the relationship unfolds at these levels.

Levels of Analysis

The CAS model is one of multilevel emergence, where lower order elements interact in such a way that higher order macrostructures form with properties that cannot be reduced to the sum of the lower order micro-level elements (Mitchell, 2009). Moreover, multiple instances of these macrostructures may also interact with each other as elements of a lower order level in a nested hierarchy of systems. Causality between two levels of a system is bidirectional, as higher order structures constrain the behaviour of the lower order elements

from which they emerge. The boundaries between levels may be arbitrarily defined by researchers, but a common set of divisions found in the literature can be determined in Figure 2 (Sheldon, Cheng, & Hilpert, 2011) .

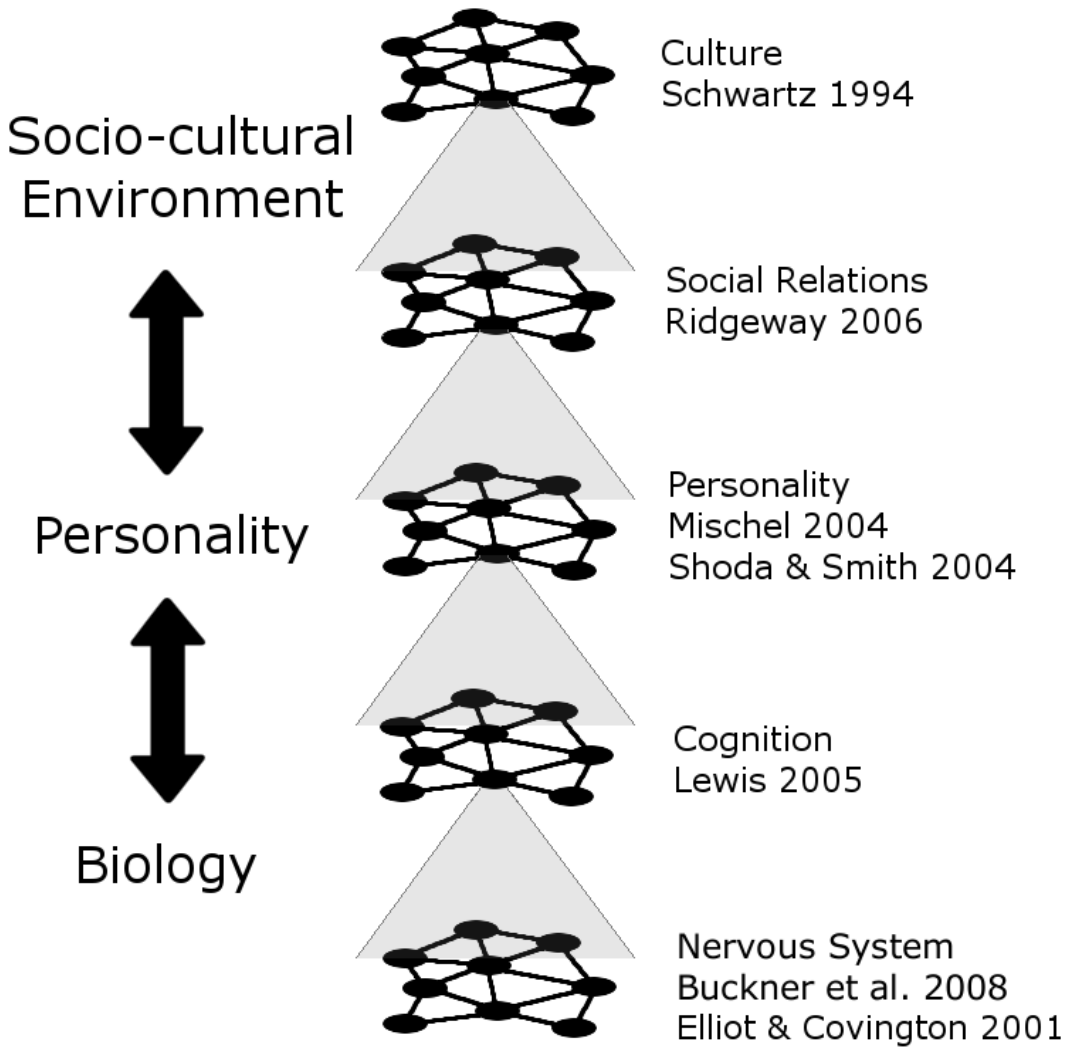

Figure 2. The hierarchy of systems where elements at each level emerge from interactions between elements in the level below but are constrained by systems at higher levels.

At the lower level, the biological system consists of interrelated neural and hormonal elements associated with say, affiliation, that drive the personality system toward interactions with others so that many of the problems that confront the biological system are incurred from the challenges of social adaptation (Buss, 2009). It is this interaction between biological systems that constitutes the network of social relationships where the behaviour of one individual provides the social environment of another (Shoda & LeeTiernan, 2002), and

responses seek to select, elicit, or manipulate social situations (Buss, 1987), resulting in a social system composed of interrelated biological subsystems. Each relationship between biological subsystems resembles a dyadic relationship where individuals both shape and are shaped by each other, which bears its own unique behavioural signature, and thus its own "personality" emerging from the interaction between partners (Shoda & LeeTiernan, 2002). In combination, these relationships result in the formation of social networks with links based on adaptive, shared cultural and interpersonal schemas (Ridgeway, 2006), from which the sociocultural system emerges. In this superordinate sociocultural system, competing schemas and ideas, such as language and culture, exist at the group level (Beckner et al., 2009). For example, the idea of the United States as a nation is shared among those who identify as Americans. At this level, shared sociocultural structures endure beyond the lifespans of individuals, and the immediate experience of an individual embedded in a social system is one where the sociocultural system of shared values and ideologies is already present and reflects the accumulation of adaptive social structures adopted in the past. It is the rejection of a received structure, either in part or in whole, that precipitates social and political change, and the probability of rejection is determined partly by the individual differences in the epistemic, existential, and relational motivations of individuals.

In order to understand a given level fully, it is necessary to treat it as a meso-level phenomenon by examining both the level above, by which it is constrained, and the level below, from which it emerges (Anderson et al., 2006). Therefore, because the level of interest to most social psychologists is likely to be that of personality, where behaviour emerges out of the interaction between lower level biological and cognitive systems and the higher level social environment (Mischel & Shoda, 1998), the CAS model can be applied at three levels of the emergent hierarchy: biology as a micro-level phenomenon, the sociocultural environment as a macrostructure, and the meeting of these in personality as a meso-level of interaction.

Process of Adaptation

Models of system adaptation typically identify distinct phases of varying lengths that can be used to describe the trajectory of a system at different levels of abstraction. These phases are often defined in terms of increasing and decreasing connectedness, which can be seen in Paperin et al.'s (2011) *dual phase evolution* model. Here, systems alternate between periods of high connectedness with many global connections, and periods of low connectedness with more isolated networks clusters. A more detailed model is Holling's

(2001) four-phase adaptive cycle that can be applied to a broad, sociopolitical context. These phases include *exploitation*, a period of increasing fitness; *conservation*, a period of relative stability and resistance to change; *release*, a period of decreasing fitness; and *reorganisation*, a period of experimentation. While the dual-phase evolution model emphasises abrupt transitions between phases, the transitions are described in more detail in the four-phase model and can provide a clear picture of social transitions.

As the name suggests, a system undergoing exploitation has the ability to predict and respond to environmental events by structurally mapping these over time in a manner akin to psychological processes of learning like assimilation (Paperin et al., 2011). For example, in a network context, the more plasticity a system has in forming connections, the more readily it can form adaptive structures and assimilate a greater variety of environmental events through its capacity to form both local and global connections, marking this phase as one of high connectivity. However, this increasing connectivity results in greater instability, as small changes in one area are more likely to spread across the network, resulting in feedback loops that can rapidly amplify minor disturbances (Paperin et al., 2011). For example, as political coalitions become more successful, it becomes more difficult to satisfy the conflicting demands of an increasing number of adherents, until any agreement made between two members inevitably impacts on those made with others, resulting in cascades of broken agreements (Brunk, 2001). Furthermore, environments inevitably change, despite the level of investment placed in existing structures, such that these structures outlive their usefulness, requiring greater levels of top-down control to maintain. The drive to maintain existing structures that are under pressure to change manifests in a fall in the level of plasticity in the system. The longer this process of conservation continues, the higher the potential for a more catastrophic release phase as individual elements struggle with the contradiction of maintaining current structures at increasing individual cost. At this time, connectivity falls as local networks become more disconnected from each other, and form groups that diverge as they follow their own trajectories (Paperin et al., 2011).

However, this increasing diversity among groups allows the system as a whole to explore a greater variety of strategies, some of which will be more responsive than others to the changes that have occurred in the environment. As events associated with release wane and plasticity increases, elements enjoy greater freedom during the reorganisation phase to seek connections beyond local networks, providing the means for greater exploration, and thus the capacity to form new structures that afford exploitation, a process analogous to that of accommodation (Paperin et al., 2011). The ensuing period of growth, followed by

increasing conservation, means that systems often undergo extensive periods of stasis or mounting tension that are punctuated by shorter release events. However, as mentioned previously, systems do not always follow such a neat path, and phases may occur simultaneously at varying lengths and time scales according to their local conditions and systems boundaries (Holling, 2001).

This dynamic model of change illustrates the advantages of the CAS approach in complementing more conventional approaches that focus on identifying relationships between variables. While these approaches are able to show that Openness to Experience is negatively correlated with a conservative political orientation (van Hiel, Kossowska, & Mervielde, 2000), for instance, the CAS model offers a framework for examining the mechanisms of change that are useful for identifying tipping points and trajectories. These may occur, for example, when individuals with liberal values switch to more conservative political choices. In doing so, the model incorporates numerous factors into a single process and identifies the role played by each at different points in the process. As such, the CAS model provides a narrative structure to explanations of phenomena relevant to personality and social psychology that can point to new areas of research and suggest hypotheses that can be addressed with more conventional approaches. This abstract model of adaptation will now be applied to the relationship between personality and political orientation, first by examining the role of individual biological differences; then the influence of the sociocultural context; and finally, the interaction between these at the level of personality.

Biological Differences

A key assumption of the CAS approach to personality is that constructs such as traits can be defined as biological processes that occur over time. This differs from the common trait approach in that it seeks to identify the processes and mechanisms from which stable patterns of behaviour emerge (DeYoung, 2015). For example, interactions between neurological elements in response to particular stimuli may be reproduced when exposed to situations that include features of those stimuli in future, thus passing as stable, but probabilistic, features of a person's behaviour (Fajkowska, 2015). While identifying stable behavioural patterns through self-report instruments can lead to the reification of these structures as personality traits (Boag, 2011), the CAS perspective views these as emergent properties of biological systems that manifest as stable adaptations to recurring features of a person's environment (DeYoung, 2015). This provides a lens through which the relationship between Openness to Experience and conservative political positions can be described as a

predictable outcome from long-term interactions between biological processes generating adaptive responses to environmental conditions, and sociopolitical structures that have emerged out of the collective interactions between these responses among individuals. Therefore, the key to understanding the role of biological processes within individuals as elements of a social CAS is to examine their contribution to the plasticity and stability of the social system through the development of personality.

Plasticity

The behavioural inhibition system (BIS) and behavioural activation system (BAS) manifest in a fundamental behavioural valency occurring even in very simple organisms based on the distinction between *approach*, where the organism moves towards a stimulus, and *avoid*, where it moves away (Elliot & Covington, 2001; Elliot & Thrash, 2002). The approach orientation results from activity in the BAS, is motivated by the perception of novelty and potential reward, and is reflected in extraverted behaviours and positive emotions that are open to exploratory activities and the seizure of opportunities. The avoid orientation results from activity in the BIS, is motivated by the perception of negative or unwanted events and potential losses, and is reflected in behaviours associated with negative emotions and motivations to "play it safe" through the exploitation of familiar behaviours.

The interaction between these systems orients responses towards stable, predictable patterns of behaviour, or towards more exploratory, experimental forms, with differences most evident in behaviour associated with the Openness to Experience trait. For example, an event signalling a threat to personal fitness that does not match expectations may be perceived, activating the anterior cingulate cortex (ACC) in the BIS. This triggers a series of reactions in the right hemisphere, resulting in an increase in subjective anxiety. This places the locus-coruleus-norepinephrine (LC-NE) function into a tonic mode in which the exploration of alternative behaviours is conducted to alleviate anxiety. A successful search switches the LC-NE back into a phasic mode, activating the dorsolateral prefrontal cortex (DLPFC) in the BAS, which increases approach motivation, exploiting the behaviour and thus reducing anxiety (Tritt, Inzlicht, & Harmon-Jones, 2012).

The selected behaviour reflects the results of the search conducted by the LC-NE, and the diversity of responses depends on the range and availability of potential behaviours. Greater exploration is possible with a broader range, which increases the probability of finding appropriate responses to a greater variety of situations. The balance between exploitation and exploration is modulated by the ACC, which, along with other structures, forms the default mode network (DMN) (Uddin, Kelly, Biswal, Castellanos, & Milham,

2009). The DMN is a set of neuroanatomical areas that are activated independently of goal-directed behaviour (Raichle et al., 2001; Raichle & Snyder, 2007), and are associated with freethinking, autobiographical memories, imagining future events, and the thoughts and perspectives of other people (Buckner, Andrews-Hanna, & Schacter, 2008). Furthermore, the DMN generates imaginative, creative, and intellectual cognitions (Beaty et al., 2016) that offer alternative information to that presented by current perception (Konishi, McLaren, Engen, & Smallwood, 2015), and is associated with Openness to Experience (Beaty et al., 2016). Therefore, individuals with a more active DMN are likely to play a greater role in generating the alternative behaviours, responses, and ideas that social systems need in order to adapt to a changing environment. Those with a less active DMN may develop more stable behavioural patterns and preferences, and may therefore contribute to the maintenance of existing adaptive social structures, thus playing a role in the encoding and long-term stability of collective learning in the social system.

Connectivity

Fundamental biological drivers of relationships can be seen in neurological models of attachment where caregivers and infants become mutually entrained in synchronised cycles of opioid and norepinephrine depletion and replenishment (T. S. Smith, 2013). Separation between infant and caregiver results in opioid depletion in the infant, which is experienced as subjective discomfort, accompanied by an increase in arousal through rising levels of norepinephrine, resulting in distress calls. On hearing these calls, a similar process occurs in the caregiver who is then motivated to comfort the infant. This increases opioid levels in both the caregiver and infant, reducing subjective feelings of distress and levels of arousal. Although the infant eventually learns to self-regulate their own internal states, the synchronisation of separation and attachment phases between dyads characterises the nature of human relationships as tensions between individual and collective pursuits.

Individual differences in the regulation of attachment and separation at the biological level play a role in the formation of social networks, particularly when individuals across the network experience rising levels of stress (T. S. Smith, 2013). For example, global, long-range ties tend to form as loosely coupled dyads that are more likely to dissipate under stress when levels of oxytocin rise, resulting in increased sensitivity to gaps in social support. This response, termed *tend-and-befriend*, promotes behaviours associated with affiliation, such as seeking support through stronger ties offered by family and friends, and attending to their needs, particularly those of offspring (Taylor, 2006). Coupled with the familiar *flight-or-fight* response, with its focus on aggression and separation, these individual responses shape the

collective response to stress in social networks by dissipating weak or outgroup ties, strengthening group boundaries and dividing the network into clusters of interrelated elements.

Sociocultural Environment

At the individual level, human beings are concerned with their personal needs, while at the immediate social level they must coordinate their actions in meeting these needs with those on whom they depend, and who also depend on them in return, thus promoting the survival of oneself through the survival of the group (Schwartz, 1994). When these needs are met through behaviours congruent with the biological preferences discussed in the previous section, values associated with these behaviours are more likely to be endorsed over others. Therefore, people express themes associated with the attainment of goals that motivate them and allow them to evaluate their progress while imparting their knowledge to others. Due to the diversity in challenges facing individuals and differences in biological preferences, this results in the emergence of universal values associated with these themes, such that these values can be mapped back onto the adaptive challenges and behaviours that produce them. The adaptive cycle describes the phases of action and events that occur as human beings collectively face these challenges, and are therefore aligned with the values that are expressed as a result of this cyclical progression. However, it is important to note that each phase in the cycle occurs in response to the one preceding it, and both emerges out of and shapes the behaviours of individuals meeting challenges relevant to each phase.

Figure 3 summarises the work by Schwartz (Schwartz, 1994; Schwartz & Bilsky, 1987) on universal human values reflecting themes associated with adaptation. Self-enhancement emphasises personal success and social dominance by valuing power, achievement, and hedonism, indicating a willingness to make social connections based on exploitation of relationships and resources. Self-transcendence emphasises equality through social acceptance and concern, reflecting values such as benevolence, which encourages helpfulness, honesty, and forgiveness; and universalism, which focuses on the understanding, appreciation, tolerance, and protection of others. Benevolence has a stronger focus on face-to-face connections over universalism, but both are indicative of valuing social connections through concern for others rather than personal gain. The arrangement of these values as a circumplex indicates the relative relationship between them, in that adjacent values such as benevolence and universalism are more likely to be held by the same individual, while universalism and power are less likely to be held together (Borg, Bardi & Schwartz, 2017).

Diametrically opposed contrasts indicate competing, but complementary goals that service adaptation, such as cooperation within groups, gratification of individual needs, and productivity (Schwartz & Bardi, 2001).

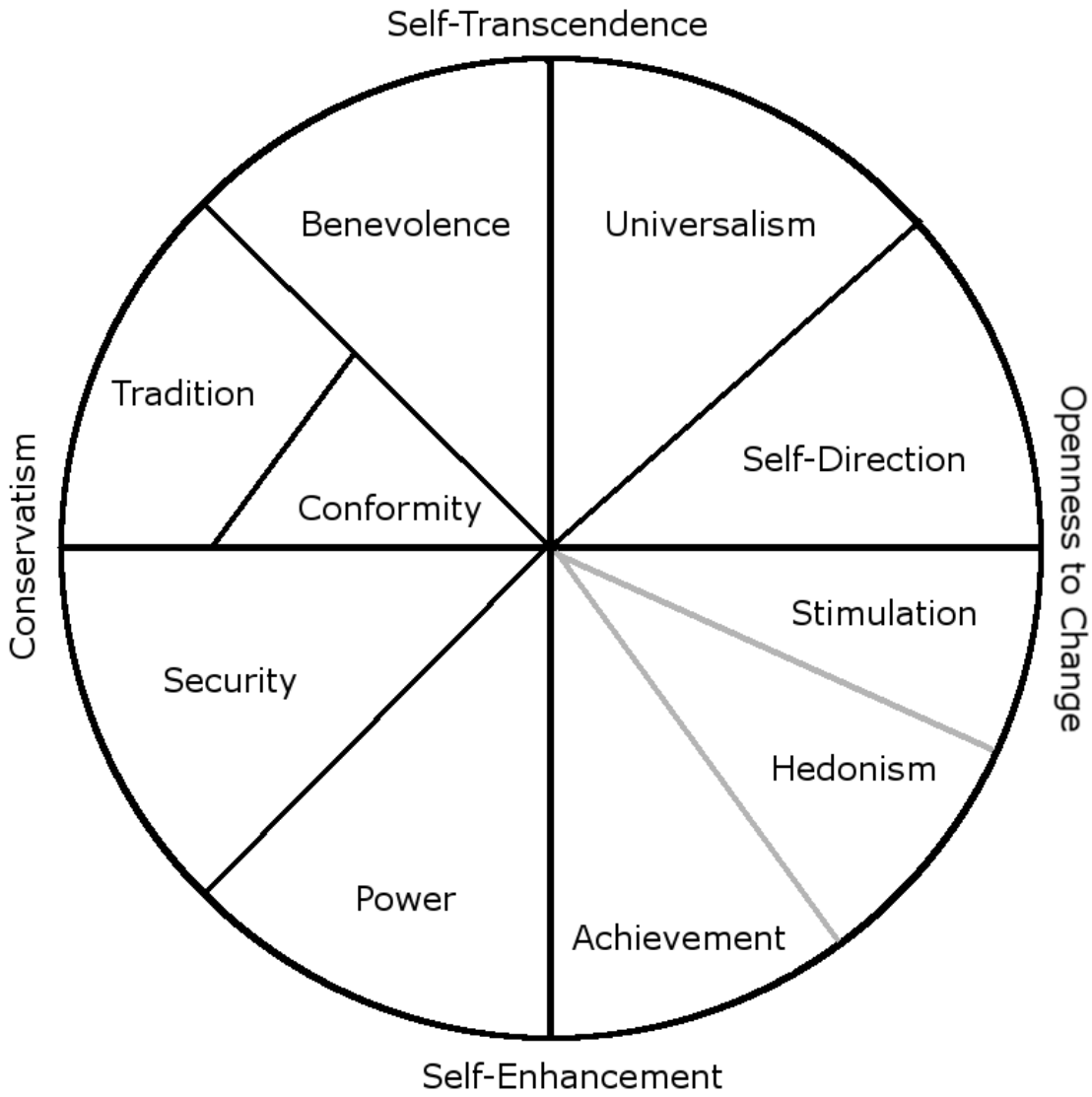

Figure 3. Circumplex of universal human values. Adapted from Schwartz (1994).

These common value dimensions are reflected in the phases of the adaptive cycle both as advocating for and responding to the trajectory of stasis, change and social organisation in human societies. For this reason, political issues serve as indicators of challenges posed by particular phases, and personality traits reflect stable adaptive strategies in meeting those challenges. This is reflected in the pattern of relationships between these values, Five Factor Model personality traits (Parks-Leduc, Feldman, & Bardi, 2015) and positions on political issues (Schwartz, Caprara, & Vecchione, 2010) displayed in Table 1.

Table 1

Statistical Relationships Between Universal Values, Big Five Personality Traits, and Positions on Political Issues

Phase	Release		Reorganisation		Exploitation			Conservation		
Value	B	U	SD	ST	H	A	P	S	C	T
Agreeableness†	.61	.39					-.42		.26	.22
Openness†		.33	.52	.36				-.24	-.27	-.31
Conscientiousness†						.17		.37	.27	
Extraversion†				.36	.20	.31	.31			
Traditional Morality††		-.19**	-.38**	-.40**	-.36**	-.15**	-.07*	.48**	.45**	.53**
Blind Patriotism††	-.12**	-.27**	-.34**	-.28**	-.25**			.43**	.35**	.37**
Law & Order††	-.20**	-.33**	-.30**	-.23**	-.21**		.12**	.39**	.30**	.32**
Military Intervention††	-.24**	-.40**	-.21**	-.14**	-.11**	.11**	.23**	.30**	.21**	.20**
Free Enterprise††	-.20**	-.39**	-.17**			.14**	.27**	.15**	.12**	.14**
Equality††	.23**	.43**		-.07*	-.08*	-.19**	-.33**			
Civil Liberties††	.18**	.32**	.19**			-.11**	-.26**	-.08*	-.08*	-.21**
Accepting Immigrants††	.20**	.36**	.25**	.23**	.09**		-.08*	-.37**	-.27**	-.26**

B = Benevolence, U = Universalism, SD = Self-Direction, ST = Stimulation, H = Hedonism,
A = Achievement, P = Power, S = Security, C = Conformity, T = Tradition
† Meta-analysis summary values for 〉 where the 80% credibility value does not include 0 (Parks-Leduc et al., 2015)
†† Values indicate *r* (Schwartz et al., 2010)
*p < .01, **p < .001

Release events occur in social systems when individuals refuse or are unable to continue engaging in actions that reproduce existing social structures. Dramatic examples include the fall of the Berlin Wall and the Soviet Union, but incidents of civil disobedience, or even the discontinuation of policy, can also count as events signalling the end of a given social structure. However, such phases in the adaptive cycle rarely occur as discrete incidents (Holling, 2001), and each emerges out of the previous phase. Therefore, the release phase occurs as a result of the contradictions that accumulate in the exploitation phase (Cumming & Collier, 2005) and begins during the conservation phase. At this time, the social system responds to increasing stress through the dissolution of global, long-range links and the strengthening of local connections, smaller groups, and tighter boundaries (Paperin et al., 2011), resulting in concurrent higher level divisions between groups and increased lower level density within groups. For example, economic stress may result in political fragmentation and the emergence of new political parties, but within these parties this process is one of increasing membership and greater political cooperation.

This transition from conservation to release is marked by a change in behaviour and preferences associated with benevolence over tradition and conformity. As can be seen in Table 1, benevolence is associated with higher levels of Agreeableness as individuals prioritise local, face-to-face relationships and relax social conventions associated with traditional morality, patriotism, and legal structures. This inevitably undermines the existing social hierarchy, to the point where elites no longer command the respect they once did, and there is an increased focus on equality and the rights of individuals through civil liberties. As this process continues and the pressures that triggered the release phase begin to ease, increasing local interdependence puts pressure on group boundaries, increasing group size, and the expression of values and behaviours associated with universalism. This can be seen in the relationship between universalism and Openness to Experience, stronger negative relationships with positions reflecting the status quo, and positive relationships with positions reflecting equality, including greater acceptance of immigrants.

As with the release phase, the reorganisation phase has its roots in previous phases. Social structures are reformed in response to the faults of the exploitation and conservation phases that precipitated the release phase. Values associated with benevolence and universalism in the release phase, such as concerns for the welfare of others and the nurturing of equal opportunities, ultimately provide a foundation for increased self-direction and greater personal freedom. This can be seen in the stronger relationships between self-direction and Openness to Experience, and the negative relationships between self-direction

and traditional morality, patriotism, legal structures, and the military, while individual freedoms and openness to alternative perspectives can be seen in the positive relationships between self-direction and both civil liberties and acceptance of immigration.

The values of self-direction, such as creativity, curiosity, and freedom, promote the kind of experimentation, pursuit of novelty, and creativity that drives the reorganisation phase (Holling, 2004). When these experiments and creative pursuits result in higher levels of fitness, whether that be social, cultural, or economic, individuals are rewarded and encouraged to actively pursue advantageous solutions to problems. An example from an economic perspective, where fitness can be understood as an increase in employment, is the experimentation undertaken by Roosevelt in creating new government agencies during the Great Depression; a policy widely replicated based on this success (Hiltzik, 2011). However, the primary motivation driving the reorganisation phase prioritises experimentation and creativity for the sake of it, rather than for gain, which only materialises as part of the transition to the following exploitation phase. This can be seen in positive relationships between values associated with stimulation and both Openness to Experience and Extraversion, and greater indifference to the kinds of risks and gains associated with free enterprise, as evidenced by a lack of a relationship between free enterprise and stimulation. Therefore, it is the features of Openness to Experience such as the rejection of convention, the pursuit of imagination, and the preference for political ideologies associated with change (Johnson, 2014) that give individuals the freedom to forge new behaviours and social structures. For these individuals, values associated with self-direction such as creativity, curiosity and freedom align with the motivation to pursue the kind of personal, unconventional goals that result in a plurality of candidate ideas and potential norms that may be more adaptive following the release phase. This pursuit of individual goals also extends to hedonism, as personal reward begins to be favoured over concerns with equality and the selflessness associated with the acceptance of immigrants, and marks the transition to the exploitation phase

The transition from the reorganisation phase to the exploitation phase also marks a broader switch from exploration to exploitation that indicates a pivotal point of adaptation, where CAS are judged to have adapted successfully to change. The willingness to identify and seize opportunities that have become available as a result of the innovations that emerged during the reorganisation phase is associated with Extraversion, and this can be seen in positive relationships between Extraversion and stimulation, hedonism, achievement, and power. Furthermore, extraverted individuals are more likely to seek out friendships that

transcend group boundaries (Turner, Dhont, Hewstone, Prestwich, & Vonofakou, 2014), which results in an increase in connectivity across social networks. These global, long-range connections are driven by the opportunities they provide for personal gain rather than values associated with selflessness, which are increasingly seen as a drag on ambition. Therefore, both ambition and power are negatively related to equality and civil liberties, while both are positively related to free enterprise.

The reorganisation and exploitation phases result in the rebuilding of social structures that are more resilient to changes in the environment than in previous structures that were dismantled during the release stage. However, these new structures have flaws of their own, and changes to the environment over time challenge their ability to respond as adaptively as they once did. Furthermore, as people are now invested in these structures, their loss represents a threat, and so measures are taken to preserve them, resulting in a period of conservation. This can be seen in negative relationships between security, conformity, and tradition with Openness to Experience, and also with positions representing the maintenance of the status quo, such as traditional morality, patriotism, and law and order, while concerns with individual liberty are apparent in the negative relationship between tradition and civil liberties.

However, this stability also allows feedback loops to remain in place, strengthening structures that may no longer be as effective as they once were and resulting in increasing extremes, for example when inequality rises as resources accumulate to fewer and fewer people (Davidson, 2010). As increasing connectivity results in greater instability and vulnerability to external shocks (Paperin et al., 2011) from an environment that continues to change, the increasing instability of the system exposes individuals to insecurity and instability, which in turn motivates those who are sensitive to threat and fearful of losing the gains acquired during the exploitation phase to clamp down on dissent and alternative views. Over time, this tension mounts, and paves the way for the next release phase.

Personality

We come now to the complex task of understanding the interaction between biological and sociocultural systems from which personality emerges. This conceptualisation of personality as an emergent process is situated within recent integrative definitions of personality as individual variations on evolutionary design that incorporate traits, adaptations, and both personal and cultural narratives (McAdams & Pals, 2006). To begin with, differences in genetic inheritance bias the expression of personality type (Réale &

Dingemanse, 2010) so that individuals possess subtle preferences reflected in behavioural responses associated with Openness to Experience (Vukasović & Bratko, 2015), for example, through a more active DMN (Beaty et al., 2016). The dynamic interplay between biological system elements such as the DMN and the BIS/BAS occurs as self-regulating cycles of increasing and decreasing levels of affect (Lewis, 2005), such that stable patterns of interaction between biological elements emerge as a network of cognitive-affective units such as beliefs, affects, and goals (Mischel, 2004; Mischel & Shoda, 1998). It is the relationships among these units that comprise the complex adaptive personality system (Shoda & Smith, 2004), a network of learned behavioural responses to problems of adaptation (Cramer et al., 2012) that emerges from the bottom-up interactions among lower order biological elements. For example, cybernetic systems of goal-directed self-regulation that can be found in mammalian brains tend to exhibit rudimentary behaviours aligned with psychological stability and plasticity. In humans, these include the big five personality traits, with Extraversion and Openness to Experience contributing to plasticity, and Conscientiousness, Agreeableness, and Neuroticism determining stability (DeYoung, 2015). This system also develops through the top-down influence of the social network structure that both constrains and develops individual preferences through feedback effects. For example, extraverted individuals are more likely to initiate relationships (Selfhout et al., 2010), occupy central positions in team networks (Klein, Lim, Saltz, & Mayer, 2004), and attain higher status (C. Anderson & Cowan, 2014), but these are all structural positions that result in situations for which extraversion is advantageous. A tendency to initiate relationships will inevitably result in the acquisition of multiple relationships, which increases the probability of occupying a central position in a social network, which encourages the kind of social skills that confer status, which attracts others. Thus, an early tendency to extraversion biases individuals towards situations where extraverted behaviour is rewarded.

This bi-directional model of personality development provides a broad schema for the relationship between low-level individual tendencies and preferences and higher-level social structures like political ideologies. An example of how this model unfolds in that context can be seen in the relationship between anxiety and support for the status quo. Individuals inclined to greater activation of the BAS in response to expectancy violation (Tritt et al., 2012) have stronger tendencies to action for the purposes of maintaining order and resolving discrepancy. In a social environment materially or culturally invested in the maintenance and exploitation of existing social structures, this behaviour is more likely to be rewarded, resulting in the accumulation of deeply ingrained cognitive schemas promoting the status

quo. This, in turn, reinforces the continuation of actions designed to eliminate opposition perceived as a threat to order (Jost, Ledgerwood, et al., 2008). As environmental changes strain existing social structures, and discrepancies between expectation and reality become more apparent, anxiety increases among diverse individuals, who respond by reaching out to those with whom they perceive a common cause. Those for whom an understimulated DMN offers few alternatives, those inclined to action through an overstimulated BAS, and those with a strong tendency for affiliation when stressed may then become mutually entrained in a social network of codependence, from which causes, narratives, justifications, and explanations emerge, further reinforcing any existing beliefs as a bulwark against anxiety in the face of change. The inevitable outcome of this process is the formation of tighter social groups with less permeable boundaries, as the mutual exchange of affirmative beliefs serves to relieve the anxiety experienced when exposed to alternatives that lie beyond the immediate social group. In contrast, those with a more active DMN are able to access a greater range of alternative responses and imagine these as potential futures, and as a result, are less likely to experience anxiety in relation to change. In an environment where arrangements no longer provide the returns they once did, these alternatives become increasingly attractive among those who perceive that there is little to be lost. When anxiety over this precarious state drives affiliative responses, group formation occurs again, separating those advocating alternatives to the status quo from those who fear its demise. This increasing isolation between social groups results in a loss of connectivity across the social network, indicating characteristics of the release phase that eventually result in greater diversity as disparate groups go their own way in supporting the status quo or exploring alternatives, which inevitably leads to the reorganisation phase.

This example shows how familiar constructs such as Openness to Experience and Conservatism can be redescribed as mechanisms of interaction between biological, interpersonal, and social phenomena. At longer time scales, it also offers a glimpse into how bottom-up diversity in genetic inheritance that may incline an individual to say, a more active DMN, and top-down dynamics of a social system adapting to its environment, interact in the coconstitution of cognitive-affective structures and interpersonal relationships. For example, given that the DMN generates potential future scenarios (Buckner, Andrews-Hanna, & Schacter, 2008), an individual generating these could contribute to the adaptive capacity of a group in need of predictive reasoning, and be rewarded accordingly. The individual might then identify with this role, further encouraging active use and development of the DSM, reinforced by social identity.

Thus, in a political context, it is not simply that a particular individual self-identifies as a conservative due to an underresponsive DMN, but that the interaction between this tendency and specific features of the social context are such that the individual has adapted to their environment by adopting conservative positions as a solution to the cognitive, emotional, and social challenges they have faced (Jost et al., 2009). For example, an ageing person who has invested in property to fund their retirement may be less likely to endorse a change in economic policy due to the potential for unexpected consequences leading to a fall in property values.

Furthermore, given that each phase of the adaptive cycle both results from and appeals to the inclinations of different individuals, and that each phase occurs as the inevitable outcome of the phase preceding it, a complex model of the long-term development of personality emerges where personality is not only coconstituted by the interplay between biology and sociocultural influence, but is a reflection of common approaches taken when adapting to social circumstances during successive phases of the adaptive cycle to which individuals living at different times may be attuned. It is important at this point to recognise that for many people, biological preferences may not be particularly strong, but they will be more easily persuaded by those whose stronger preferences are attuned to the current phase, than those whose stronger preferences are not attuned to the current phase.

For example, during the release phase when familiar social structures are disrupted, individuals may experience stress associated with unexpected and uncontrollable change. The relationship between stress and affiliation (Taylor, 2006) means that these individuals may then turn to those closest to them for support, such as family and close friends. This would then account for theories regarding self-categorisation with higher or lower order groups in the context of social change (Reynolds, Jones, O'Brien, & Subasic, 2013), as greater identification with lower order groups indicates a release phase where individuals not only perceive the global order as acting against their interests, but are more attuned to the advantages of identifying with lower order groups due to the relationship between stress and affiliation.

Therefore, in this example, individuals seek to carve out a niche for themselves in a changing social structure that satisfies their existential, epistemic, and relational needs, but in doing so, they contribute to structural change that is occurring. For this reason, it may often be the case that individuals who score highly on Openness to Experience also express support for liberal political positions, while those that don't may have developed a niche within the sociopolitical structure where it has been advantageous to perform behaviours related to

Openness to Experience in support of a conservative political position. For example, in late 1970s Britain, despite the fact that advocating free-market economics was an alternative course of action that went against decades of economic policy, it was a formal position of the Conservative party.

This perspective offers a number of advantages in addressing questions in personality and social psychology concerning the role of individual differences in the formation of and change in social structures (Eidelson, 1997). Theoretical approaches to attitudes to inequality, ingroup-outgroup relations, and disruptive change are often beset by a proliferation of variables and factors indicating relationships between independent and dependent variables, but the CAS perspective, as a process-based model of dynamic structuration and change, offers a means of incorporating these disparate constructs into a single theoretical framework. Therefore, once a relationship between, say, personality and status has been established, hypotheses can be generated regarding the circumstances under which status emerges in groups of individuals, the role played by personality, and the role that both variables could play in the coherence and growth of the group. Furthermore, recent developments in technology have enabled methodologies grouped under the term *design sciences* to examine these processes in greater detail (Reilly, 2019). The use of agent-based modelling (ABM) has already enabled social psychologists to address questions regarding the relationship between individual and social phenomena (E. R. Smith & Conrey, 2007), including in-group bias and ethnocentrism (Hammond & Axelrod, 2006), and social comparison and shared attitudes (Van Rooy, Wood & Tran, 2016). While these models tend to focus on small groups, with greater computing power, there is the potential to model larger social organisations. Furthermore, the use of multiplayer computer games in research also holds significant promise in gathering fine-grained, temporal data relating to individual and social processes of interest to personality and social psychologists, as well as in validating existing models (Reilly, 2019).

Conclusion

The CAS perspective allows for a number of tentative conclusions to be drawn. Firstly, that adaptive responses to stress and anxiety at the individual level can contribute indirectly to the emergence of political division at the societal level through links between biological responses and social behaviour, for example. While divisive attitudes such as out-group prejudice can be addressed by exhortations for greater tolerance, a more effective approach might be to address the anxieties driving the expression of these attitudes, for

example by showing that perceived losses are unlikely (Major, Blodorn, & Major Blascovich, 2018). Furthermore, social change occurs not as an event, but as a process of interactions between individuals adapting to their immediate circumstances that exerts a cumulative force driving the social system through phases of exploitation, conservation, release, and reorganisation, each of which emerges inevitably and continuously from the one before. Therefore, questions regarding how and why people with particular preferences are attracted to certain political ideologies, or why they identify with one group more than another can be addressed by examining the trajectory of the social system as a whole through the social and psychological interactions that facilitate adaptation and drive the system inexorably into the next phase. Therefore, along with asking how needs and motives interact with social structures like groups to produce social change, we can ask under what circumstances individuals with high Openness to Experience scores pursuing affiliative behaviours in response to stress are more likely to advocate for or against existing social arrangements. By answering these questions for particular social groups, more nuanced, yet effective strategies can be developed that are targeted towards specific groups or individuals in a way that can potentially dampen the effects of wrenching social change.

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Foreword to Paper 2

The relationship between stress, social structure, and adaptation is examined in more detail in the second paper using an ABM. A lack of clarity between existing theories and empirical findings regarding relationships between stress, social network structure, and belief persistence are addressed by recasting these relationships as dynamic interactions between individuals regulating stress. Then, an ABM is constructed that draws heavily from the existing literature, as well as principles of CAS introduced in the first paper, including exploration-exploitation and adaptive cycles. It is then used to simulate the dynamic relationships between stress, belief, and ingroup-outgroup behaviour over time, and provides support for the proposed theory that the role of stress in belief persistence is to strengthen ingroup ties as it increases, and outgroup ties when decreasing, thus clarifying issues in the existing literature.

In doing so, this paper illustrates the utility of ABM in responding to research questions in social psychology that are not easily addressed using more conventional methodologies. Furthermore, the ability to extend the model to provide more in-depth explanations and clarify relationships is demonstrated, and provides support for the advantages of design sciences in efficiently exploring questions that arise during the research process.

Belief persistence, stress, and shared reality: An agent-based model

Abstract

Shared Reality Theory suggests that people align their beliefs with socially significant others to avoid stress associated with the dissolution of important relationships. However, stress is also associated with ingroup bias, and should promote greater clustering when beliefs are challenged. We propose a theory that stress plays a dual role in belief persistence by promoting ingroup clustering when it is high, and broader ties when it is low. We then test this theory using an agent-based model. Results show that when stress levels determine the expansion of relationships and ingroup clustering based on shared beliefs, both are associated with belief persistence. We also find that differences in stress thresholds make a greater contribution to belief persistence. Further examination of the model shows that when doubt in a belief increases, agents with higher clustering, more numerous relationships and higher stress thresholds are more tolerant of doubt. Results clarify the role of stress in social reality theory in relation to ingroup and outgroup relationships, and imply that leaders with high stress thresholds who are connected to multiple local groups may also play a key role in belief persistence.

Introduction

The spread of misinformation and false beliefs poses a threat to social stability, and there has been some difficulty in countering the persistence of these beliefs (Lewandowsky, Ecker, & Cook, 2017). Much of the research on belief persistence to date has focused on the role of individual cognition in sustaining false beliefs, including the role of emotion (Weeks, 2015) and logical coherence with worldview (Cook, Ecker, & Lewandowsky, 2017). For example, system-justification theory (SJT) argues that people continue to support positions that work against their interests due to existential fears associated with system collapse, and are therefore more willing to overlook logical flaws in views that support the status quo (Jost, 2004).

Social factors also contribute to belief persistence when support for beliefs is underpinned by important social relationships (Hardin & Conley, 2001; Hardin & Higgins, 1996). Jost, Ledgerwood and Hardin (2008) combine these perspectives in a theory of ideological belief based on a complex interplay between negative emotions such as anxiety and stress, and the maintenance of important social relationships through belief conformity. In this shared reality theory (SRT), individuals adjust their beliefs to align with those of

partners in socially important relationships, resulting in a stable, self-sustaining social network of mutually entwined beliefs. When these beliefs are challenged, individuals perceive this as a threat to important relationships, and seek to reinforce beliefs shared with socially significant others, resulting in belief persistence, despite, or even because of, attempts to challenge those beliefs.

However, SRT does not make a clear distinction between ingroup and outgroup members when individuals align their beliefs in response to stress. This contrasts with evidence showing that the release of the hormone oxytocin in response to stress (Onaka, Takayanagi, & Yoshida, 2012) drives affiliative behaviours associated with ingroup-outgroup bias (De Dreu, 2012). Therefore, when beliefs are challenged, individuals should be more likely to seek support from ingroup members, resulting in a cluster of beliefs aligned with ingroup relationships. Nonetheless, studies have found that the number of relationships maintained, or degree centrality, is also a factor in sustaining false beliefs in social networks (Hahn, Hansen, & Olsson, 2018). Furthermore, Lee et al. (2014) suggest that degree centrality is associated with lower stress, and that this may be due to the fact that individuals with more relationships have greater access to social support that reduces stress. Degree centrality is associated with leadership (Chiu, Balkundi, & Weinberg, 2017), which, in turn, is often associated with high stress thresholds (Baron & Franklin, 2016; Sherman et al., 2012). Taken together, these studies suggest an important role for degree centrality in promoting belief persistence among people with high stress thresholds, as this allows them to maintain more social relationships through which beliefs are sustained.

On the basis of these perspectives, we propose and test a dual theory in which belief persistence results from alternating phases of ingroup and outgroup interactions in response to dynamically changing levels of stress. When interactions with outgroup actors raise stress levels by exposing people to unfamiliar beliefs that may be difficult to sustain, or that raise the level of doubt and uncertainty related to existing beliefs, they seek support from ingroup members due to the release of oxytocin and the resulting increase in affiliative behaviours (Onaka, Takayanagi, & Yoshida, 2012; De Dreu, 2012). Once this support is received, stress levels fall, and people feel confident enough to explore beyond the group again. If it is the case that people with a higher stress threshold have less need to seek support for their beliefs from ingroup members in order to sustain their beliefs, then they would be more likely to establish more outgroup relationships. These relationships provide them with more social resources in sustaining diverse beliefs (Lee et al., 2014), leading to a relationship between degree centrality and belief persistence. Conversely, individuals with a lower stress threshold

are more likely to seek support from ingroup members for beliefs shared within the group, resulting in a relationship between network clustering and belief persistence.

In order to test this hypothesis, we use an agent-based model (ABM). ABMs offer simplified, computational representations of dynamic, networked structures that can be examined over time, and are increasingly used to investigate social dynamics due to their ability to represent a wide range of social phenomena, including opinion dynamics, crowding, and economic behaviour (Quang, Jung, Cho, Choi, & Lee, 2018). We will begin by explaining how the ABM was constructed based on principles derived from theory, before introducing the model and explaining how it reproduces key elements of the relationship between stress and belief persistence. We then present the results of simulated experiments and explore their implications. We conclude by discussing the utility of the model, along with limitations and directions for future studies.

Principles of an agent-based model of belief persistence

Social networks as complex adaptive systems

A dynamic social network within which beliefs are shared can be viewed as a complex adaptive system (CAS) (Paperin, Green, & Sadedin, 2011), which cycles through phases of network connectivity that explore new structures and exploit those that increase fitness. As shown in Figure 1, these phases consist of a *local* phase, in which people cluster into groups with fewer connections to outgroup members, and a *global* phase, in which more connections form across group boundaries to people located across the whole network. Consensus is more likely to occur during the global phase as there are more connections spreading information across the network. However, this also means that information diffuses across the network more quickly, increasing instability. When events occur that place pressure on these global connections, for example by raising stress in a more unstable, unpredictable social network, these connections dissolve, and greater priority is placed on ingroup connections, leading to the local phase. During this period, groups are more isolated, and have greater freedom in developing local, unique solutions, resulting in greater diversity of information and ideas across groups as the consensus effects associated with global connections weaken. However, this also means that the instability associated with the global phase passes, and over time, people become more confident in accessing this diversity of information by forming more global connections, and the process begins again.

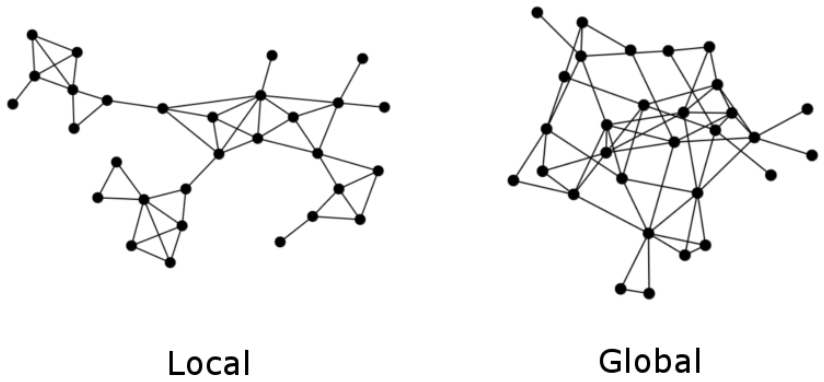

Figure 1. Networks in local and global connectivity phases. The more sparsely-connected local network is clustered into groups. Global connections across groups dissolve group boundaries, resulting in more densely-connected networks.

Such alternating phases of social and individual activity in response to stress are not unusual, and occur between caregivers and infants coupled through oscillations in opioid and norepinephrine release that motivate soothing behaviours from the caregiver in response to distress signals from the infant, and then separation between them once the distress is reduced (Smith, 2013). More broadly, Smith (2013) argues that anxiety forms a fundamental driver of social network structures through repeated phases of local and global interactions, and that local interactions can stabilise as religious or communal activities separated by periods of global, outgroup interaction. This suggests that organisations such as churches or political parties sustain their collective beliefs through regular meetings that provide mutual support among ingroup members.

In our model, changes in stress levels incurred from justifying beliefs and maintaining relationships result in transitions between behaviours associated with local and global connectivity phases. When stress increases, individuals engage in local behaviour by seeking reassurance and mutual support for their beliefs from ingroup members, and by discarding beliefs and relationships with outgroup members. Because ingroup support is limited to beliefs shared among group members, stress is reduced, allowing individuals to engage more with outgroup members again, leading back to global behaviour. This process results in both the selection of beliefs and the social relationships on which they depend, on the basis of stress as an indicator of individual fitness. However, this abstract model posits phase transitions as idealised temporal structures, and real-world social systems may typically resemble this in degree. Therefore, a social system may exhibit an increasing level of

behaviour associated with one phase, and a decreasing level of behaviour associated with the other, rather than neat, revolutionary transitions between pure states. Furthermore, the definition of these states rests on the distinction between ingroup and outgroup connections, with an increase in outgroup connections coupled with a decrease in in ingroup connections representing tendency towards global behaviours, and the converse, a tendency towards local behaviours. The individual strengths of the social connections between individuals can be defined in a variety of ways, including the frequency of contact and the level of assurance provided. However, this level of detail is not explicitly examined in this study. Furthermore, as the network structure is determined by agent behaviour, the model is not run on pre-defined network structures. Instead, the structure dynamically emerges as a function of agent actions.

Representation of beliefs and stress

Beliefs are defined as elements of a sociocultural system that are reproduced through repeated actions or practices made possible by cognitive mechanisms such as memory (Bourdieu, 1990). However, in the context of this study, beliefs are further defined as functions of social relationships, in that beliefs and relationships are coconstituted through mutual support as forms of social exchange (Ridgeway, 2006). For these reasons, agents must have the ability to possess representations of beliefs and establish relationships with other agents based on mutual efforts to maintain those beliefs. Representations of beliefs differ across disciplinary contexts, with the philosophical approach that beliefs are semantic propositions that individuals consider to be true or false being the most common. However, people may also hold beliefs to be true or false in degree (Cromby, 2012). As this study uses a numerical model representing the strength of belief, beliefs are represented as symbols to which numerical values indicating attributes such as strength are attached (Marsden & Friedkin, 1993).

A common approach to defining stress is to describe it as a reaction that occurs when individuals are unsuccessful in efforts to meet their needs (Semmer, McGrath, & Beehr, 2004). However, physiological reactions alone cannot suffice as indications of stress and difficulties in maintaining psychological states must also be taken into account (Koolhaas et al., 2011). In the context of this study, interactions between agents must address difficulties in maintaining beliefs, such as skepticism or doubt. Therefore, attached to these representations of beliefs are numerical values that indicate the level of doubt or uncertainty associated with the belief, from which stress levels can be derived and interactions with others evaluated.

Essential to the concept of stress is a tipping point at which stimuli exhaust the adaptive capacity of an organism (Koolhaas et al. 2011), and so when levels of doubt reach a certain point, beliefs may be discarded. However, it is not uncommon for people to remain undecided on a particular belief, and intolerance of uncertainty can also be a source of anxiety (Carleton, 2012). Therefore, while agents may be open to adopting beliefs that have previously been discarded, they should do so within a tolerable level of stress.

Social support for beliefs

In order to select beliefs and social partners according to perceived levels of fitness, or stress, agents should be able to share beliefs with each other. They should also be able to identify the degree to which partners are instrumental in providing support for their beliefs, and quantify the level of stress associated with maintaining a particular belief when seeking support from partners. The contextual reasoning that occurs with these judgements is facilitated by attaching numerical values to interaction partners and actions stored in memory (Alam, Geller, Meyer, & Werth, 2010). As such, memories function as selection mechanisms for actions and partners in such a way that one-off interactions are more likely to be forgotten, while those with positive outcomes for the agent are more likely to be recalled and repeated, thus laying the basis for a model that accurately reproduces structural features of social networks (Zhao et al., 2015). Furthermore, as a representation of a social network where people are open to supporting both ingroup and outgroup agents, the model should include a simple mechanism of direct reciprocity to ensure that relationships are genuinely cooperative (Nowak, 2006).

Difference between behaviours and actions

A common design of ABMs is for agents to interact through a turn-based process. In this model, agents select either a local or global approach that governs actions for the duration of the turn, resulting in two timescales of interaction. At a shorter scale, *actions* occur as a single interaction between two agents providing mutual support for a shared belief. When agents store actions, each is associated with a specific belief and partner, and in this sense, actions are explicit events that can be repeated. Therefore, a series of actions can occur as part of an overarching local or global approach, as local and global behaviours represent broad preferences that are realised over longer periods. For this reason, a series of actions performed in line with either a local or global approach is referred to as a *behaviour*.

Individual differences in behaviour, stress, and stress thresholds

Because the selection of behaviours is determined by the level of stress, a threshold value is used to select behaviours. This value can then be varied among agents as a means of preserving heterogeneity in terms of tolerance of information that contradicts held beliefs (Webster & Kruglanski, 1994). This means that an agent with a lower stress threshold will exhibit less tolerance for conflicts that make it difficult to justify beliefs, and seek support from ingroup agents sooner than an agent with a higher stress threshold. These stable individual differences in stress tolerance suggest that preferences for associated behaviours can be described in terms of personality: an enduring system of behaviours performed according to variations between individuals and situations (Mischel, 2004). Therefore, the implementation of these behaviours is based on observed associations between behavioural preferences aligned with phases of adaptive cycles (Reilly, 2019). For example, the low-connectivity phase is associated with the restriction of interactions with ingroup partners and conformity to group preferences. In contrast, the high-connectivity phase is represented by the global behaviour reflects opportunity, competition, and resource acquisition (Paperin et al., 2011), and is associated with openness to interactions with outgroup partners. Therefore, a mechanism for improving on existing actions or partners should occur as part of global behaviour, as this is aligned with opportunity and competition. Similarly, placing a priority on opportunity and openness may mean that an agent is open to adopting previously discarded beliefs for the sake of establishing a relationship with a potentially beneficial partner, provided that the level of doubt associated with the belief is within their stress threshold.

Model Description

Model Space

Agents indexed by $1 \ldots N$ each attempt A interactions according to one of two selected behaviours: *local* or *global*. At any time, each agent's state is characterised by the following state variables:

- a set, B, of beliefs, each consisting of a set of values e, c and v that are updated at the beginning of each time step t: $B = \{\{e_1, c_1, v_1\}, \{e_2, c_2, v_2\} \ldots\}$.
- c represents the level of doubt relating to a given belief that has accumulated over multiple time steps. In order to represent individual differences in the level of doubt associated with a belief, values of c are initialised at $\sim U([0,1])$ for each belief instance, such that the level of doubt associated with a given belief is different for each agent.

- *e* represents the level of doubt associated with a given belief at any given point in time, and is updated to *c* at the beginning of each time step. It is also updated following the completion of each action.
- *v* represents an agent's perceived level of stress associated with holding a given belief, and is the value of *e* at *t* prior to updating, thus reflecting the ability of the agent to reduce the value of *e*, or doubt, at $t - 1$.
- *s* represents an agent's overall level of stress, and is the sum of all values of *v* for each belief held by the agent, i.e. $s = v_1 + v_2 + \ldots$.
- *f* is the threshold at which the agent selects a new behaviour, local or global.
- a set of actions, *Q*, that functions as a memory of actions that the agent has undertaken in the past. Each action is associated with two values: q_{act}, which represents the strength of recall and q_{value}, representing the benefit of the action to the agent, each of which are updated when the action is conducted.
- A set of agents, *P*, that functions as a memory of agents with whom the agent has interacted with in the past, each of which is associated with two values, p_{act} and p_{value}, as per the case with *Q*.

The social distance method (Hamill & Gilbert, 2009) is used to situate agents in a realistic social network prior to running the simulation. As shown in Figure 2, agents are randomly located on a bounded, two-dimensional plane and *P* for each agent is populated by the agents within their neighbourhood with an initial p_{value} of 1, along with their respective beliefs.

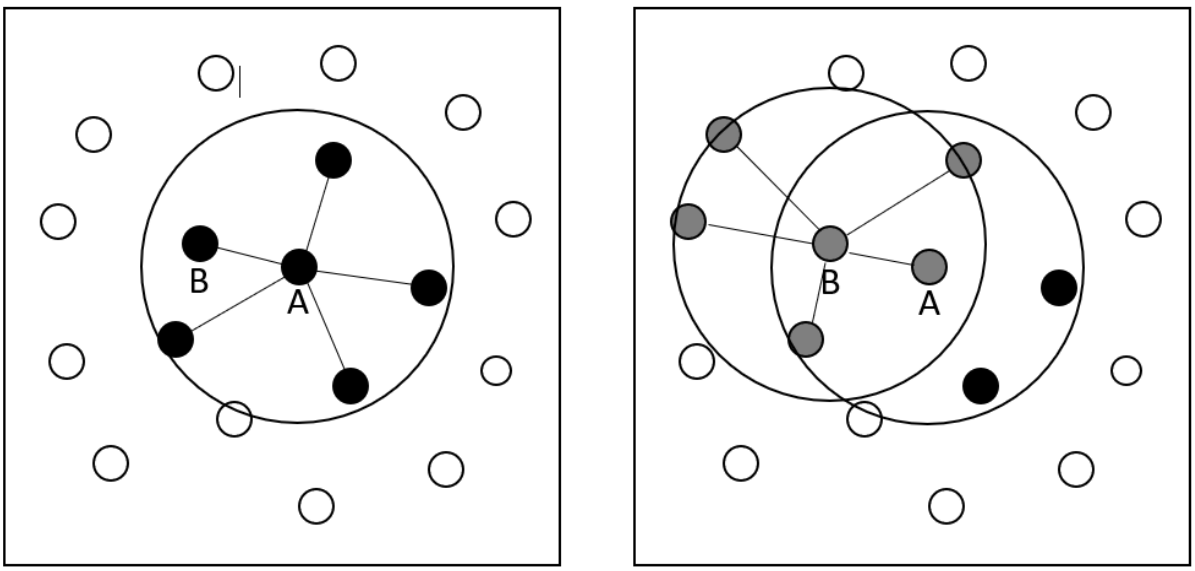

Figure 2. The social distance method of establishing a realistic social network. Agents within the radius are connected to the central agent, creating overlapping local networks, such that

the black nodes are connected to A, and the grey nodes to B. Note that both A and B are in each other's local network.

A number of global parameters are also used to describe the model space:

- A decay parameter, D, is used to determine the rate at which values of q_{act} and p_{act} change on updating, such that $0 < D < 1$.
- R is the threshold value below which items with q_{act} and p_{act} values are removed from Q and P, and thus has the same range as D.
- T is the global threshold at which agents select a new behaviour, such that values of f lie either above or below T, with a range of $(-\infty, \infty)$.
- V is the maximum extent to which f can deviate from T, such that $f = T + V \sim U([-1,1])$, with a range of $(-\infty, \infty)$.
- A is the maximum number of interactions and agent is able to undertake each time step.

Agents

During a given time step, each agent, i, attempts to reduce the overall level of stress, s, resulting from holding the beliefs in B by seeking mutual support from another agent, j. Support is obtained by performing an action, a_{ij} associated with a particular belief held by both agents. Each action subtracts values x_i and x_j from e_i and e_j respectively, where both values of $x = \sim U([0,1])$ in order to reduce the level of doubt associated with that belief for the remainder of the time step, and thus the level of stress associated with holding that belief. However, as the values of x_i and x_j differ, each action benefits i and j differently, indicating the varying levels of support that accrue from different approaches to upholding a given belief.

In order to achieve a valid representation of a social network, we include a simplified version of the memory function provided by Zhao et al. (2015) with which items acquired recently or often are more likely to be recalled, as one-off interactions are less likely than repeated encounters to amount to long-term relationships. To facilitate this, let items p and q be represented by m for ease of description, so that each stored item, m, can be associated with values *act* and *value*, as introduced previously. A decay function is used to remove memories using the global parameter D, which determines the rate at which memories decay with each time step, d. When an item, m, is first placed in memory, $m_{act} = D$, and $d = D$, and for each subsequent time step, $m_{act} = dm_{act}$. When $m_{act} < R$, m is removed from memory. Each time m is recalled, it is *refreshed*, such that $m_{act} = D$, and

$$d = 1 - d + \left(d\left(1 - \frac{1}{r^2}\right)\right)$$

where r is equal to the number of times that the exchange has already been refreshed. Therefore, an item stored but never recalled will have a high value of m_{act} for a short time before being forgotten, but items that are refreshed before being forgotten will take longer to forget. Also, as people tend to recall more beneficial information, a feedback loop is created simulating the ability to recall more beneficial items when agents retrieve items based on m_{value}. Each agent possesses a separate memory for actions, Q, and other agents, P. Over time, this results in a stable collection of actions and partners tagged with values that represent their usefulness to the agent in maintaining beliefs.

At the beginning of each time step, agents select either the local or global behaviour, each of which contributes to either greater local or global connectedness respectively. Local is selected when $s < f$, otherwise global is selected. However, local is the default behaviour for the first ten time steps in order to socialise agents into a group and build up a store of partners and shared solutions.

Interaction

The process undertaken at each time step is shown in Figure 3. Firstly, agents are updated before any interaction takes place. For each belief, v is set to e prior to updating, and then e is updated so that $e = c$. This means that the value of v can be used as a stable indicator of an agent's stress level through the remainder of the time step, against which changes in e can be compared to determine whether these changes have benefited the agent. Memories P and Q are also updated, and a behaviour is selected to determine how the agent will interact with other agents for the remainder of the time step. Each behaviour consists of two processes: *initiating*, where the agent offers an action to another agent, and *receiving*, where the agent on the receiving end of an initiation decides whether or not to accept the offered action. For the remainder of the time step, agents are selected at random to conduct one of A interactions, either through initiating an action, or both receiving and accepting an action. In order to implement direct reciprocity between agents, i bears the cost of initiating the action even when j rejects the offer (Nowak, 2006). This means that initiating always counts as an interaction for i regardless of whether or not the action is accepted by j, but receiving only counts as an interaction for j when j accepts the action. When initiating an action, each agent,

i, selects or creates an action and then offers this to a partner agent, *j*. If *j* has partaken in less than *A* interactions and *i* has not yet initiated an action with *j* in the current time step, then *j* is considered to be *available* to interact with *i*. If *j* is available and accepts the offer then the action is performed. Agents do not perform interactions consecutively, thus allowing other agents to initiate actions with them in the same time step, as shown in Figure 3.

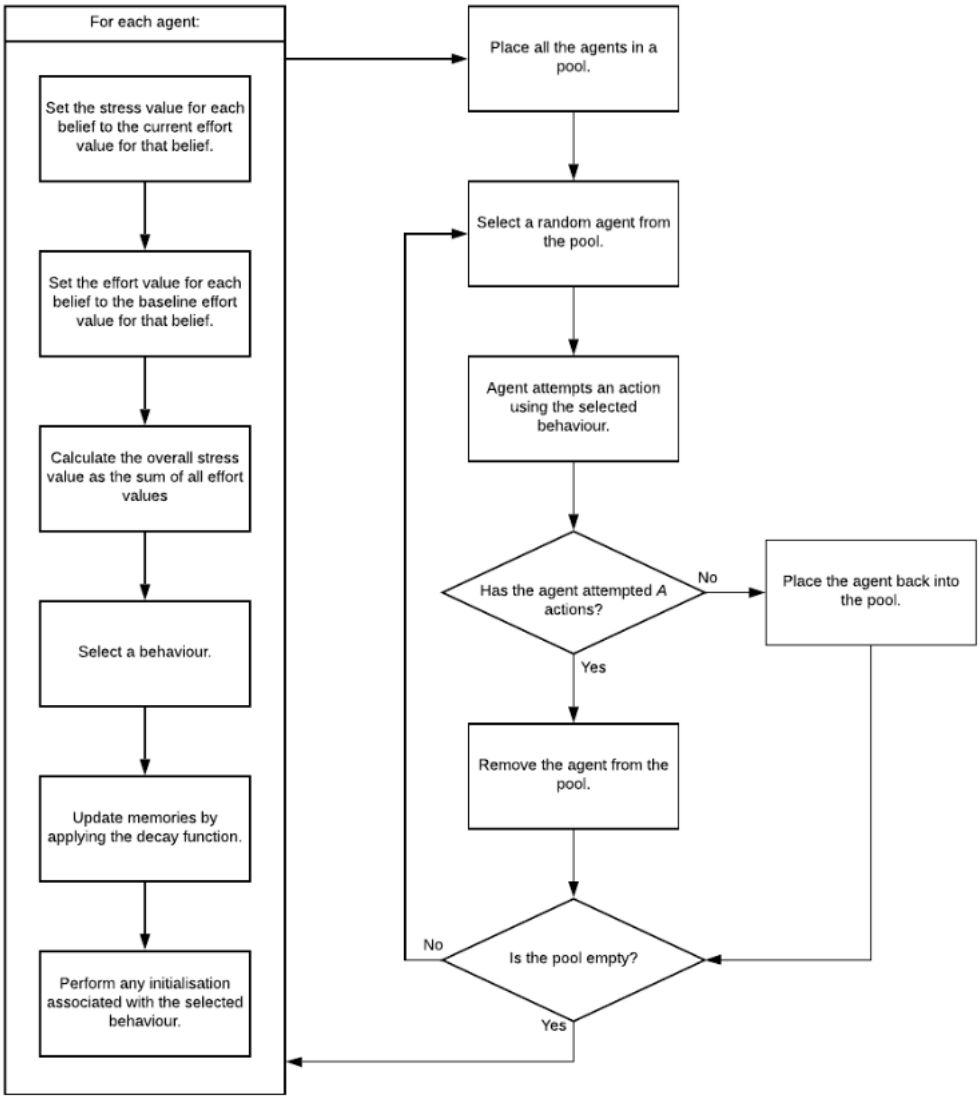

Figure 3. A flowchart showing the processes that occur in each time step.

Actions that are accepted indicate mutual support in addressing doubt associated with the relevant belief, which is represented by subtracting the respective values of *x* from *e* for each agent. Both agents then calculate a value, *g*, as the difference in *s* before and after conducting the action, such that higher values of *g* represent actions that have had greater success in alleviating overall stress. After this, each agent adds the other to *P* (or refreshes it,

if they are already present) and the action is added to Q, using g in both cases to indicate the benefit of the interaction. In doing so, a new p_{value} and q_{value} for each item is calculated as a moving average of the past five values entered as a means of dampening trivial fluctuations in support.

In order to maintain direct reciprocity, both rejected actions and rejecting agents are added to Q and P respectively with $g = 0$. In this way, agents can reciprocate the efforts of other agents in supporting mutually held beliefs when those agents' p_{value} is greater than 0, as this suggests that they have accepted the agent's actions in the past (Nowak, 2006). Agent interactions are recorded, and indicate an edge on a network graph. Thus, a social network graph can be generated at the end of each time step.

Agents select and perform actions according to the following behaviours that are selected at the beginning of each time step. Each behaviour represents a different approach to adopting and removing beliefs, but for both behaviours, s is updated when a belief is removed, and if there are no beliefs remaining, a new one is created. Also, when a belief that was previously removed is restored, the values associated with that belief at the time of removal are retained in order to preserve the level of doubt associated with the discarded belief.

Local

As this action is performed when $s >= f$, it represents an affiliative response to stress that promotes ingroup preferences and outgroup bias, and reflects the low-connectivity phase. Therefore, before any interactions occur in a given time step, agents selecting this behaviour identify ingroup members as transitive members of their local network. Transitivity is a common feature in social networks where each person is more likely to associate with another if they have a relationship with a third person in common (Newman & Park, 2003). To identify group members, a given agent, i, identifies ingroup agents by selecting each agent, j, in P with $p_{value} > 0$, and calculating a value, z, for j as the number of common agents in both P_i and P_j. In order to conform to ingroup belief preferences at the expense of outgroup beliefs, agents remove beliefs that are not held by any ingroup members.

When initiating actions, agents select an action in memory with the highest q_{value} containing both the available ingroup member with the highest z value and the belief with the highest level of v. If no such action exists, a new action is created with the ingroup member and the belief. If no ingroup members are available, then no actions are attempted; otherwise the selected or created action is offered to the selected ingroup member.

When receiving actions, only those actions offered by an ingroup member with a belief that has not previously been removed are accepted. If the receiving agent does not possess the belief associated with the offered action, it is added before accepting. In this way, agents restrict their interactions to ingroup members, but are open to adopting beliefs held by ingroup members as a means of conforming to the group.

Global

This behaviour is initiated when $s < f$ and represents efforts to maximise gains and interact with outgroup agents that characterise the high-connectivity phase. Therefore, when initiating, agents search Q for an action addressing the belief with the highest value of v, and an available agent in P. If an action is found, agents seek to improve on it by generating a new action with the same agent and belief when the q_{value} of the selected action is less than $\sim U([0,1])$. However, if no action can be found, the agent attempts to interact with an outgroup agent by selecting a random agent that is not contained in P as a potential high-status interaction partner. In this context, where agents strive to balance competing demands of multiple relationships, beliefs, and levels of stress, status can be thought of in terms of low perceived stress levels. Therefore, if the randomly selected agent, j, has a level of stress lower than that of the agent, i, and all the agents contained in P, then i will attempt to learn from j by adopting the belief held by j with the lowest value of v less than zero. If a belief is adopted, an action is then created with j and the selected belief.

When receiving actions, agents accept actions addressing held beliefs as well as actions addressing unknown beliefs as a means of maximising opportunities. In order to improve on maintaining beliefs and relationships that may still have some potential, agents are also open to adopting previously held beliefs as long as the level of doubt associated with the belief does not exceed their stress threshold i.e. the last value of v for the removed belief is less than f. When this is the case, or if the agent has never held the belief before, the belief is added before accepting the action.

Hypotheses

The aim of this study is to examine the role of stress in the persistence of beliefs in social networks. To do this, we created an ABM informed by theory and empirical research, in which agents display a rise in stress resulting from difficulties in maintaining mutual support for their beliefs with other agents (Jost et al., 2008). The ABM will allow us to test a number of specific hypotheses. First, it is argued that individuals with higher stress thresholds tend to maintain a greater number of relationships (Baron & Franklin, 2016; Chiu et al., 2017;

Sherman et al., 2012), thus providing more opportunities for mutual support in sustaining beliefs (Lee et al., 2014). Second, the literature suggests that individuals with lower stress thresholds tend to maintain relationships that provide them with support for mutually held beliefs (Jost et al., 2008), but that this support is biased towards ingroup members (De Dreu, 2012; Onaka et al., 2012), which also contributes to belief persistence. To explore these hypotheses, agents in our model will seek support for their beliefs from ingroup members when their level of stress rises above a threshold, and with both ingroup and outgroup members when it falls below the threshold.

The literature on social networks provides a number of measures that can be used to test our hypotheses, and we use the following to identify features relevant to these theoretical predictions:

Clustering is to the degree to which nodes that are connected in a network share connections to other nodes, and represents social situations where individuals have friends and acquaintances who also know each other. For this reason, it is often used to identify groups in networks (Newman & Park, 2003), while low levels of clustering indicate more diverse connections to other nodes.

Degree centrality is the number of nodes that a given network node is connected to. Higher values indicate a greater number of connections to other nodes and are associated with belief persistence (Hahn et al., 2018).

Persistence is the mean length of time that the beliefs held by an agent have been present in the simulation, and is used to identify agents that have played some role in maintaining persistent beliefs.

Hypothesis 1: Based on the prediction that individuals with higher stress thresholds tend to maintain a greater number of relationships that provide more opportunities for supporting beliefs, there will be positive correlations between degree centrality and persistence, and between degree centrality and stress threshold.

Hypothesis 2: Based on the prediction that individuals with lower stress thresholds tend to maintain relationships within groups that provide support for mutually held beliefs, there will be a positive correlation between clustering and persistence and a negative relationship between clustering and stress threshold.

Hypothesis 3: Based on the prediction that individuals lower stress thresholds and individuals with higher stress thresholds both contribute to the persistence of beliefs, there will be no correlation between belief persistence and stress threshold.

Model Exploration

To be able to reliably observe system performance and track key measures such as clustering and stress, a benchmark model was identified (ten Broeke, van Voom, & Ligtenberg, 2016) that exhibited a balance of clustering and modularity indicative of a social network with both local and global connectivity and an overall reduction in stress among agents. This decline in stress provides evidence of learning and adaptation through the mutual selection of sustainable beliefs, actions, and relationships that allows agents to regulate their stress levels. Eventually, most models are expected to reach a point at which the majority of agents are able to maintain their beliefs through a stable network of relationships and shared actions that keep stress levels down. The following measures relevant to the hypotheses were used to determine that the system displays a stable progression towards lower stress and greater connectedness, leading to a stable state with little aggregate change:

Stress is mean level of stress displayed by the agents. Stress is expected to rise when agents do not find partners that can sustain their beliefs, or create effective actions, and falls when these are accomplished.

Behaviour is the proportion of agents performing the global behaviour, the inverse of which is the proportion of agents performing the local behaviour. This is expected to remain low as stress level, rise, and then rise as stress falls.

Clustering is the mean clustering coefficient of all the agents, with the clustering coefficient for each agent calculated as the proportion of connecting agents who are also connected to each other (Newman, 2003). This is expected to fall as more stable outgroup connections are formed.

Modularity indicates the degree to which agents are clustered into groups with few outgroup connections and is calculated using the Louvain method (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008). Although similar to clustering, in a complete network where all agents are connected to other agents, clustering is equal to 1, while modularity is equal to 0. This is initially expected to be high, but to decrease over time as more outgroup connections are formed.

Using a model with 300 agents, the means of these measures at intervals of 100 ticks over 30 random seeds are shown in Figures 4 and 5.

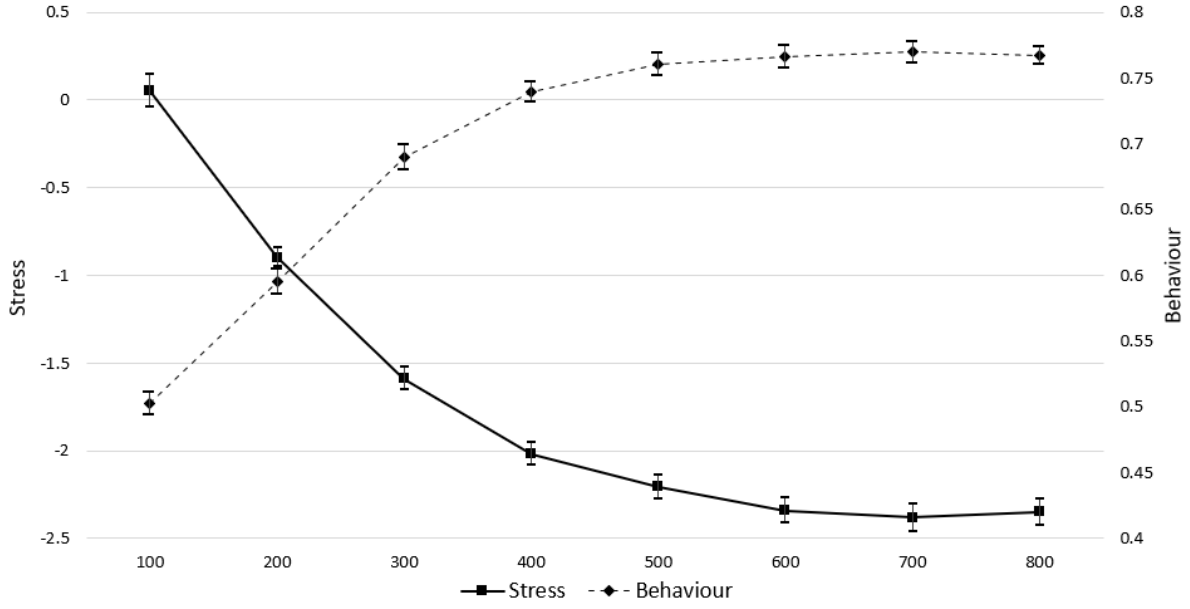

Figure 4. Mean measures of stress and global behaviour over 30 random seeds with 300 agents.

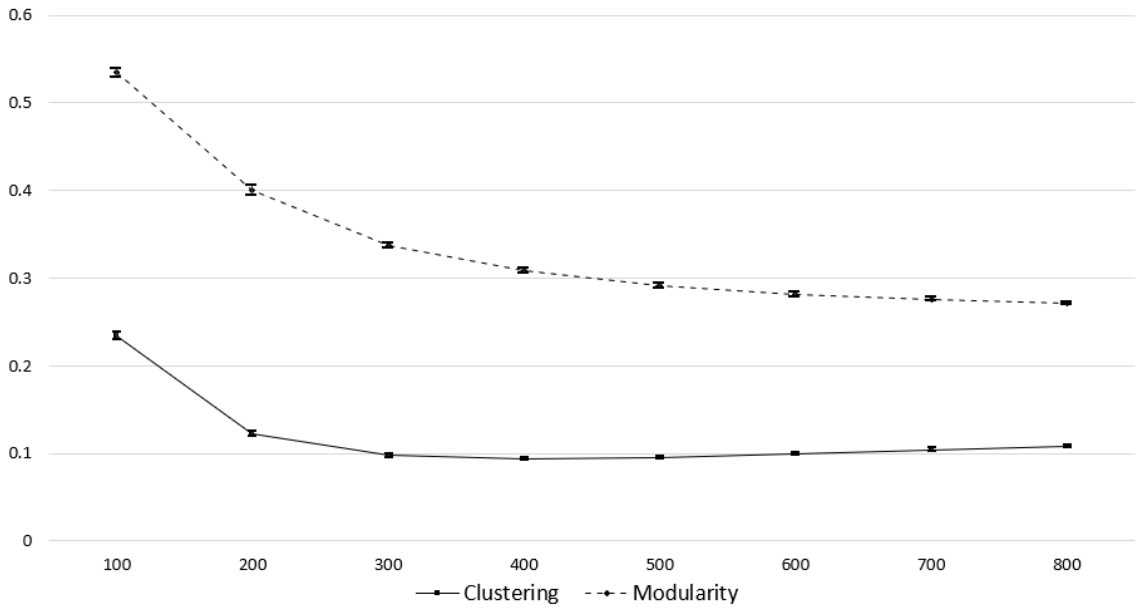

Figure 5. Mean measures of clustering and modularity over 30 random seeds with 300 agents.

These data show that agents typically moderate their stress and increasingly adopt global behaviour as a result, leading to a gradual decline in network features associated with local behaviours such as clustering and modularity. By the time the model settles into a stable

state at t = 800, less than a quarter of agents enact local behaviour, and the model appears to be in a global state, as shown in Table 1.

Table 1.

Descriptive Statistics for Measures of the System

Measure	M	SD
Behaviour	.77	.05
Clustering	.11	.01
Modularity	.27	.01

Taken together, these results from the benchmark model suggest that once agents have been socialised into their local groups, new actions are created to maintain shared beliefs. However, due to the random values allocated to actions, these are limited in their ability to maintain beliefs, and as a result, stress rises, increasing the selection of local behaviour. A process of selection then occurs among partners, actions, and beliefs, where those that incur increases in stress and are not shared by ingroup members are lost. Reducing beliefs to those that can be mutually supported by group members also reduces stress levels, leading eventually to adoption of global behaviour. The focus on improving actions and sampling beliefs from outgroup agents raises the possibility of acquiring more sustainable beliefs and improved actions for existing beliefs, but eventually results in the acquisition of more beliefs and partners than the agent can support, and stress rises again. However, as actions have improved and the composition of the group may have changed, the ability to sustain ingroup beliefs gradually grows, driving stress down. Eventually, after t = 400, most agents have acquired a set of beliefs and partners that are easy to sustain, and there is little significant change in aggregate measures after this point.

Hypothesis testing

Correlations between degree centrality, persistence and stress threshold were obtained in order to test the hypothesis that individuals with higher stress thresholds tend to maintain a greater number of relationships that provide more opportunities for supporting beliefs. Similarly, the hypothesis that individuals with lower stress thresholds tend to maintain relationships within groups that provide support for mutually held beliefs was also tested by

obtaining correlations between clustering, persistence, and stress threshold. A final correlation between persistence and stress threshold was obtained in order to test the hypothesis that people with high stress thresholds and people with low stress thresholds both contribute to belief persistence. These correlations and partial correlations were obtained from 30 iterations of 300 agents each, and are displayed along with the relevant descriptive statistics in Table 2.

Table 2.

Correlations at Benchmark Conditions.

	4	3	2	1
1. Degree Centrality	-.09	.49 (.62)	-.03	
2. Clustering	.48	.42 (.31)		
3. Persistence	.46 (.45)			
4. Threshold				
M	0.01	337	.12	16.28
SD	0.86	140	.07	11.59
N	9,000			

Note: All correlations are significant at $p < .01$. Partial correlations are displayed in brackets.

These results show moderate positive correlations between degree centrality and persistence ($r = .49$), and between clustering and persistence ($r = .42$). There is also a moderate positive correlation between persistence and threshold ($r = .46$). However, there is only a very weak correlation between degree centrality and threshold ($r = -.09$), but a moderate positive correlation between clustering and threshold ($r = .48$). The unique contributions of each variable to persistence indicate a high degree of unique variance contributed by degree centrality ($r = .62$), but less so of clustering ($r = .31$). Furthermore, almost all of the variance contributed by the stress threshold is unshared ($r = .47$). These results are robust across a number of parameter values indicated in Table 3.

Parameter sweeps of the model indicated that agents were largely included in the network when values of A were greater than 12. With no theoretical reason for setting *T* at any value besides 0, a parameter sweep was conducted on *V*, *D* and *R* to determine the bounds of the model at which these results were stable, as shown in Table 3.

Table 3.

Parameter Values for the Benchmark Model

Parameter	Lower Bound	Benchmark Value	Upper bound
V	1.30	1.50	1.50
D	.22	.30	.30
R	<.01	.20	.20

These values show that the relationships between social network structures, stress threshold and persistence in this model depend on the combination of constraints on heterogeneity of stress thresholds and memory. When *D* and *R* high, memories of decay and are removed quickly, and agents are unable to maintain relationships with other agents or store beliefs to the point where they can be mutually supported. However, the model runs to a stable state with little change in network characteristics, and both modularity and clustering are fairly low. In combination with low aggregate levels of stress, this suggests that the networks generated are highly connected, thus reducing the capacity for moderate to high correlational measures involving clustering.

Discussion

The aim of this study was to test theoretical predictions using an agent-based model. In particular, the role of stress in belief persistence was examined in relation to network effects of degree centrality and clustering. The hypothesis that degree centrality would be positively related to belief persistence was met, as was the hypothesis that clustering and belief persistence would also be positively related. However, the hypothesised lack of a relationship between belief persistence and stress threshold was not met, as there was a moderate correlation found between them. Furthermore, the hypothesised relationships between degree centrality and stress threshold, and clustering and stress threshold were not met, as the correlation between degree centrality and stress threshold was very weak, and the correlation between clustering and stress threshold was positive rather than negative.

The zero-order and partial correlations suggest that stress threshold, degree centrality, and clustering all contribute somewhat independently to belief persistence in this model. This

provides support for the theory that belief persistence can occur among individuals with low stress thresholds clustered into groups, and well as those with higher stress thresholds sustaining both ingroup and outgroup relationships. This aligns with similar results found in social network studies indicating that both clustering and degree centrality can contribute to belief persistence (Grow, Flache, & Wittek, 2017; Hahn et al., 2018), along with the claim by SRT that beliefs persist through the mutual support of socially significant others, (Hardin & Conley, 2001; Hardin & Higgins, 1996), while also accounting for the role of oxytocin in promoting ingroup relationships in response to stress (De Dreu, 2012; Onaka et al., 2012). These results also indicate that degree centrality contributes to belief persistence by allowing individuals to draw support from a diverse range of relationships, as suggested by Lee et al. (2014). Therefore, while individuals may adjust their beliefs to fit those of ingroup members, it may also be the case that outgroup members are selected based on their ability to support existing beliefs, and the unique contribution of degree centrality in the results shows that this can occur independently of one's stress threshold.

The results also show that stress threshold does have a unique contribution to belief persistence over and above that of network effects, and this is likely due to the increased ability of agents to sustain beliefs that have higher levels of doubt. As a result, these agents relied less on support networks to sustain beliefs, and they persisted due to individual differences in stress tolerance between agents rather than social factors. This also accounts for the weak correlation between degree centrality and stress threshold, as many agents are in a position to regulate stress effectively, despite a low stress threshold, due to the number and variety of social connections maintained through degree centrality. However, this does not explain the positive correlation between clustering and stress threshold. One explanation for this may be that when agents with high stress thresholds do perform local behaviour, a stable cluster of mutually supportive agents forms, such that when global behaviour is performed, there is no need to seek support from outside the group for beliefs that cannot be sustained.

There are a number of limitations to the model, many due to the lack of an ontology or semantic structure to the set of beliefs generated by the agent. A more valid model reflecting the reality of social belief systems would include a logical structure, such that a given belief would be contradicted by another (Bicici, 2006). This simulates the realistic constraints on belief adoption posed by the logical contradictions of the semantic structure of the belief system in addition to the effect of social pressure that occurs in our model (Clark, 2007). Furthermore, consensus and disagreement often occur when beliefs are associated with context-specific actions (Brigido, 2014), but our model was based purely on a more

abstract belief system independent of action. These features were not included due to constraints on model complexity. However, having established a range of baseline parameter settings in this model, a simpler model can now be created that will allow for the increased complexity of a semantic belief structure or context for belief. It is therefore recommended that this model be developed further to include this, and thus shed greater light on the role of social division in an ideological or resource-allocation context, for example.

Further implications

Implications of this model can be discerned from the use of the local and global behaviours that agents select in accordance with their level of stress. Agents sought to improve on actions that sustained beliefs in the global behaviour when stress was low, which acted as a feedback loop in allowing these agents to use these improved actions to maintain lower levels of stress. However, other factors may also result in feedback loops that contribute to belief persistence. For example, people are more likely to perceive information as being valuable from those who are perceived to be knowledgeable (Borgatti & Cross, 2003), as well as those who are high in education, but low in Neuroticism (Klein, Lim, Saltz, & Mayer, 2004). This suggests that individual differences in cognition may also be important in determining network centrality, with those individuals having a greater ability to retain and use knowledge attracting a greater range of potential partners seeking information. Moreover, stress increased in our model with the proliferation of multiple beliefs, and therefore, it may be that greater cognitive ability in entertaining a broader range of beliefs without experiencing stress is a factor in the relationship between network centrality and belief persistence.

The ability to discern both individual and social sources of belief persistence and the spread of information has implications for gaining an understanding of how these interrelate. For example, considerable research has shown that the personality trait of Extraversion is associated with degree centrality, while Openness to Experience is associated with diverse network ties (Selden & Goodie, 2018). With the ability to discern changes in network and agent states simultaneously, ABM has the potential to examine theoretical predictions regarding the bi-directional relationships between individual and network effects, such as Extraversion and degree centrality, that may contribute to a clearer understanding of the relative contribution of each to phenomena such as belief persistence or the spread of misinformation.

In conclusion, it is clear that this model provides support for a dual role of clustering and network centrality in belief persistence, and extends SRT by clarifying the role of stress in distinguishing the between ingroup and outgroup interactions, both of which play a role in belief persistence across the social network. In particular, it suggests that stress plays a greater role in belief persistence through ingroup relationships, while the relationship between degree centrality and belief persistence is less dependent on stress. This implies that system justification, in which individuals maintain beliefs supporting a system that works against their interests (Jost, 2004), may be more likely to occur through ingroup relationships, thus clarifying the distinction between ingroup and outgroup relationships when combining SJT with SRT. Furthermore, the model indicates that individuals exhibiting low stress levels associated with holding beliefs are attractive to others seeking support for their beliefs, suggesting that high-status leaders with multiple connections to local networks, such as a politician or a pastor, could play a key role in belief persistence and system justification.

Finally, this study demonstrates the utility of ABMs in clarify elements of existing theories, and highlights the potential of this approach for other studies. It also shows that exploring results further by introducing a semantic or ontological belief structure could provide additional insights beyond the initial research question, thus supporting ABM as useful research tool in social psychology.

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Foreword to Paper 3

In the third paper, the idea of a computational artefact for research purposes is extended to games, with a key difference being that human players replace agents in the model. Computer games have only recently begun to realise their potential as research artefacts, due to developments in technology that include the ability to collect large volumes of data over the internet from mobile devices. This ability to simultaneously record behaviour from multiple players is important to the CAS approach, as process-based explanations require a method in which changes in behaviour across numerous actors over time can be observed with a high degree of detail. Furthermore, the distribution of games across devices means that changes to games can be made without involving the player, providing researchers with the flexibility to vary conditions by modifying games through selective updates.

This flexibility in modifying games is similar to the ability to extend ABMs, and illustrates support for the efficiencies offered by design sciences. However, this paper also argues for the integration of design sciences and conventional methods, and offers a number of insights into how both games and ABMs can be used with conventional approaches to increase validity and gain insights into social and psychological processes that are difficult to address using laboratory studies.

This paper also argues that the production of bespoke games offers significant advantages to researchers, which is made possible by the availability of game engines that increase the efficiency of game development, allowing researchers and developers to produce engaging and compelling games that players enjoy on a comparatively low budget with respect to many commercially available titles. Therefore, this paper also addresses the lack of literature on the design, development and use of purpose-built games that function both as research instruments and as engaging forms of culture and entertainment, particularly in relation to the study of CAS.

Design Sciences in Social Psychological Research: Using Computational Models and Serious Games to Complement Existing Methods

Abstract

The emerging field of design sciences has the potential to extend and complement existing methods in social psychology through the use of computational models and serious games. Agent-based modelling can be used to examine the relationship between individual behaviour and social processes, while serious games combine increased participant motivation with the potential to capture rich datasets of behaviours occurring over time. When used together, these methods complement existing methods by informing models, confirming results, and cross-validating outcomes of alternative approaches. However, the artful combination of engaging gameplay and validity requires a dedicated development team integrated into research teams and an iterated development environment where research and development are intertwined to produce a family of models and games. With an initial investment of resources, a foundation for design sciences can be built that offers enormous potential to researchers investigating individual and social phenomena.

Introduction

Methodology in social psychology has long been dominated by field and laboratory experiments that have provided a wealth of knowledge, but have neglected to provide process-based accounts or generative descriptions of phenomena (Back & Vazire, 2015; Smith & Conrey, 2007). Furthermore, while it has long been acknowledged that social psychology is an area of study where interactions occur at multiple levels of analysis (Reynolds et al. 2010) conventional approaches are often unsuited to examining these interactions (Eberlen, Scholz & Gagliolo, 2017). For example, social-psychological accounts of social change tend to focus on measuring the variance explained by predictor variables, such as social identification, on dependent variables related to social or group phenomena (Smith, Livingstone, & Thomas, 2019). However, experimental approaches in social psychology are unable to capture the multilevel, reciprocal, and temporal causal mechanisms that define the relationship between individual's internal states and social processes (Vallacher, Nowak & Read, 2017). Recent approaches to gaining a more granular understanding of social-psychological processes have made use of advances in technology to sample behaviour over time through intensive longitudinal measures (ILM). By recording participants' behaviours and self-reported thoughts and feelings at short intervals, rich

datasets of individual behaviour, social interactions and relationship structures can be acquired (Bamberger, 2016). However, the intrusive and demanding nature of these measurement schedules can often result in issues of retention, reactivity and poor-quality data due to participant fatigue or complacency (Barta, Tennen & Litt, 2011), while from the researchers' perspective, the implementation and maintenance of data collection can be resource-intensive (Pomerantz, Ruble, & Bolger, 2008) and costly (Cook & Groom, 2008). Many of these issues relate to a fundamental disconnect between the interests of the researchers and the participants, with the latter often less motivated by the external validity of the study than the former.

However, the emerging field of *design sciences* (Klabbers, 2006) offers a means of overcoming these obstacles by using digital artefacts such as computational models, which do not rely on human participants, and serious games, in which data collection is motivated by the intrinsic interests of participants. The term *design sciences* refers to the construction of artefacts to both generate and collect data from complex, dynamic phenomena (Klabbers, 2006). In contrast to *analytical sciences*, where the aim is to derive predictable rules defining relationships between variables, design sciences focus on examining processes where actors have the capacity to form their own rules and change them according to experience. Computational artefacts can be created that are capable of representing relations between actors and changes to those relations over time. These actors may be computational agents simulating generative social processes that cannot be recreated in the laboratory (Smith & Conrey, 2007), or human participants interacting through virtual social environments (Schönbrodt & Asendorpf, 2011). Agent-based models (ABMs) are purely computational models of social processes in which behaviour of individual agents and the emergent social structure can be examined simultaneously in order to understand the relationship between them. Similarly, computer games place human participants in virtual environments that motivate behaviour so that both individual and collective action can be recorded in areas such as status (Korsgaard, Picot, Wigand, Welpe, & Assmann, 2010), social networks (Ducheneaut, Yee, Nickell, & Moore, 2006), and collective action (Barreteau, Bousquet, & Attonaty, 2001).

In this paper, we extend existing arguments for the use of ABM and serious games in social psychology by arguing that the integration of these two approaches with more conventional methods offers greater validity in addressing research questions relating to the interaction between individual differences and social structures. In doing so, we present a number of challenges in integrating these approaches and argue that these challenges can be

addressed through the development of research ecosystems of serious games, computational models, and conventional laboratory methods. In particular, bespoke applications that harness the increasing popularity and acceptance of computer games across all age groups (Järvelä, Ekman, Kivikangas, & Ravaja, 2014) would provide researchers with the opportunity to build a foundation for the future of design sciences in social psychology.

Analytical vs design sciences

The relationship between conventional research methodologies and the use of computational modelling and games can be understood as the distinction between analytical and design sciences (Klabbers, 2006). Analytical science refers to approaches where experiments isolate and control variables with the aim of inferring uni-directional causality from one variable to another, or, with more relaxed constraints, a mere relationship between the two. For example, when a correlation of .50 is found between rated attractiveness of couples, it may be inferred that people select partners based on how similar they are in perceived attractiveness, but establishing this correlational relationship does not tell us whether or not this is indeed the method by which people select partners (Smith & Conrey, 2007). However, when a computational model of artificial agents seeking partners based on similarity in attractiveness fails to produce this correlation, and instead produces it when agents seek the most attractive partners first rather than those that are similar, an alternative explanation is offered. By examining the process by which the model generates this result, it can be determined that the assortative outcome results from successive changes in the range of available partners that occurs as more attractive agents pair off first (Smith & Conrey, 2007).

The difference between these approaches points to underlying assumptions regarding the actors in each. Approaches taken in analytical sciences are often based on the assumption that actors produce outputs from inputs according to stable, predictable rules from which theories may be developed. Design sciences, on the other hand, assume that actors are capable of creating their own rules, and that these rules may change over time as a result of repeated interactions with other actors (Klabbers, 2006). For instance, game players update their strategies as they learn more about the mechanics of the game, which in turn, may change according to player's actions, through dynamic difficulty adjustment for example (Lach, 2017). In ABMs, agents may adopt different strategies throughout the simulation by learning from other agents (Xu et al. 2019). Unlike analytical sciences, where variation in the strength of the relationship between individual behaviours and social outcomes is allocated to

unexplained variance or error, design sciences allow for multiple explanatory factors through recursion, learning, temporal adoption, and interaction. Therefore, design sciences focus on constructing computational artefacts that represent relationships between actors and changes to those relationships that occur over time as a result of recursive, internal changes to the way actors process information. This means that while an aggregate of individual actions may appear to result in a collective outcome in principle, the practical consequences of each action over time results in changes to the scope of possible future actions, which can then lead to unexpected outcomes (Smaldino, Calanchini, & Pickett, 2015).

Social psychology is the study of the interaction between the thoughts and behaviours of individuals and the real or implied presence of social situations (Cook & Groom, 2008; Reynolds et al., 2010). Design science has characteristics that make it an ideal approach for studying this interaction in terms of the relationship between individuals and social groups, moderated and mediated through a variety of psychological constructs, such as motivation and personality. Traditionally, explanations of fundamentally interactionist phenomena tend to be process-based descriptions of how changes in global variables are generated by mechanisms of interaction between individual elements of a system. An example of this can be seen in the study examining the assortative matching of couples discussed previously. When the most attractive actors pair off first, the remaining actors are more limited in the range of partners they may choose from, and the most attractive potential partners change. Thus, the global phenomenon of assortative matching among couples by attractiveness is driven by recursive choices made over time between an increasingly smaller group of actors. Furthermore, these individual-level interactions may involve bidirectional relationships in that person A's behaviour forms person B's social environment, which in turn may trigger behaviour in person B that then becomes the social environment for person A. These relationships often occur as feedback mechanisms in which repeated interactions between individuals mutually reinforce or dampen attitudes or behaviours, resulting in self-organising and self-sustaining relationships between individuals and social groups (Smaldino et al., 2015). As the process of satisfying competing demands completes, the social system self-organises into a global configuration with properties that cannot be reduced to individual behaviours or characteristics, and can only be explained by describing the process by which interactions between individuals produced the emergent properties.

Despite their differences, both analytical and design sciences are complementary and can inform each other. For example, analytical sciences focus on identifying common characteristics or behaviours that shape interactions as independent variables that are

manipulated in order to ascertain changes in the emergent phenomenon, or dependent variable. This is useful for identifying variables that are relevant to the phenomenon, and informs the construction of artefacts in design sciences that examine the role of independent variables in generating the phenomenon of interest. These artefacts may also clarify bidirectional relationships between variables, for example when individuals interact to produce a given social structure that, in turn, imposes constraints on those actions to produce a mutually sustaining relationship (Bruch & Atwell, 2015). These explanations may then be useful for generating research questions that drive the development of further analytical studies (Smaldino et al., 2015).

Examples of design sciences

Agent-based modelling

Agent-based modelling (ABM) is a common approach in design sciences that is useful for deriving generative, process-based explanations, of which the Schelling segregation model is a good example (Schelling, 1969). In this computational model, residential segregation is examined by creating a two-dimensional grid of virtual agents that perform one of two possible actions during each time step: to remain in their location or move to another. This decision is based on a single value that determines the threshold of dissimilar neighbours that will trigger a move to a new, random location. Therefore, the behavioural output of each agent is contingent on the inputs from actions of other agents, and each move has the potential to initiate a cascade of moves that ultimately results in the spatial segregation of agents over a wide range of starting positions and variations to the threshold. Thus, the majority of agents find themselves completely surrounded by agents of their own kind, with no alternative locations available that lie below the threshold of dissimilar neighbours. This illustrates a phenomenon where even though individual actions are undertaken with a fairly high tolerance of dissimilarity, they nonetheless converge on a global solution that constrains agents' ability to exercise this high level of tolerance. It is important to note that this simplified model does not claim to provide a fundamental answer to the question of why residential segregation occurs, and remains open to the influence of other variables such as economic inequality. However, it does offer a competing causal mechanism (Ylikoski & Aydinonat, 2014) that contributes to an explanation of the relationship between individual preferences and an emergent social structure of residential segregation. The mechanism of tolerance and movement that drives this relationship can be further examined under a variety of conditions by systematically adjusting model parameters and using Monte

Carlo sampling to determine regularities in outcomes over numerous models. These models exist in a parameter space that can be extended by incorporating new variables or adjusting further parameters, resulting in a family of models that illustrate the theoretical contributions of different variables during the process of emergence as a collection of related but varied representations of a given phenomenon (Ylikoski & Aydinonat, 2014).

An example of a family of ABMs that have contributed to an understanding of cooperation are the Prisoner's Dilemma (PD) models from behavioural game theory (Gintis, 2009). PD models simulate situations where pairs of individuals decide whether to cooperate with each other without knowing the intention of their partner. Each agent receives a payoff according to the combination of their own and their partner's intention to cooperate or not (defect). When both agents cooperate, both gain a moderate payoff, and when both defect, the mutual payoff is smaller. However, if one agent cooperates and the other defects, the cooperating agent gains nothing, while the defecting agent wins a large payoff. On the face of it, the most advantageous strategy is to defect, however, this is only the case when agents do not possess the capacity to recall past interactions. When agents are able to recall whether or not their partner has cooperated or defected previously, and they repeat their partners last action, the initial popularity of defection among agents is outweighed over time by mutual cooperation, which has a larger payoff than mutual defection (Axelrod, 1980). By creating variations on this capacity for agents to learn, for example by copying behaviours from other agents that are more successful (Rong, 2013) or popular (Xu et al. 1029), an understanding of how individual interactions result in collective knowledge and cultural evolution can be gained (Traulsen, Semmann, Sommerfeld, Krambeck & Milinski, 2010).

A number of models have also focused more directly on the relationship between microlevel psychological phenomena and macrolevel social structures. For example, Zhao et al. (2015) produced a model illustrating the effect of memory size, spatial configuration, and population size on social network density, while another model by Cho, Mansury, and Ye (2016) shows the influence of relationship formation and dissolution on network density and personal network size that reflects differences in social capital. Like many ABMs, this study abstracted human behaviour to simple rules operationalising complex and multifaceted constructs like personality, in this case representing Extraversion simply as a preference for establishing more connections to other agents. However, given this constraint, there is no shortage of studies indicating a relationship between Five Factor Model (FFM) personality traits and social network position (Selden & Goodie, 2018) that are easily operationalisable in this way.

Despite the apparent success of these and other models, many lack empirical validation, partly due to the difficulty in acquiring relevant data (Troitzsch, 2015). Furthermore, validating simulations in the social sciences is difficult due to the intangible nature of the constructs examined, the representation of time, and the fact that the target phenomena often consist of interactions between multiple processes (Mas, 2019). One solution that has been suggested is to replace the agents in the model with human participants to create *gaming simulations* (Hofstede, Jonker & Verwaart, 2014). When interacting with each other within the constraints of the model architecture, participants generate behaviours and emergent structures that can be compared with the agent-based model to determine how closely agent behaviours reflect human behaviours. Therefore, design sciences can be thought of as a system of computational artefacts that can include human participants to varying degrees, with agent-based modelling representing the removal of human participation altogether.

Computer games

Games are systems of rules providing conflicts that engage players in a way that produces a quantifiable outcome (Salen & Zimmerman, 2004). Therefore, games used in research offer a system of rules providing conflicts to the player that are resolved by performing behaviours of interest to the researcher (Martin, 2018). Often, these games are played under laboratory conditions for relatively brief periods of time, and tend to focus on the needs of the researcher rather than on motivating players. For example, stochastic games, in which players interact though a series of discrete game states offering potential payoffs to each player, focus on modelling real-life situations in economics, political science and operations research (Solan & Vieille, 2015). In contrast, the challenges of ILM require games that are designed to engage the player's interest and motivation over extended periods of time, with short daily recordings over months or even years. Therefore, the aim of the researcher in using games to examine social-psychological phenomena at the behavioural microlevel and the social macrolevel is to seamless marry the mechanism required to generate the target behaviour with the enduring need to motivate and engage the players.

In order to motivate players to the extent that they become absorbed in the game and want to continue playing, the game must offer a system of rules from which meaningful choices emerge. This means that game designers are unable to directly determine the trajectory of play, as meaning emerges out of the possibility space that is explored through the interaction between the player and the system of rules. This relationship is illustrated by

the card game poker, in which bluffing is an integral part of the game, but is not described in the rules. Instead, it emerges as a strategy on the part of players in adapting to the conflict between the affordances and constraints imposed by the rules (Salen & Zimmerman, 2004). For this reason, computer games that motivate the player will often be more dynamic and open-ended than many tasks that are currently employed in decision-making studies, for example.

Designing games that sustain the interests of players over longer time periods also requires attention to the relationship between micro- and macro-decision contexts. Micro-decisions occur at a moment-to-moment level as the player makes individual choices, while at a macro-level, these choices have consequences that shape the trajectory of the game by opening up or closing off further options. Meaningful gameplay that motivates the player and affords a level of complexity necessary for research seamlessly ties together micro- and macro-decision contexts in such a way that players experience a profound sense of tension between the two that encourages further or repeated play, as each individual choice at the micro-level plays a role in shaping the trajectory of the game at the macro-level (Salen & Zimmerman, 2004). For this reason, computer games designed to constantly engage the player over long periods of time will often be more dynamic, varied, and open-ended than many games used in research, such as stochastic or simulation games.

An example of how micro- and macro-decision contexts and the emergence of meaningful gameplay can be useful for researchers can be seen in a study by Jang (2007) into reward distribution in an online community playing *World of Warcraft* (*WoW*). In this multiplayer game, players defeat monsters for rewards that enhance their ability to defeat more challenging monsters. However, as part of the system of rules, the difficulty of the game forces players to join teams that cooperate in defeating monsters. Furthermore, minimal support is given to players in managing these teams, resulting in the use of policies and mechanisms of self-government among team members to maintain a just distribution of rewards accruing from their joint efforts. This means that there are two separate modes of involvement in the game: the core game mechanic of fighting and defeating monsters, which is focused on the system of rules and micro-decision making; and the emergent structure of team member relations that are maintained before and after gameplay, in which rewards are distributed and disputes settled. Discrete, moment-to-moment decisions made during the first mode have significant consequences for the team as a whole in the second mode, which both constrains and enables action in the first mode. The data made available included interviews with team members, archived discussion texts, and live gameplay, providing a more granular

sample of data than is often available from conventional studies. This yielded information on the way in which online communities self-organise and establish social structures such as norms and formal policies, and the relationship between these emergent social processes and factors like group size and task characteristics.

This example shows the potential of games for studying the interaction between individual and social behaviour, as this requires large, rich datasets that include measurements of long-term behavioural patterns (Back & Vazire, 2015). The ability to distribute games as applications on multiple devices and collect gameplay data as it occurs provides an unobtrusive means of conducting ILM relating to behaviour, preferences, and interpersonal processes that is not bound by geographical limitations. This is similar to existing approaches where participants complete surveys asking them to report on past behaviour, but games on mobile devices acquire a sample of actual behaviour over time, both individually and collectively. It is also important to note that in this example, the game is a commercially-available product designed purely for entertainment i.e. to engage the player. While published games of this kind may occasionally happen to offer opportunities for research, it is more efficient to intentionally design entertaining games that also capture the target behaviour.

Applications of design sciences

Establishing validity

Design sciences have a role to play in complementing existing approaches by addressing shortcomings in validation. Controlled laboratory experiments, computational models, and games all possess strengths and weaknesses in terms of validity, but together they provide opportunities for cross-validation that could improve the generalisability of results. For example, although ABMs can provide computational models that generate structures of social relationships from individual behaviours, their construction should nonetheless be informed by empirical evidence (Smith & Conrey, 2007). These two approaches can work well together, but ABMs are limited in that agents cannot attain the level of complexity afforded by human participants, making it difficult to establish external validity. Moreover, conventional studies often identify numerous factors involved in the production of a given phenomenon, but including all of these factors in an ABM can result in models that are too complex to offer information of any real value (Wooldridge & Jennings, 1998). Games provide a means of addressing the shortcomings of both approaches as they use human participants instead of agents, but in a semicontrolled environment focused on the

phenomena of interest. As with more conventional laboratory studies, psychological attributes of participants such as personality and motivation can be measured using self-report instruments, but games offer a means of gathering fine-grained data of behaviour and interaction over time in the same manner as ABMs. Therefore, there is a sense in which games allow for the construction of ABMs where the agents are human, offering a degree of validity unavailable to purely computational models (Hofstede, 2014), while allowing for some degree of control that is common to more conventional approaches. Integrating these approaches into a single research program would therefore allow researchers to conduct ILM studies offering greater external validity than any of these approaches can offer alone.

An example of the potential for this approach can be seen in studies on the relationship between social network structure and the psychological attributes of the individuals that comprise them. Conventional studies have shown that social networks in lower socioeconomic contexts tend to be smaller, more densely connected, and composed of individuals exhibiting more interdependent self-construal. In higher socioeconomic contexts however, social networks tend to be larger, more loosely connected, and composed of individuals with a more bounded, independent self-construal. This phenomenon is thought to occur through a complex process involving numerous variables related to social class, economic inequality, and the mutual influence between these and individual attributes such as personality and motivation. For example, children adopt behaviours by being socialised into social network structures that promote the adoption of these behaviours, yet these behaviours also facilitate the construction of those same network structures (Carey & Markus, 2017). Despite these regularities, not all children follow the predicted path into adulthood, and not all unequal societies remain so. This displays enormous gaps in our knowledge of the circumstances under which individual differences in personality and motivation impact on social mobility, and how these differences interact with the social environment in reducing inequality (Markus & Stephens, 2017).

Games offer a means of establishing a virtual environment in which these network structures could be reproduced. For instance, players could be measured on psychological constructs such as self-construal prior to beginning the game, and their interactions with other players mapped over time in order to understand how differences in self-construal contribute to social network structures that reinforce inequalities. Once a reliable model has been established, this could then be used to create an ABM that would allow researchers to investigate areas that are not possible in either conventional or game studies.

It is this integration of design sciences with conventional approaches in social psychology that can address shortcomings in the validity if ILM studies through cross-validation between ABMs, games, and existing approaches. Table 1 shows how these three approaches mutually inform each other according to the complexity of the actors and the environment, the ability to gather process data, and the strengths and weaknesses of each approach.

Table 1

Features of ABMs, Games, and Conventional Approaches in Relation to Validity

	ABM	Games	Conventional
Actor	Low	High	High
Environment	Low	Low	Low or high
Process data?	Yes	Yes	Rarely
Strengths	Can identify competing causal mechanisms. Can explore hypothetical situations.	Can confirm the role of competing causal mechanisms. Authentic human behaviour increases external validity.	Can identify relevant variables. Provides measurements of relationships that can be used to establish validity in games and ABMs.
Weaknesses	Artificial actors and environment make it difficult to establish external validity.	Artificial environment limits generalisation to real-world environments.	Offers little information on generative mechanisms.

An example of how these approaches can be combined to validate studies investigating the relationship between individual differences and social structure is as follows. Firstly, data can be collected using conventional approaches in order to determine the key variables in the model relevant to both individuals and observed social structures. This data can then be used to inform the construction of a game designed to produce the target structure among human participants, which can be validated against the data gained from previous studies. The real-time data gained from the game can be analysed for the purposes of constructing an ABM with agent behaviour informed by the game data. This ABM can then be validated to ensure that it not only produces the target structure, but does so in a way that resembles the process undertaken in the game. Once this is done, the model can be used to explore hypothetical situations that would not otherwise be possible due to

expense, practicality, or ethical constraints. Data from these simulations may then provide useful hypotheses for further studies involving games or laboratory studies.

An example of this process can be seen in a study by Ahmad, Borbora, Shen, Srivastava, & Williams (2011) that used data from *WoW* to clarify group formation models proposed in an earlier study by Johnson et al. (2009). The earlier study used an ABM to explore the role of two mechanisms in group formation: homophily, in which groups accept similar members to promote homogeneity; and complementarity, in which groups accept diverse members with complementary skill sets to promote adaptiveness. The target phenomenon was the relative distribution of group size in street gangs and online guilds in *WoW*, which was similar for both datasets, and the ABM indicated that complementarity rather than homophily was responsible for producing the target distribution. However, Ahmad and colleagues (2011) focused on how game mechanics shape the role of each mechanism in group formation, noting that the rules of *WoW* reward diverse teams, while other games contain mechanics that could point to alternative explanations. They focused on *Everquest II*, which, although similar to *WoW*, allows players to own a virtual house in which they can store items. Access to this house can be provided to selected others who can then remove items from the house and return them, thus providing an opportunity to measure the level of trust between players. Incorporating this mechanic into the ABM created by Johnson et al. (2009) showed that a network model of group formation reflecting trust could also produce the target distribution of group size, confirming the existence of another competing causal mechanism alongside complementarity.

Computer games in social psychology research

One of the key challenges in developing serious games is the seamless integration of both player experience and intended outcomes (Boyle, 2014), and this is relevant to researchers in the fundamental dilemma between making a game that participants will want to play versus one that achieves the aims of the study. Creating enjoyable games decreases participant attrition and increases validity by ensuring that players make decisions based on genuine intent rather than out of boredom, malice, or misunderstanding. However, this does not mean that introducing an enjoyable game mechanic that appears to reproduce the target phenomena will be valid. For example, when a virtual disease was mistakenly introduced into *WoW*, researchers saw this as an opportunity to study the epidemiology of real-world diseases. However, the risks and rewards of *WoW* do not map well onto the context of real-world diseases, as emotional rather than physical discomfort is the primary punishment

mechanism, and the experience of death is obviously different when applied to a virtual character rather than a human being. Therefore, players engaged in behaviours that would be less likely to occur in the real world, such as deliberately catching the disease and infecting their friends (Williams, 2010). An iterative development process with frequent prototyping and testing can resolve these issues early, but the challenge remains to ensure that whatever game mechanic is introduced, the interaction between the player and the game system maps onto the target phenomena, for example through meaningful reward and punishment systems.

Motivating players to stick with the game requires a focus on creating games as systems of meaning (Salen & Zimmerman, 2004) linking player actions to outcomes that have consequences the player cares about. Player engagement increases when individual choices have the potential to form a chain of consequences that steer the overall trajectory of the game in ways that players find interesting. The greater the potential game space to be explored, the greater the capacity for the kind of variety, novelty, and surprise that drives continuous or repeated play, and the more likely it is that the data generated from a game exhibiting external validity will reflect that of an individual who is immersed in the real-world environment it represents. However, it is only when this exploration of actions and outcomes also aligns with the phenomena under investigation that the game is able to achieve validity. This is represented in the breach in the example of the disease introduced into *WoW*, as players were motivated to spread the disease to their friends, resulting in the failure of the game to map the negative feedback mechanism that would prevent people from doing so in the real world. It is important to note, though, that introducing a more valid negative feedback mechanism into the game would not solve the problem if it discouraged players from engaging in the game to the point where it compromised player retention. The art of creating serious games such as these is to innovatively create game mechanics that encourage retention by engaging the players with activities that map onto the target phenomena, such that the motivation to continue playing drives the mechanic that produces the target phenomenon in the game (Habgood & Ainsworth, 2011).

This challenge of marrying player motivation with the target phenomenon in game development for research is more easily met in some areas of social psychology than others. One area that is particularly suited to the use of games is the interaction between stable personality characteristics and the situations in which they are expressed (Webster, 2009). Gaining knowledge of how interactions between fundamental internal needs and the diverse situations in which individuals strive to meet them is essential to understanding a range of social outcomes, including occupational success, social status, leadership, the quality and

stability of close personal relationships, and the sense of social embeddedness (Back & Vazire, 2015). However, conventional research methods often struggle to acquire the kind of detailed, temporal data that is needed to advance our understanding of the complex interactions between individual differences and social behaviour, and calls have been made in recent years for the increased use of technology to capture and analyse this data (Wrzus & Mehl, 2015).

Games offer a useful means of gathering more detailed data on the interaction between individuals and situations as they draw on fundamental motivations that are linked to personality. Based on the principle of biology as the foundation of human nature, personality can be defined as an ongoing process of adaptation that fulfils basic psychological needs such as autonomy, competence, and relatedness. These needs can be summarised as two, often conflicting, sets of behaviours: *getting along*, which includes social acceptance, cooperation, and relatedness; and *getting ahead*, which refers to competition for status and the need for autonomy (McAdams & Pals, 2006). Resolving the problems that occur when meeting these needs requires abilities that are often found in personality descriptions, particularly in relation to understanding the motives and abilities of others. For example, Goldberg (1981) suggests that the commonly used FFM personality traits address fundamental questions human beings have of their interaction partners: how socially dominant are they? (Extraversion); How moody are they? (Neuroticism); how cooperative are they? (Agreeableness); how reliable are they? (Conscientiousness); and how open are they to change? (Openness to Experience). These characteristics form the basis of successful interactions, both in terms of the way people evaluate each other and the advantages they provide in facilitating collective adaptation to the environment.

Computer games offer players experiences that reflect needs for competence, autonomy, and relatedness that drive the development of personality. This is particularly true of multiplayer games that require behaviours relevant to social adaptation (Boyle, 2014). For example, all games require some degree of competence and offer players the opportunity to master a skill, acquire knowledge, or meet challenges that fulfil a need for achievement. Games also offer an environment in which decisions can be made, priorities set, and agendas pursued relevant to personal interests, that meet needs for autonomy and the sense that one is in charge of one's destiny. Multiplayer games offer a means of meeting needs for relatedness, particularly Massively Multiplayer Online Games (MMOGs), where players may compete and/or cooperate in attaining goals. Multiplayer games also offer the ability to examine the relationship between personality and social interaction in that they include motivations for

players to both get along and get ahead. Players commonly cite forming relationships through teamwork and a sense of achievement through competition as top motivations for playing MMOGs, which have become so complex that they offer the opportunity to develop the kind of interpersonal skills that are in demand by many employers (Tran, 2014).

An example of how multiplayer games address players' needs can be seen in *WoW*, where success requires a level of social organisation and discipline among teams, or guilds, to ensure that players cooperate in achieving collective goals (Vesa, Hamari, Harviainen, & Warmelink, 2016). The following recruitment notice posted by a guild named *Alpha* seeking new members illustrates the role of personality evaluation and social interaction skills required for players to both get along and get ahead.

> You will want to raid minimum 3 times each week from 19:30 to 24:00 CET. (Alpha raids 4 days a week Monday, Wednesday, Friday, and Sunday 19:30 to 24:00). Grind whatever is needed for raiding outside the raid hours. If you show up without potions, elixirs, flasks and food it is a sign that you don't want to perform at your best and that won't get you membership in Alpha. Able to use TS. Listening required, having a mic and using it preferred. All gear must be enchanted with the best enchants suited for your role. Do not bother to apply with poor quality gems or unenchanted gear. Previous raiding experience is something we are looking for. You should always as a goal want to outperform any veterans in the raid or there is no reason to invite you. You have to be able to handle criticism and learn from mistakes. Willing to accept being benched for certain fights when raid needs new setup. You will be judged on how consistent your performance is. (Vesa et al., 2016, p. 227)

In this post, Conscientiousness is evaluated in terms of showing up without potions, elixirs, flasks, or food, and the requirement for players to perform at their best. Extraversion is inferred in terms of social dominance, both in terms of seeking to outperform veterans and a willingness to accept being benched. Agreeableness in the form of cooperation is also highlighted in terms of being able to listen to and communicate with other team members, as well as handle criticism, which could also reflect a player's level of Neuroticism. Finally, players must display Openness to Experience in learning from their mistakes. *WoW* players tend to fall into two camps according to their strengths and preferences in getting along and getting ahead. Those placing an emphasis on getting along are considered to be more "casual" gamers who pursue harmonious and cooperative group-based interactions, while

“hard-core” players tend to focus more on improving performance and increasing their status as an elite player (Vesa et al., 2016).

This example illustrates the potential for examining behaviour related to personality by recording game events, chat logs, and communications between players, not only for the purposes of identifying behaviours and traits among players, but also for gaining an understanding of how these play out over time and across situations. Furthermore, it offers an opportunity to investigate how these behaviours interact to produce stable group configurations, divisions, and collective differences between groups. An example of this is a study of bonding and bridging social capital by Shen, Monge, and Williams (2012) based on data gathered from *Everquest II*. Bonding social capital occurs when people form relationships in closed, interdependent groups indicative of lower socioeconomic networks, while bridging social capital refers to more open networks of relationships formed beyond the immediate social group that are found more in higher socioeconomic networks (Carey & Markus, 2017). *Everquest II* encourages collaborative play by forcing players to cooperate as characters with limited but complementary abilities, while also allowing communication and trade. Because there is an enormous amount of valuable information available that can only be gained through social learning, players are incentivised to form collaborative relationships with other players that increase individual reward. Shen et al. (2012) found that this results in a diverse range of cooperative network structures within the game, yet the relationship between structure and status is reproduced. Players with more open networks tend to achieve higher performance goals, while those with closed networks maintain greater levels of trust in their relationships. This study could be extended further by gaining information related to the psychological characteristics of players that may have a role in contributing to these outcomes. Including more conventional approaches to measuring constructs such as personality and motivation offers the potential to gain an understanding of the nature of the relationships between individual differences, status, and network structure in an environment where competition and cooperation both offer pathways to maintaining performance.

Artefact development for social research

This discussion on the application of design sciences to social psychology has shown that in order to address the needs of ILM, frequent iteration between empirical data, ABMs and games is required in order to strengthen external validity. Furthermore, like the commercially available products designed for entertainment purposes in the examples presented throughout this paper, data quality and participant retention rely on producing

games that meet participant's needs and motivations. Therefore, the application of design sciences to research requires a strong focus on the development of computational artefacts: both games and ABMs.

Much of the potential offered by games depends on the use of custom designs tailored to the requirements of the research undertaken. That said, genuinely entertaining games that can compete with commercially-available products for participants' time are difficult and expensive to make, often requiring a diverse range of skills in software engineering, coding, and graphic design. Generally, the more immersive and compelling the gameplay, the greater the range of skills and human resources required (Braad, Zavcer, & Sandovar, 2016). For this reason, researchers wishing to create a game targeting a particular phenomenon are required to work with a team of game developers who have the skills to design a game that will keep participants interested while providing the researcher with the data they need. Furthermore, given limited resources, there is considerable pressure to ensure that any game produced can easily be modified according to the requirements of similar studies that researchers may wish to carry out in the future. To achieve this, it is advantageous to take an iterative approach to game development, where successive waves of development, testing, and adjustment are carried out (Braad et al., 2016), such that the release of a given version indicates a particular point in the continuous development of the game, and any further versions or adjustments are considered part of the process of continual development and modification. Similar to ABMs, this opens the door to providing a family of models that can be used to examine the relative contribution of numerous competing causal mechanisms in producing phenomena of interest (Elson & Quandt, 2016).

Although producing a game can be time consuming, faster processing speeds and data transmission, along with increased memory, have resulted in the production of high-level development tools that reduce the need for detailed coding. For example, the availability of game engines like *Unity* and *Unreal* have made it possible for relatively sophisticated games to be produced by small teams of artists and developers for a fraction of the price of many commercial games. Furthermore, the ease with which these applications can be distributed and run on ubiquitous mobile devices means that games can be updated as needed with little input from the participant, such that the game can be altered to vary conditions for discrete groups of players with little fuss. This ability to adjust games in real time means that a family of related models with different conditions can be administered to multiple samples to investigate the effects of these conditions on behaviour and the formation of social structures. For example, *Market Farmer* (Reilly, 2019) is a game designed to identify different decision-

making strategies people employ that uses an internal clock to advance the game events in one-second increments. This results in a fast-paced game where players struggle to monitor the flow of information. However, it is possible to disable the clock and link the advancement of time to a button, giving control over the speed of the game to the player, and thus examine more deliberative forms of decision making with one group, while another continues to play the faster version of the game.

The fluid nature of game development, with constant cycles of playtesting and modification, coupled with the advantages of producing multiple versions of the same game, means that it is more efficient in the long term to establish tools for producing games than it is to develop each game or version of a game from scratch. Creating a game engine or development environment in which multiple versions of games can be assembled efficiently is a long-term strategy for a department aiming to establish a strong foundation in design sciences. This kind of "virtual lab" would be similar to those run by commercial game companies such as Riot Games, who employ social psychologists to test adjustments to games in order to improve user experience and reduce online abuse (Hsu, 2015), with the exception that the games produced would focus on examining specific behaviours associated with a given set of research questions. This would broaden the scope of research undertaken, as researchers would not be bound by the limitations of games produced purely for entertainment purposes, and would allow greater flexibility in manipulating variables and tracking behaviours of interest.

Future directions

Research is often shaped by the methodologies available, and the kinds of questions posed are often limited to those that can be answered using available technology. Given recent advances in information and communication technology, there is enormous potential to broaden the scope of research in social psychology to address questions that have remained beyond the reach of researchers until now. However, constructing computational artefacts like simulations and games is still a labour-intensive approach, requiring many hours of development and testing. Therefore, a serious commitment to this approach requires implementation at scale by embedding dedicated design sciences teams in university departments and research institutes. These teams would include both researchers skilled in developing computational artefacts for research purposes and digital application developers with specific skills in coding, graphic art, and game design. In this article, we have not only shown how design sciences can be used to address new areas of research, but also how this

approach complements conventional methodologies in a way that strengthens research output. Therefore, design sciences represent an opportunity to extend existing research to provide more comprehensive answers to questions in social psychology.

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Foreword to Paper 4

While the third paper laid out a case for using bespoke games as instruments of research, the fourth paper provides an example of a bespoke game developed to investigate individual differences in strategy formation. Performance depends on the exploration and exploitation of features of the game, thus illustrating a key difference between games and self-report instruments. Because the game was able to track the use of exploration- and exploitation-based behaviours in real time, a more insightful understanding is gained of how individual differences in personality relate to choices and consequences in the formation of strategies.

The game was developed using an iterative process common in the games industry, where successive phases of development and playtesting shape the final product through constant feedback (Braad, Zavcer, & Sandovar, 2016). This took place over the course of a year, starting with a simple text prototype exploring the mechanics of the game through to multiple, competing versions with different mechanics and user interfaces. The decision to take this path was driven by the requirement to create a game that was both genuinely engaging and captured the target behaviour. However, the expense of time and resources indicates the scale of the challenge in creating bespoke games that meet the needs of both researchers and participants, supporting the recommendations made in paper 3 regarding the employment of research teams, or “virtual labs” in pursuing research using games. This issue is reflected in the choice to present the game to participants in a web browser rather than as a downloadable application, as this is more convenient at this point in development. The resulting Javascript files are provided as a reference, and the game can be played at https://www.adaptivebehaviour.com/projects/marketfarmer/game.html

Exploring the Relationship Between Personality and Strategy Formation using *Market Farmer*: A Pilot Study on the Use of a Bespoke Computer Game in Behavioural Research

Abstract

A study was conducted to assess whether or not theoretical relationships between personality dispositions and behaviours associated with strategy formation could be examined using a computer game that simulates this in a dynamic environment where initial knowledge is limited. A total of 38 females and 56 males aged between 18 and 62 completed measures of Openness to Experience, Conscientiousness, and exploration-exploitation before playing *Market Farmer*: a game specifically designed to engage players and record strategy formation behaviour over time. As predicted, participants showed a pattern of high behavioural exploration and low behavioural exploitation before switching to low behavioural exploration and high behavioural exploitation. Also as expected, a decrease in behavioural exploration and increase in behavioural exploitation were positively related to score: Participants who identified successful strategies during exploration relied on these strategies instead of further exploration, which resulted in higher performance. Although relationships found in previous studies were not confirmed, this was attributed to the use of a game as a real-time measure of behaviour, and the implications of this are discussed. *Market Farmer* offers a promising tool for the examination of personality and strategy formation.

Introduction

Over the last decade there have been a number of calls for the use of games in psychological research (Coovert, Winner, Bennett, & Howard, 2017; Schönbrodt & Asendorpf, 2011; Szell & Thurner, 2010). Games place participants in semicontrolled situations where changes in behaviour can be recorded over time to address research questions that focus on behavioural processes (Schönbrodt & Asendorpf, 2011). In the broader context of methodology, they complement existing approaches by offering a trade-off between the kind of mundane realism of observational studies and the high levels of experimental control available in laboratory experiments (Blascovich et al., 2002). Furthermore, where studies require participants to be motivated to complete a given task, games engage participants in a way that can produce more authentic behaviour (Washburn, 2003). This tends to distinguish games from other synthetic task environments, such as microworlds, that are often used to examine strategy formation and decision making (Gonzalez, Vanyukov, & Martin, 2005), as games deliberately incorporate elements that

motivate players' needs for competence, autonomy and relatedness (Boyle, 2014) such that players experience a desire to continue playing the game.

However, as with any approach, games have their drawbacks as research tools. Developing a game is a resource-intensive process and the focus on engagement often comes at the cost of external validity, particularly when mechanisms unrelated to the target phenomena are introduced (Washburn, 2003). For example, a number of approaches have avoided the issue of development by using commercially available games, but validity and cross-platform reliability are limited by the existing constraints of the selected game (Williams, 2010). One way of resolving this is to select or produce games that can easily be modified according to the demands of individual studies (Elson & Quandt, 2016). This leads to a design sciences approach, where a platform is created that is capable of producing a wide variety of games with a common theme or genre relevant to a broad field of research, thus reducing the need to "reinvent the wheel" every time a game is produced (Reilly, 2019). The aim of this pilot study is to develop an online game that is sufficiently open-ended to offer the potential for further development into such a platform, while also displaying sufficient utility as a research tool. In order to demonstrate this utility, the game is used to examine the relationship between personality and strategic cognition.

Individual Differences in Strategic Cognition

Studies in strategic cognition examine the role of cognitive structures and processes in the formation of strategies that can occur, for example, in a business environment (Narayanan, Zane, & Kemmerer, 2011). In this context, the conclusions drawn can differ according to the type of environment that managers work in, and recent years have seen a particular focus on the use of the *doing first* approach to strategy formation as a result of disruptive change in the technology sector (Mintzberg & Westley, 2001). In an environment where there is little understanding of an optimal strategy, this approach advocates action as a means of generating responses from the environment that are then evaluated. Actions that produce positive results are retained and others are discarded, and strategies are thus derived through a process of trial and error (Gibcus, Vermeulen, & Radulova, 2008).

The trade-off between exploration and exploitation is fundamental to strategic cognition, as the exploitation of existing information or resources may be compromised by exploration that results in new sources (Hills et al., 2015). An optimal model of an exploration-exploitation strategy produced by Berger-Tal, Nathan, Meron, and Saltz (2014), suggests that in environments where there is little or no existing knowledge, individuals

acquire strategies by initially exploring the environment and gradually acquiring information through feedback. Over time, however, the costs of exploration outweigh the returns from exploiting information gained in the past, and individuals gradually transition to an approach dominated by exploitation.

Considerable interest has been shown in understanding the antecedents of exploration and exploitation related to individual differences. In particular, the Five Factor Model (FFM) personality traits of Openness to Experience, which reflects a willingness to change and try new approaches, and Conscientiousness, which indicates a preference for accuracy and consistency in following rules and completing tasks (Johnson, 2014), appear to naturally align with behaviours associated with exploration and exploitation respectively. Although studies have found small but positive correlations between Openness to Experience and exploration, and conscientiousness and exploitation (Keller & Weibler, 2014a, 2014b), these focus on establishing relationships between dispositional variables measured through self-report scales rather than on behavioural observation. Furthermore, Openness to Experience and conscientiousness are each composed of a number of subfactors, or facets (Johnson, 2014), each of which may contribute to differences in the way individuals manage the transition from exploration to exploitation. Therefore, studies examining relationships between exploration-exploitation and Openness to Experience-Conscientiousness may result in weak or nonexistent correlations because different facets of Openness to Experience and conscientiousness may impact on exploration and exploitation at different points in time.

Conventional approaches to examining exploration-exploitation have been valuable in developing an understanding of individual differences in strategic cognition. However, these approaches have not been able to give us much insight into how individual differences in personality affect the strategic use of exploration and exploitation *over time*. As argued at the start, the use of computer games as research tools to gather behavioural data in real time can address this, as they are ideal for capturing data on the dynamic employment of exploration and exploitation in strategy formation. For example, deviations in game behaviour can indicate an exploratory approach, while establishing consistent, rewarding behaviour can indicate exploitation. A combination of measures, where participants are measured on personality traits of interest that are then compared to patterns of game behaviour indicating a transition from exploration to exploitation, can yield insights into the relationship between personality and the manner in which this transition occurs. The use of a bespoke game would also allow for the development of a game specifically designed to capture this behaviour,

while ensuring that participants begin with little or no knowledge of optimal strategies, thus simulating an environment where these are unknown.

Development of *Market Farmer*

The purpose of developing a game for this study was not just to provide a means of examining the dynamic use of exploration and exploitation, but also to pilot and evaluate the use of a bespoke game that could be easily adapted for future studies. Therefore, a generic task encapsulating many features of strategy development in dynamic environments with little initial knowledge was developed that also met the requirements of a pilot study, including constraints on time. This meant that it needed to be possible to complete the game within 30 minutes, including time taken to learn how to play the game and become proficient enough to explore and exploit strategies in a way that reflected differences between participants. It also meant that it was not possible to provide a truly dynamic game in which player actions result in permanent changes to the game dynamics or trajectory. Instead, a deterministic system simulating a dynamic environment was developed. Furthermore, the game is designed as a single-player game with the goal to advance as far as possible for the sake of simplicity. Although multiplayer games are useful for examining variables related to social interaction, this is not the focus of this study.

Strategic cognition is a process that includes exploration of the environment and the exploitation of information gathered through feedback (Cohen, McClure, & Yu, 2007). Activities designed to capture this behaviour over time must provide participants with the opportunity to make decisions regarding the acquisition and use of this information. As our focus is not on decision-making behaviour under time pressure (Maule, Hockey, & Bdzola, 2000), the game is structured in a way that allows participants to control the advancement of the game. Game time was divided into 1200 *ticks*, each activated by a button or the space bar that triggered game events for the subsequent tick. This allowed players time to deliberate over decisions, though players were limited to a maximum of two hours to complete the game. A game of 1200 ticks also provides players with enough time to develop a range of strategies through exposure to elements of the game that become available as they progress.

Games that succeed in engaging players draw on fundamental motivations of competence and autonomy (Boyle, 2014). Players enjoy facing and overcoming challenges that fit their skill level, as well as the sense of control in setting and meeting game goals. This can be achieved by creating a system of rewards and punishments within the game that motivates players to form and improve on strategies. These considerations resulted in the

game *Market Farmer*, based on a simple mechanic where players plant crops in fields when the price of the crop is low and then wait for the crops to grow while the price changes. When the crops mature, they are automatically sold at the current price, and thus the only control players have over their ability to make a profit is to gauge the best time at which to plant the crops. This provides players with an opportunity to observe changes in crop prices and learn from past mistakes in selecting the right time to plant crops through a system of rewards and punishments that occur when players make a profit or loss. For example, when players plant at the wrong time, the crop will sell at a low price and the return will be less than the cost of planting the crop, thus incurring a loss. In order to prevent gameplay developing a trajectory in which players are unable to continue playing, and to provide a consistent player experience, prices follow a set trajectory.

This simple mechanic provides a low-level decision-making process, but meaningful gameplay that sustains interest over longer periods should allow the development of higher level strategies. This requires a macro-level decision-making context that interacts with these micro-level decisions in a way that increases the tension experienced by the player (Salen & Zimmerman, 2004). Therefore, the concept of *improvements* was introduced to allow players the ability to increase profits and prevent losses. In order to create more dramatic potential losses, floods that destroy crops and birds that eat them were also introduced. This provides the player with the opportunity to install improvements to prevent losses incurred from floods and birds, and increase profits from fields, while constraining the number of improvements in each field forces the player to make decisions regarding which fields improvements should be installed in.

To create further tension in making these decisions, crop varieties were given different qualities according to predictability of price volatility and levels of investment and return, such that varieties with more unpredictable volatility required a larger investment, thus increasing the potential loss, but offering an equally large potential for profit. Thus, players were able to offset the risk of more volatile higher value varieties using improvements, while small differences in volatility between varieties offered players the opportunity to experiment with varying levels of risk. The combination of crop varieties with varying levels of risk and return, floods, birds, and improvements offers players many ways to achieve a high score, with the values, timing, and offsets of each game element carefully balanced to ensure that on average, preferences for a particular improvement type, for example, would not result in a difference in overall score.

Finally, as the target behaviour involves cognitive performance, there is the potential for reactivity when participants to engage with the task (Naveh-Benjamin & Klib, 2012). One of the advantages of using games as research tools is the potential to address this issue (Reilly, 2019) by distracting players from the observation of their performance. This was done by creating an enjoyable experience that would hold their interest for the duration of the game through the use of common game elements such as bright, colourful graphics and lively animations to create a sense of action and movement in the game, along with cartoon-like auditory cues to provide feedback to the player. To control for differences in ability, a tutorial was included at the beginning of the game using a narrative to engage the player in a purposeful understanding of what was required, and to show examples of the game mechanics. To maintain motivation, the ability to acquire new crop varieties, fields, and improvements as rewards was staggered throughout the game to encourage goal-setting. Pop-up alerts and hints were also used throughout the game to ensure that players were aware of their options, particularly as new elements were being introduced, or rewards provided. Table 1 shows each element of the game and the mechanic or gameplay feature it contributes to.

Table 1

Game Elements and the Features or Mechanics That Contribute to Them

	Challenge	Trade-offs / dilemmas	Micro-/macro-decision making	Creates needs / wants	Engagement	Ensures playability
Time delay between sowing (decision) and harvesting (feedback)	X					
Crop varieties with graded difficulty / reward payoff	X	X		X		
Improvements		X	X	X		
Improvement cap		X	X			
Floods and birds		X	X	X		
Staggered crop varieties, improvements, and fields		X	X	X		
Hints				X	X	X
Alerts					X	X
Narrative				X	X	X
Cartoon graphics and animations					X	
Visual and auditory cues					X	X

Playing *Market Farmer*

On loading the game, the player is presented with an introduction screen showing two farmers of the same gender as the player, who provide instructions on how to play the game in the tutorial that follows. The farmers state the broad aim of the game in terms of maximising the amount of money made, and the player clicks through further screens with each farmer presenting aspects of gameplay from positive and negative perspectives: one stating a problem and the other offering a suggestion for solving it. For example, players are told that they can plant new crops and make improvements, but that some crops are expensive and risky. Players are then given an opportunity to sow and harvest a crop of potatoes, which provides very little profit, but is also very low risk. The tutorial continues with the farmers explaining to the player how the price for potatoes changes, what the different pieces of information on the screen mean, and the best time to sow. The player is then asked to sow three more potato crops while the farmers appear in an information box at the bottom of the screen repeating instructions and advice on how to sow the crops to make a profit. Once these three crops have been sown and harvested, the player is congratulated on their success and further information is then provided relating to time, crops, and improvements. After this, the option to sow potatoes is removed and replaced with broccoli, thus signalling the beginning of the game. The player begins with $1000, and if this amount falls below $20, it is automatically topped up to $20, thus allowing the player to sow broccoli crops and continue playing the game. Features of the game such as floods and improvements are explained to the player as they appear in the game in a similar manner to the tutorial. Figure 1 shows a screenshot from the game with a farmer explaining how to access improvements.

Figure 1. A farmer explains how to access improvements in the *Market Farmer* tutorial.

Over time, the player receives more fields at predetermined points unknown to the them, until they have a maximum of eight fields. Players also receive access to more crop varieties based on the cumulative total of crops sown, i.e. the more crops the player sows, the faster they gain access to new varieties. Players also purchase improvements using farmhands that accrue over time, with a total of 32 farmhands available throughout the game. Information relating to these and other aspects of gameplay is available at the top left of the screen, where, from the top, the number of ticks remaining, the number of crops that need to be sown in order to gain the displayed variety, the number of farmhands accrued, and a button that advances the game to the next tick are displayed. The amount of money available to the player (score) is displayed at the top centre of the screen. When clicking on the farmhands icon, the screen shown in Figure 2 is displayed, allowing the player to select an improvement when there are farmhands available to pay for it.

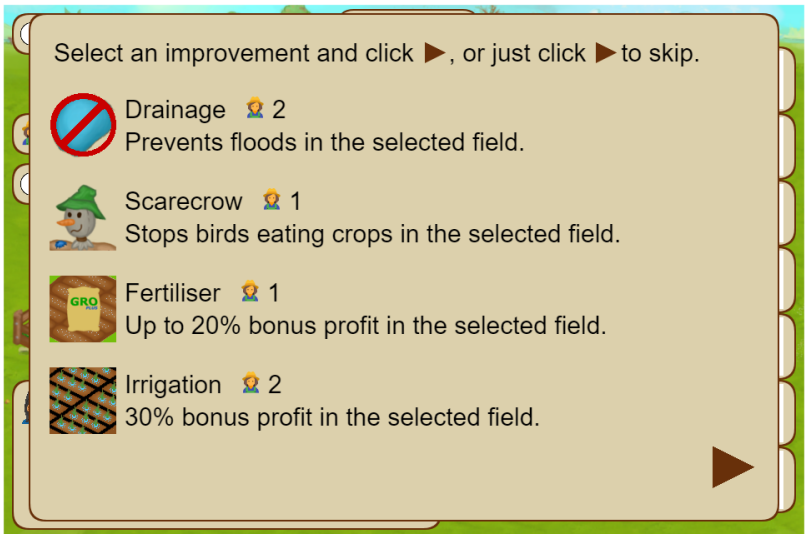

Figure 2. A screen in *Market Farmer* showing the selection of improvements available to the player, the advantages they confer, and the cost in farmhands.

Once installed in a field, improvements produce a given benefit in that field for the remainder of the game and cannot be removed. The following improvements are available for purchase:

- *Drainage* prevents floods from occurring in a field and costs two farmhands. A total of 27 floods are scheduled to occur at regular intervals throughout the game, and the more often a player sows a crop in a given field, the more likely it is that a flood will occur in that field. When a flood occurs in a field with a crop, the crop is removed from the field and the player loses their entire investment for that crop.

- *Scarecrow* prevents birds from landing in a field and costs one farmhand. Birds land on crops at regular intervals and reduce the profit of the crop by a random amount of up to 20%.
- *Fertiliser* adds a random amount of up to 20% of the profit from a crop when it is sold, but has no effect on crops that are sold at a loss. Fertiliser costs one farmhand.
- *Irrigation* adds 30% of the profit from a crop when it is sold but has no effect on crops that are sold at a loss. Irrigation costs two farmhands.

These improvements are balanced so that the use of drainage and scarecrows, for example, will have the same mean effect on overall profits as irrigation and fertiliser, respectively. Therefore, players who implement improvements are more likely to be more successful in making money, providing them with more resources to plant crops.

Figure 3 shows the screen in the second half of a game where all of the seven crop varieties are available. Players sow each crop by dragging the relevant icon into a field. The fixed cost of sowing each crop is displayed above the respective icon, while the figure to the right of this shows the amount of money the player would gain if the crop were harvested in this tick. The recent history of these values is displayed in the accompanying chart, which illustrates the increasing volatility of each variety.

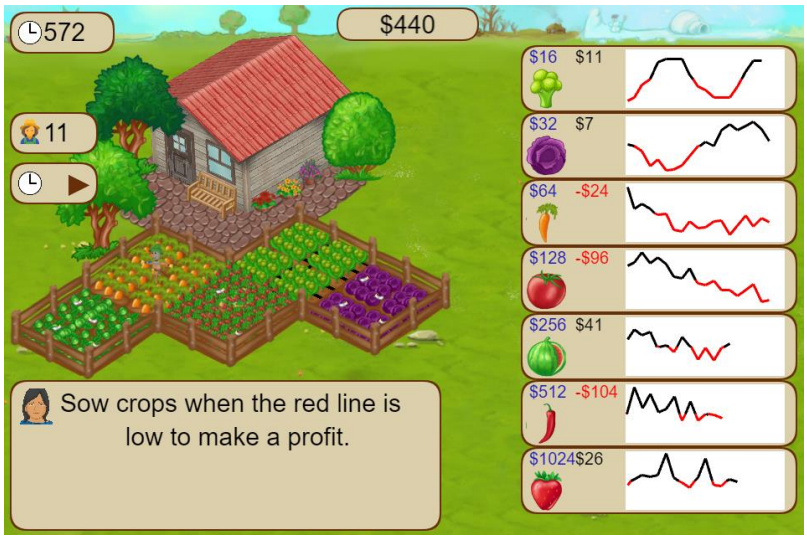

Figure 3. The screen in *Market Farmer* showing all of the crop varieties available to the player by the end of the game and their price volatility.

The combination of increasing volatility and profitability with each crop and the advantages offered by the improvements affords players a number of different strategies for success when defined as the amount of money made at the end of the game. As players are limited to two improvements per field, choices must be made regarding the potential losses and gains provided by a combination of improvements, and the effect this has on mitigating the risk inherent in planting more volatile crops. Initially, there is a strong incentive for players to explore by experimenting with different combinations, and once a successful strategy has been established, players may then continue to exploit that strategy, or explore other strategies. However, players are not forced to choose between these approaches, and it is possible for players to pursue a given strategy in some fields while exploring alternatives in others, or to adopt a broad strategy within which there may be some room for exploration.

The Current Study

We now demonstrate how *Market Farmer* can be used to explore a number of hypotheses regarding the relationship between personality and exploration-exploitation. First, we determine whether or not aggregate patterns of exploration and exploitation in gameplay reflect those established by Berger-Tal et al. (2014), and then examine the relationship between these patterns and game performance. We also determine whether or not any relationship can be established between the exploration-exploitation construct as examined through game behaviour, with the construct as examined through dispositional measures employed in conventional studies. Finally, we test the relationship between dispositional measures of the personality traits Openness to Experience and Conscientiousness, behavioural patterns of exploration and exploitation performed in the game, and score. These patterns of behaviour are identified according to the extent to which players repeat strategies by trying new crop varieties and improvements, and varying the combination of these (*behavioural exploration)*, or by planting the same crop varieties in fields with the same combination of improvements (*behavioural exploitation)*.

The game consists of 1200 ticks, during which the game pauses so that players can perform actions, but there are a number of phases that occur during the course of the game. Initially, players learn about how to play the game, during which separate elements are introduced in a staggered fashion to prevent overwhelming the player with information. Furthermore, as the player begins with only one crop and one field, the ability to extract meaningful information regarding strategies undertaken is limited until the player receives more crops and fields. As the crop growing times increasingly exceed the remaining game

time in the last 100 ticks of the game, players' choices become more limited in regard to the crops that can be sown. For this reason, this period is not included in the analysis. Given that players begin the game with very little knowledge of what an optimal strategy might be, a period of behavioural exploration is expected, during which behavioural exploitation should be quite low. However, as the game progresses, players are expected to acquire successful strategies due to the predictable rise and fall in prices of the less profitable crops, and the ability to use improvements to offset the level of risk and uncertainty in high-value crops. As the nature of the improvements and crops are stable across the game, the balance between exploration and exploitation is expected to reverse in line with the model offered by Berger-Tal et al. (2014).

Hypothesis 1: Mean levels of behavioural exploration will increase and then decrease, while mean levels of behavioural exploitation will decrease and then increase as shown in Figure 4.

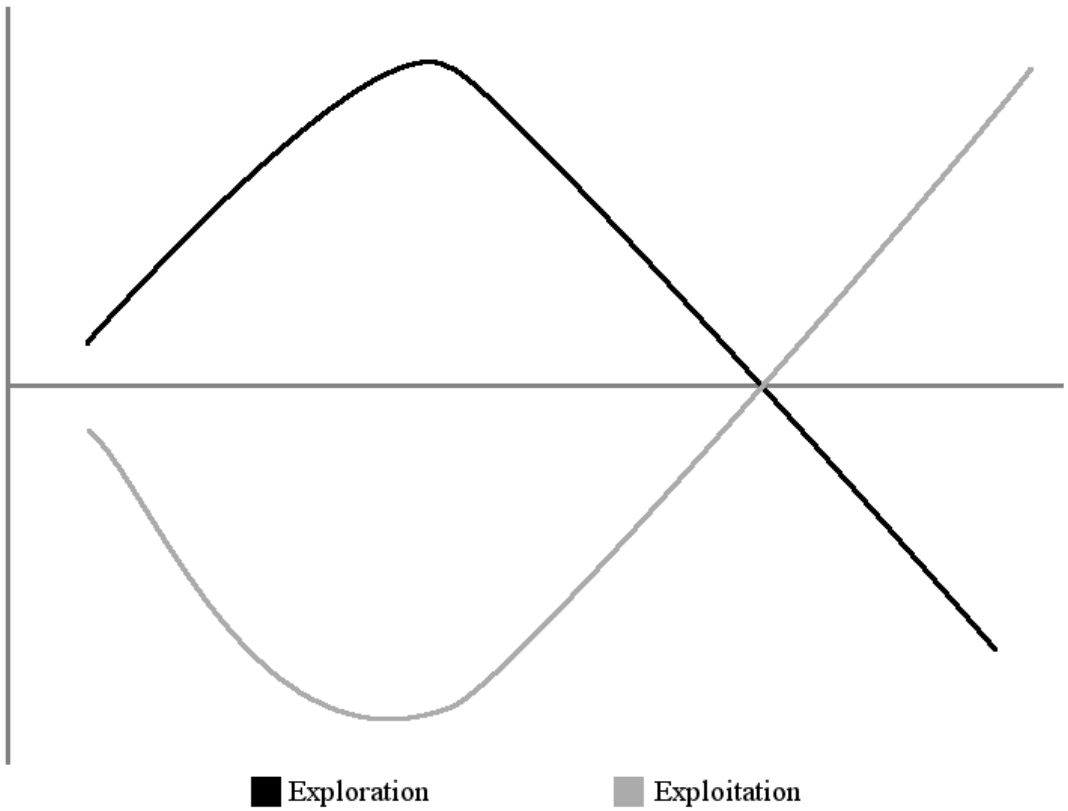

Figure 4. Trends in exploration and exploitation predicted by hypothesis 1.

As the *doing first* approach to strategy formation is optimal in environments where there is little or no initial information available, the game offers little indication of how participants should employ improvements to offset risk, thus forcing them to experiment with new crops and improvements as they become available. However, according to the model offered by Berger-Tal et al. (2014), at some point behavioural exploration should peak, after which a decline in behavioural exploration should be accompanied by an improvement in performance, along with a rise in behavioural exploitation as participants select successful strategies. This suggests that performance may be associated with an understanding of the optimal time at which exploitation should take precedence over exploration. Therefore, once participants have had enough time to acquaint themselves with potential strategies, and mean levels of behavioural exploration have peaked, participants who decrease their levels of behavioural exploration should experience a concurrent increase in score (in-game money), while those who increase their levels of behavioural exploitation should also experience a concurrent increase in score.

Hypothesis 2: Following a peak in mean levels of behavioural exploration, a decline in levels of behavioural exploration will be positively related to score over time, while an increase in behavioural exploitation will also be positively related to score over time.

Behavioural exploration-exploitation, as measured using data recorded from players' actions in the game, is contrasted with dispositional exploration-exploitation, which is measured using conventional self-report techniques. Dispositional exploration indicates a general preference for exploratory activities, while dispositional exploitation suggests a preference for carrying out familiar activities. Participants with preferences for novel activities may prefer to continue exploring new strategies rather than focusing on existing strategies that have been shown to work. Conversely, players that prefer familiar activities may prefer to repeat successful strategies once they have been discovered. Furthermore, if a reduction in behavioural exploration following a peak in mean levels of behavioural exploration is positively related to score, the relationship should be negatively moderated by participants' dispositional preference for novel activities. Similarly, participants' preference for familiar activities should positively moderate the relationship between their levels of behavioural exploitation and score.

Hypothesis 3: Following a peak in mean levels of behavioural exploration, dispositional exploration will positively moderate the negative relationship between behavioural exploration and score, while dispositional exploitation will positively moderate the positive relationship between behavioural exploitation and score.

As discussed previously, the relationship between exploration and exploitation and personality appears complex, with facets of each personality factor potentially contributing differently to both. Therefore, in accordance with previous studies (Keller & Weibler, 2014a, 2014b), the positive relationship between Openness to Experience and dispositional exploration should be weak or nonexistent. Facets likely to moderate the negative relationship between behavioural exploration and score include: Intellect, as participants scoring higher on this measure may be more likely to recognise and select successful strategies rather than continuing to explore; and Adventurousness, as participants scoring higher on this may be more likely to continue exploring instead of employing successful strategies. Also, the lack of a moderating effect of Imagination, Artistic Interests, Emotionality, and Liberalism on the relationship between behavioural exploration and score means that the overall relationship between Openness to Experience and exploration remains low.

Hypothesis 4: Following a peak in mean levels of behavioural exploration, higher levels of Openness to Experience facets Intellect and Adventurousness will positively moderate the negative relationship between behavioural exploration and score, Imagination, Artistic Interests, Emotionality, and Liberalism will not moderate the relationship between behavioural exploration and score.

In regard to exploitation, only those facets of Conscientiousness that relate to the reproduction of successful strategies should contribute to the positive relationship between behavioural exploitation and score, thereby leaving the overall relationship between exploitation and Conscientiousness low. However, as dispositional exploitation is congruent with behaviours that contribute to score in this phase of the game, facets related to the reproduction of strategies, such as Self-efficacy, Achievement Striving, and Self-discipline, should all positively moderate the positive relationship between behavioural exploitation and score, while Orderliness, Dutifulness and Cautiousness should exhibit no moderating effect.

Hypothesis 5: Following a peak in mean levels of behavioural exploration, Conscientiousness facets Self-efficacy, Achievement Striving, and Self-discipline will positively moderate the positive relationship between behavioural exploitation and score, while Orderliness, Dutifulness, and Cautiousness will not moderate the relationship between behavioural exploitation and score.

Method

Participants

Participants were recruited through an online recruitment service and remunerated for their time. Only participants aged at least 18 and using devices with screen dimensions of at least 640 pixels were able to take part in the study. Due to compatibility issues, participants were not able to complete the study using the Firefox browser. A total of 94 participants completed the study, including 38 females and 56 males with ages ranging from 18 to 62 (M = 31, SD = 9.93).

Procedure

After providing demographic information, participants completed a number of surveys as part of a wider study before playing the game, with the time taken to play the game ranging from 21 to 129 minutes (M = 51, SD = 20.81). At the end of the game, participants were shown their score and asked a series of questions on how much they enjoyed playing the game.

Surveys completed by participants relevant to this study include the IPIP-NEO-120 and an exploration-exploitation scale developed by Keller and Weibler (2014a).

The IPIP-NEO-120 is a short-form adaptation of a longer scale developed as a measure of factors and facets of the FFM. Only the Openness to Experience and Conscientiousness scales were administered, and participants were asked to indicate the extent to which statements accurately described their personality on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). Statements related to facets of Openness to Experience include “I have a vivid imagination” (Imagination), “I love to read challenging material” (Intellect) and “I believe that there is no absolute right or wrong” (Liberalism), while those related to Conscientiousness include “I know how to get things done” (Self-efficacy) and “I carry out my plans” (Self-discipline). Chronbach’s alpha for Openness to Experience is .83, with alphas for facets ranging from .64 (Liberalism) to .76 (Imagination and Artistic Interests). Alpha for Conscientiousness is .90, with values for facets ranging from .63 (Self-efficacy) to .87 (Cautiousness).

The scale used to measure dispositional exploration-exploitation was originally developed to indicate the extent to which managers had engaged with activities associated with exploration and exploitation in the past 12 months. However, it has been adapted for this study to focus on preferences by asking participants "How much do you enjoy doing the following activities?" Statements were unchanged but the 7-point Likert scale was altered to indicate preferences from 1 (strongly dislike) to 7 (like a lot). The eight exploration items include "Activities that require a good deal of adaptability on your part" and have a combined alpha of .81, while the eight exploitation items include "Activities that you carry out very routinely" and have an alpha of .82.

While dispositional measures use conventional self-report approaches, behavioural exploration-exploitation is measured using participants' activity in playing the game. For each tick, there exists a matrix representing the player's strategic behaviour in terms of the number of improvement-crop combinations in use at that point. These strategic instances of behaviour are then compared to infer the extent to which a player is repeating a previous strategy (exploitation) or creating a new strategy (exploration) that can include combinations of previous strategies or alterations to them. A simplified example of how this is calculated in a game with five fields; crop varieties, *a*, *b*, and *c*; and improvements, *x* and *y*, is shown in the matrix below.

$$\boldsymbol{M}_t = \begin{array}{c|cccc} & - & x & y & xy \\ \hline a & 1 & 0 & 0 & 0 \\ b & 0 & 0 & 2 & 0 \\ c & 0 & 0 & 0 & 1 \end{array}$$

This indicates that at *t*, there was a field with no improvements containing variety *a*, two fields with improvement *y* containing *b*, and one field with both improvements *x* and *y* containing *c*. This matrix $\mathbf{M}_t$ is then compared to all previous matrices by subtracting it from each matrix and summing the absolute values of the differences to derive a single value, *d*, representing the difference between both matrices. For example, the matrix at *t* - 1:

$$\boldsymbol{M}_{t-1} = \begin{array}{c|cccc} & - & x & y & xy \\ \hline a & 1 & 0 & 0 & 0 \\ b & 0 & 0 & 1 & 0 \\ c & 0 & 1 & 0 & 0 \end{array}$$

indicates that, at *t*, the player has added a *b* crop to a field with improvement *y*, along with the *c* crop in a field with improvements *x* and *y*. Meanwhile, a crop of *c* in a field with improvement *x* has harvested. Subtracting $\mathbf{M}_t$ from $\mathbf{M}_{t-1}$ yields:

$$\begin{array}{cccc} & - & x & y & xy \\ a & 0 & 0 & 0 & 0 \\ b & 0 & 0 & -1 & 0 \\ c & 0 & 1 & 0 & -1 \end{array}$$

the summed absolute values of which is $d = 3$. The exploration value for $\mathbf{M}_t$ is the lowest value of *d* obtained after iterating over all previous matrices, multiplied by 1 divided by the number of fields in the game at *t* to control for the expansion of fields as the game progresses. Therefore, in a game with 5 fields:

$$exploration = d_{min}\frac{1}{n} = 3 \times .2 = .6$$

The exploitation value for $\mathbf{M}_t$ is calculated using a matrix representing the sum of all previous matrices, **P**, and iterating over the corresponding cells *ij* of both matrices where each cell contains a value greater than 0:

$$exploitation = \sum \boldsymbol{C}_{ij}\frac{1}{n}\left(1 - \frac{1}{\boldsymbol{P}_{ij}}\right)$$

where *n* is the number of fields currently in the game. In this way, the result reflects the similarity between the current matrix and previous matrices weighted by the number of times each crop-improvement combination has been used in the past, while controlling for the number of fields in the game. Together, these approaches also allow for the measurement of simultaneous exploration and exploitation behaviours where matrices contain a combination of repeated and novel crop-improvement combinations.

To measure the extent to which participants enjoyed playing the game, six statements were provided on completion that represented different aspects of fulfillment in gameplay: “I enjoyed playing this game”, “I felt like I was in control when playing this game”, “I would enjoy playing this game more if I could play with other people”, “I am satisfied with my performance in this game”, I would like to play this game again” and “I felt like I knew what

I was doing when playing this game." Participants indicated their agreement with each statement using a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

Results

Table 2 shows descriptive statistics and correlations for dispositional variables included in the analysis, as well as score and the enjoyment of the game. Note that values of score are calculated as the square root of the in-game value to resolve issues related to differences in magnitude and normality that occurred during analysis. Relationships between dispositional variables exploration and exploitation were stronger and more consistent than in previous literature. While Keller and Weibler (2014a, 2014b) found either weak positive or nonexistent correlations between exploration and Openness to Experience, we found a moderate positive correlation ($r = .43$, $p < .01$). Similarly, while Keller and Weibler found only weak positive correlations between exploitation and Conscientiousness, we found a moderate positive correlation ($r = .48$, $p < .05$). Furthermore, exploitation was negatively correlated with Openness to Experience ($r = -.29$, $p < .01$); a relationship that was not found by Keller and Weibler.

Table 2

Descriptive Statistics

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Score																		
2. Enjoyment	.30**																	
3. Exploration	-.18	.09																
4. Exploitation	-.16	.17	-.21*															
5. Openness	-.05	.06	.43**	-.29**														
6. Imagination	-.00	.09	.22*	-.12	.70**													
7. Artistic Interests	-.16	.03	.23*	-.07	.68**	.39**												
8. Emotionality	-.18	.12	.22*	.07	.61**	.46**	.26*											
9. Adventurousness	.06	.02	.54**	-.49**	.60**	.29**	.28**	.18										
10. Intellect	-.13	-.13	.33**	-.21*	.63**	.27**	.39**	.25*	.25*									
11. Liberalism	.25*	.06	.05	-.33**	.47**	.15	.16	.02	.30**	.19								
12. Conscientiousness	-.16	.09	.07	.48*	-.19	-.29**	.01	-.02	-.12	.00	-.29**							
13. Self-efficacy	-.26*	.14	.20*	.28**	-.16	-.20*	-.07	-.10	.04	-.03	-.25*	.64**						
14. Orderliness	-.23*	-.03	-.09	.36**	-.11	-.13	.07	.07	-.16	-.05	-.26*	.66**	.29**					
15. Dutifulness	-.09	.10	.06	.43**	-.17	-.24*	.04	-.04	-.13	-05	-.22*	.64**	.23*	.30**				
16. Achievement Striving	.04	.12	.21*	.27**	.11	.08	.06	.21*	.09	.07	-.13	.65**	.39**	.29**	.38**			
17. Self-discipline	-.12	.13	.09	.41**	-.17	-.20	-.08	.01	-.11	-.01	-.27**	.83**	.59**	.48**	.37**	.59**		
18. Cautiousness	.03	-.06	-.10	.21*	-.21*	-.41**	.01	-.19	-.17	.06	-.07	.61**	.19	.25*	.37**	.09	.32**	
M	85.23	3.46	4.41	5.25	3.42	3.57	3.54	3.68	2.94	3.54	3.26	3.57	3.74	3.30	3.93	3.66	3.26	3.50
SD	35.21	0.87	0.96	0.80	0.49	0.82	0.86	0.85	0.76	0.77	0.73	0.48	0.60	0.76	0.60	0.65	0.77	0.92

*$p < .05$, **$p < .01$

Figure 5 shows mean standardised behavioural exploration and exploitation values recorded in 50-tick intervals over time.

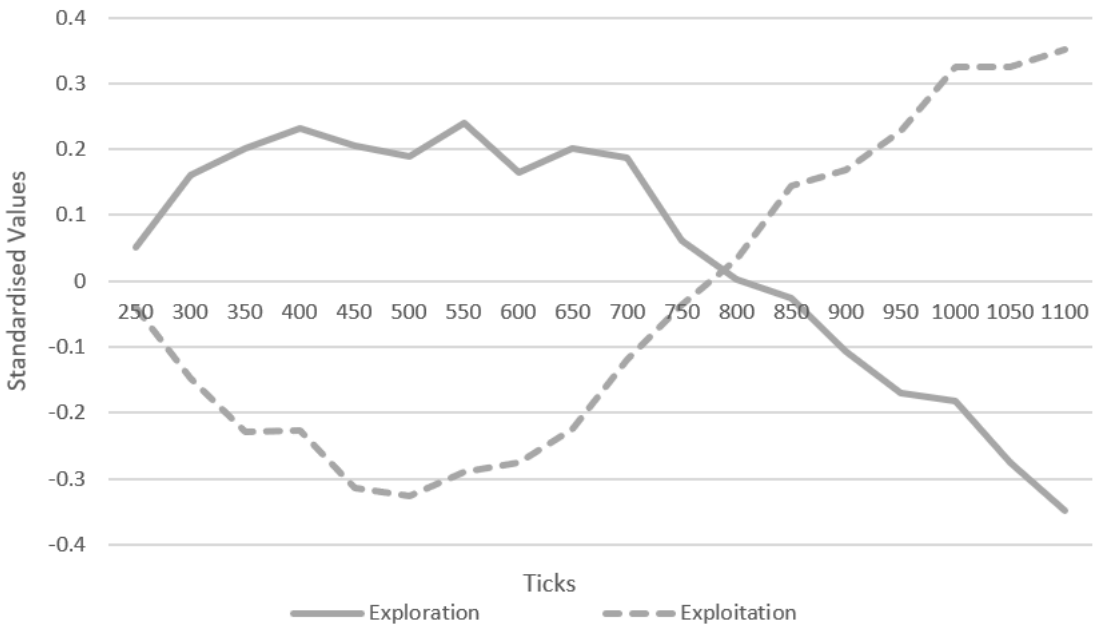

Figure 5. Means of standardised behavioural exploration and behavioural exploitation values generated from player actions recorded at intervals of 50 ticks.

This indicates that there are two broad phases in the game. The first of these occurs from tick 250 and extends to 550, when behavioural exploration increases while behavioural exploitation decreases as players extend their strategies to include more crops and improvements as they become available. Once behavioural exploration peaks at around 550, it then declines as successful strategies have been identified, and behavioural exploitation increases as these selected strategies are increasingly exploited.

Table 3 shows results from multilevel regression models, with score as the dependent variable, measures of behavioural exploration and exploitation as level 1 predictors, and measures of dispositional exploration and exploitation, and both factors and facets of Openness to Experience and Conscientiousness as level 2 predictors. As the study focuses on the influence of dispositional variables (level 2) on the slope between behavioural variables (level 1) and score over time (γ_{10}), slope values are presented for level 2 on score controlling for level 1 (γ_{01}), and the moderation of level 2 on the slope between level 1 and score (γ_{11}).

Table 3

Multilevel Regression Models with Dispositional Measures at Level-2, Behavioural Measures as Level-1 Independent Variables, and Score as the Level-1 Dependent Variable.

Exploration				
Level 1	γ_{10}	Error		
Behavioural	-5.10***	1.05		
Level 2	γ_{01}	Error	γ_{11}	Error
Dispositional	-3.13*	1.83	-1.46	1.10
Openness	-0.45	3.59	-4.30*	2.06
Imagination	0.72	2.15	-1.32	1.28
Artistic Interests	-1.93	2.06	-0.93	1.23
Emotionality	-4.58*	2.02	-0.39	1.21
Adventurousness	1.47	2.33	-3.83**	1.37
Intellect	-1.19	2.29	-1.29	1.29
Liberalism	6.42**	2.34	-2.90*	1.39
Exploitation				
Level 1	γ_{10}	Error		
Behavioural	3.59***	0.66		
Level 2	γ_{01}	Error	γ_{11}	Error
Dispositional	-4.63*	2.35	-1.44	0.82
Conscientiousness	-8.63*	3.90	-2.11	1.45
Self-efficacy	-8.23**	3.10	-1.45	1.16
Orderliness	-5.95**	2.44	-0.32	0.91
Dutifulness	-6.01*	3.13	-1.39	1.17
Achievement	-0.70	2.95	-0.42	1.08
Self-discipline	-6.91**	2.40	-1.86*	-2.20
Cautiousness	1.25	2.09	-0.33	0.75

*p < .05, **p < .01, ***p < .001

Multilevel regression analysis shows that on average, there was a significant negative slope between behavioural exploration and score (γ_{10} = -5.10, p < .001) and a significant positive slope between behavioural exploitation and score (γ_{10} = 3.59, p < .001) following the peak in exploration at 550 ticks. However, there was a significant negative relationship between dispositional exploration and score when controlling for behavioural exploration (γ_{01} = -3.13, p < .05), and no moderation of the relationship between behavioural exploration and score by dispositional exploration. Similarly, there was a significant negative relationship between dispositional exploitation and score when controlling for behavioural exploitation

(γ_{01} = -4.63, $p < .05$), and no moderation of the relationship between behavioural exploitation and score by dispositional exploitation.

Openness to Experience reduced the negative slope between behavioural exploration and score (γ_{11} = -4.63, $p < .05$) through the facets of Adventurousness (γ_{11} = -3.83, $p < .01$) and Liberalism (γ_{11} = -2.90, $p < .05$). However, when controlling for behavioural exploration, Emotionality was negatively related to score (γ_{01} = -4.58, $p < .05$), while Liberalism was positively related to score (γ_{01} = -6.42, $p < .01$). Both the factor of Conscientiousness (γ_{11} = -8.63, $p < .05$) and the facets of Self-efficacy (γ_{11} = -8.23, $p < .01$), Orderliness (γ_{11} = -5.95, $p < .01$), Dutifulness (γ_{11} = -6.01, $p < .05$), and Self-discipline (γ_{11} = -6.91, $p < .01$) were negatively related to score when controlling for behavioural exploitation, but none moderated the relationship between behavioural exploitation and score except for Self-discipline (γ_{01} = -1.86, $p < .05$), where higher levels increased a negative relationship between behavioural exploitation and score.

Discussion

The aim of this study was twofold. Firstly, it aimed to determine whether relationships between personality dispositions and strategy formation could be identified based from a sample of game behaviour, and secondly to evaluate the potential of this approach for future research in the fields of personality and social psychology. In doing so, a study was conducted using a game that motivated participants to form strategies in an environment where initial knowledge is limited. In this environment, where a *doing first* approach to strategy formation is optimal, the expected pattern of high behavioural exploration and low behavioural exploitation, switching to low behavioural exploration and high behavioural exploitation, was confirmed. Also as expected, once the level of behavioural exploration had peaked, both the decrease in behavioural exploration and the increase in behavioural exploitation were positively related to score, such that participants who were able to identify successful strategies that had emerged during exploration were able to increasingly exploit these instead of exploring further, and were more likely to experience an increase in score.

However, the pattern of results in relation to the personality factors of Openness to Experience and Conscientiousness was mixed. Based on the literature, we were expecting that higher levels of Openness to Experience facets Intellect and Adventurousness would positively moderate the negative relationship between behavioural exploration and score,

while Imagination, Artistic Interests, Emotionality, and Liberalism would not moderate the relationship between behavioural exploration and score. Although Adventurousness moderated the negative relationship between behavioural exploration and score as expected, Intellect did not, but Liberalism did. This suggests that either the ability to recognise successful strategies and curtail further exploration is not related to Intellect, or that the task is not as cognitively demanding as it might be in real-word contexts. For example, businesspeople often face complex decision-making situations in dynamic market conditions with multiple feedback effects, which were not present in the game. However, Intellect focuses on reading challenging material, philosophical discussions, and abstract ideas, and may not reflect the kind of pragmatic application of cognition required by this task. For example, entrepreneurs, who tend to operate in environments with initial levels of low information, are more likely to exhibit lower levels of cognitive motivation and rely more on heuristics and advice from others when solving cognitive tasks (Curseu, Vermeulen & Bakker, 2008). This ability to make decisions in the absence of information is also related to entrepreneurs' higher levels of ambiguity tolerance, which may account for the role of Liberalism in reducing the negative relationship between behavioural exploration and score.

One surprising result was the significant relationship between Liberalism and score after controlling for behavioural exploration, as expectations were that traits related to Openness to Experience would maintain higher levels of exploration at a time in the game when the focus should be shifting to exploitation in order to achieve a high score. However, this result suggests that Liberalism is one of the more significant aspects of personality that contributes to success during this period of the game. Liberalism focuses on the rejection of moral absolutes and greater latitude in the use of punishment for crimes. Therefore, it may be that participants with a preference for ambiguity accurately sense that there is no right or wrong strategy to pursue, and are happy to assume this in exploring new strategies.

We also expected that the Conscientiousness facets Self-efficacy, Achievement Striving, and Self-discipline would positively moderate the positive relationship between behavioural exploitation and score, while Orderliness, Dutifulness, and Cautiousness would not moderate the relationship between behavioural exploitation and score. However, contrary to expectations, none of the hypothesised relationships between Conscientiousness and its facets and behavioural exploitation could be found. In fact, higher levels of Self-discipline negatively impacted on the relationship between behavioural exploitation and score. A clue to the reason for this may lie in the fact that the pattern of relationships between exploitation, Conscientiousness and particular facets of Conscientiousness, and score when controlling for

behavioural exploitation, is replicated in the overall pattern of relationships between these measures and Liberalism in Table 2. That is, the reason why participants scoring highly on these measures did not perform as well in the latter part of the game after controlling for behavioural exploitation may be similar to the reason why those who score highly on the measure of Liberalism did. Both the Conscientiousness and dispositional exploitation scales focus not just on the repetition of behaviour, but also on preferences: for familiarity, clarity, and preparedness in the case of dispositional exploration; and behavioural adherence, order, and efficiency in the case of Conscientiousness. This suggests that they may not relate well to the measure of behavioural exploitation that focuses solely on replication of behaviour in the context of this game. Also, because the *doing first* approach is optimal in novel situations, there is less advantage to be gained from relying on past experience, and a strict adherence to preconceived ideas, assumptions, or principles is likely to impede the kind of learning required to establish novel solutions that fit the context (Mintzberg & Westley, 2001). In contrast, an open-minded, flexible approach comfortable with the notion that there are no preordained right or wrong strategies may be easier to adopt among participants with a more liberal political orientation that is comfortable with ambiguity and tolerant of solutions that are not based on black-and-white thinking, and therefore these participants tend to exhibit a higher level of performance in this game.

Future directions and limitations

The current study begins to demonstrate the advantages of using a game to examine behaviours associated with dispositional constructs over time, particularly in combination with multilevel modelling to examine the relationships between dispositional variables and temporal changes to behaviour. In a complex decision-making task, where exploration and exploitation can be either beneficial or detrimental to performance at different points in time, and where the successful use of one approach depends on the prior use of another, individual scores representing dispositions may not be adequate for capturing the optimal employment of these strategies. Furthermore, while broad dispositional measures may capture a wide range of preferences, these may impact differently on performance at different points in time and across different task contexts. However, this is not to say that dispositional measures are inferior, but rather that they offer different information that informs and complements the current approach (Schönbrodt & Asendorpf, 2011).

Despite these advantages, there are a number of limitations to using a game like this in research. One is the difficulty in controlling and standardising the data generated, which

often occurs as a result of creating a dynamic task environment (Gonzalez et al., 2005). While these environments provide a level of complexity that players find appealing, and that may generalise more easily to real-world tasks, dynamic dependencies result in nonlinear gameplay trajectories that differ across players. For example, the provision of new crops depends on the number of crops sown in the game, thus giving players a goal and motivating them to plant more crops. However, this means that players receive new crops at different times, and because the timing of these new crops underpins the rate of exploration, this peaks at different times for different players. Therefore, there is no common point in the game where players switch from exploration to exploitation, and the variation among them limits the ability to draw more precise conclusions. Issues such as this are further evident in the limited way in which exploration and exploitation were measured. Perhaps one reason as to why no effect could be found for behavioural exploitation was that it was limited to consistent or repetitive play, and did not take into account any feedback from the players on what their strategies were. More subtle or implicit behaviour could be detected by using data mining techniques to identify patterns of behaviour associated with scores on dispositional measures. Taken together, these issues suggest that data mining techniques may provide a more efficient and effective approach to analysis in the long term (Drachen, Thurau, Togelius, Yannakakis, & Bauckhage, 2013). Other feedback from players that would be useful include previous gameplay experience, particularly in relation to the game genre. Controlling for previous experience may result in a more reliable measure of player behaviour.

These limitations point to recommendations for future research, particularly in regard to the development of the game and the choice of domain. Acquiring detailed feedback from player during and after playing the game is essential for ensuring validity, and game design decisions should be made accordingly, with a focus on the particular requirements of the domain. For example, the game used in this study was a single-player game, but in a social network or cooperation study, multiplayer games may be more appropriate. For example, the current study allowed players to use resources at their disposal, while a study into common resource pools might be better suited to a multiplayer game where reputation effects could be examined (Milinski, Semmann & Krambeck, 2002).

On the whole, this study has shown that despite significant limitations, there is enormous potential in the use of games like *Market Farmer* for understanding how behaviours are employed over time and in response to particular situations, and relating these to dispositional measures. On the other hand, it is often difficult to predict how players will

respond to different, interacting features of a game, such that any data generated should inevitably lead to the further development and improvement of the game. This blurs the line between development and research, as an iterated development process, where successive versions of the game are produced based on feedback generated by the previous version (Braad, Žavcer, & Sandovar, 2016), lends itself well to the successive gathering and analysis of data needed to establish validity. From this perspective, a game may never be truly finished, as further development can occur to improve validity, or to branch off into a different study. This is in contrast to a common approach in experimental design, where a task is developed to measure a particular behaviour, and implemented, perhaps with a manipulation check, on the assumption that it will perform as required. In order to engage players and examine more complex interactions between individuals and behaviours, games incorporate greater functionality, which requires iterative testing for validity.

This long-term, iterative approach to game development in research also opens the door to extending a prototype like *Market Farmer* to a downloadable app that allows participants to play over an extended period of time, such as days, weeks, or months. This would not only allow for a greater variety of manipulations, but also result in a more reliable measure that takes place over time rather than a single window of 30 minutes. Furthermore, the ability to offer different versions of the game within a single app, or to manipulate events in the game in order to examine responses to particular situations would also offer a long-term benefit to researchers. Although the use of games in research is still in its early stages, these possibilities highlight its huge potential.

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Discussion

This thesis aimed to apply the CAS approach and associated design science methodologies to examine bidirectional relationships and process-based explanations in personality and social psychology. In doing so, an integrated approach to both theory and methodology was achieved in that principles relevant to CAS presented in the first paper provided a foundation for exploring and understanding the utility of the design sciences approach. For example, the concept of exploration-exploitation served as a starting point for applying CAS to the relationship between personality and social structure, while also providing a basis for defining agent behaviour in the ABM, and measuring behaviour in the game. Therefore, in applying the CAS approach to questions in personality and social psychology, it would appear that identifying processes associated with exploration and exploitation is key to interpreting familiar concepts through the theoretical lens of adaptation, and provides a starting point from which computational artefacts can be constructed to examine questions relating to these concepts. This demonstrates the utility of principles of CAS theory in providing a foundation for a new research paradigm based on integrating design sciences in establishing digital or virtual laboratories with teams that draw on a wide range of skills across research and computational domains.

The first paper laid a foundation for this endeavour by providing useful conceptual tools that reinterpreted familiar relationships between personality and social structure as generative processes. In particular, the utility of the adaptive cycle and associated dimensions was demonstrated through an explanation of how individual differences contribute to social stability and change while also being shaped by it. This perspective offers support for the theory of elective affinities outlined by Jost, Federico and Napier (2009) by providing greater explanatory detail for the bidirectional causality that defines the relationship between individual differences and ideological positioning. Furthermore, this approach situates the theory of elective affinities within other dimensional approaches, such as those taken by Block (2010) and DeYoung (2015) in presenting stability and plasticity as parsimonious, higher-level categories of personality, and Janoff-Bulman, Sheikh, and Baldacci's (2008) bidimensional model of motivation and political orientation. Furthermore, an important insight offered by the first paper was the role of stress in driving both social stability and change. While stress initially encourages the maintenance of social structures as a response to the threat of losing accumulated structural advantages, eventually it contributes to the dissolution of these structures through the strengthening of ingroup boundaries. This confirms the theoretical relationship between anxiety and conservative ideological positioning

suggested by Jost, Kruglanski, Glaser and Sulloway (2003) and illustrates the significance of defining the relationship in terms of a dynamic social-psychological response.

The role of stress in maintaining social structures was then examined in the second paper where a dynamic theory of stress, social network structure and belief persistence was tested in order to clarify a shared reality theory of belief persistence (Jost, Ledgerwood, & Hardin, 2008) in relation to empirical findings. The results of this study not only confirmed the theory, but also extended it by showing that both ingroup bias and local network size contribute to belief persistence through dynamic responses to stress. It also illustrated the utility of ABMs in rigorously testing theories of dynamic, interactive processes and providing robust support for the generative mechanisms underpinning theoretical relationships established through conventional studies. While the model does simplify human behaviour, it nonetheless contributes a degree of knowledge regarding the potential role of degree centrality in belief persistence, as well as offering some indication of the importance of cognition. More conventional approaches may claim greater validity in measuring behaviour performed by real participants, but fail to capture the processes by which the relationships they establish are generated (Hughes, Clegg, Robinson & Crowder, 2012), and therefore in the context of this study, they lack the ability to account for the dynamic contribution of variables such as stress, social interaction, and memory. Like all models, ABMs can only focus on a simplified representation of a given relationship, but this study nonetheless shows the potential for more work of this kind in creating models that address other aspects of the relationships between stress, social structure, and adaptation.

This study has also shown that ABMs can contribute more than the results addressing hypotheses. In this process of creating this model, it was necessary to make assumptions regarding agent behaviour explicit, both in terms of decision-making and more fundamental cognitive functions such as memory. By conducting a full-factorial exploration of the model, the precise parameters required to generate the target phenomena could be identified, and inferences made about the role these have in doing so. It also shows that even seemingly minor decisions regarding agent cognition can have a significant impact on the validity of the model such as the significance of memory and heterogeneity. However, this also highlights the importance of basing these design decisions on empirical evidence and theoretically-relevant principles to avoid the inclusion of arbitrary or trivial mechanisms in generating the target phenomena. When these are excluded, the process of creating and testing an ABM can also bring to light other variables that also play a crucial role. In this case, these variables

highlight the role of cognitive mechanisms such as memory in establishing relationships and stable belief systems.

The potential of computational artefacts in research was then extended in the third paper to explore the use of bespoke computer games in social psychological research by replacing models of interacting agents with models of interacting people. Although games are also simplified representations, they offer the advantage of being able to provide detailed records of behaviour from many individuals simultaneously over time. This allows for a more granular examination of processes related to transition and change occurring within and across individuals, and the ability to test theories of dynamic social-psychological phenomena with real human beings rather than with simplified agents. Thus, games are able to integrate principles of CAS with a computational approach that examines real-time behaviour, and provides a methodological bridge between conventional research methods and purely computational models like ABMs. Therefore, a key insight from this paper was that conventional approaches, ABMs, and games all have complementary roles to play in testing theories and improving validity. This was illustrated to some degree in the second paper, in which results from conventional studies played a crucial role in defining agent attributes and behaviours, and in making decisions regarding the parameters of the ABM. However, in order to explore this idea fully, further research is required into the use of ABMs, games, and conventional studies in an integrated research environment.

The final paper then addressed claims made in the third paper by developing a game that examined the dynamic role of exploration-exploitation in strategy formation in real time. This showed that it was possible to gain key insights into the relationship between personality and strategy formation by replacing dispositional measures of exploration-exploitation with a dynamic measure of behaviour that revealed individual differences in the transition from exploration to exploitation, and the role of this transition in performance. In doing so, a number of surprising results were obtained concerning the relationship between personality dispositions and the employment of exploration-exploitation over time. For example, despite the theoretical predictions made, the facet of Liberalism in predicting score both directly and indirectly through the moderation of exploration was not expected. This illustrates the potential for this approach to reveal insights into familiar relationships in personality psychology that are not easily obtained with more conventional approaches.

Despite these advantages, the limitations of the study conducted suggest that a greater investment is needed in order to realise the potential for the integrated approach discussed in Paper 3. For example, Market Farmer is a single-player game that provides a snapshot of

behaviour over a short period of time based on a single measure of behaviour that is then correlated with a conventional measure of personality. From a social-psychological perspective, extending this study to include a multiplayer version of the game could address questions relating to the role of personality in shaping, for example, team performance over time. However, developing a multiplayer game that people will not only play over an extended period of time, but will *want* to play, is far more challenging and requires a much greater investment of resources. This would also have important implications for the practical aspects of conducting research, as participants would be both consumers of a product, while also being research participants by agreeing to share their game data and providing other personal information, such as data from personality scales. This could potentially raise a number of ethical concerns, particularly if games were monetised in some way, or included features that encouraged repeated play. It remains to be seen whether these potential issues could be balanced by the acquisition of more detailed samples of behaviour in more complex and realistic situations that provide greater contributions to the field than are otherwise available through conventional studies.

Despite the insights gained, there are a number of limitations to the studies presented in these four papers. While many theoretical claims are made and supported by empirical evidence in the first paper, some do not lend themselves well to the methodological approaches outlined in the papers that follow. Similarly, the advantages of multiplayer games outlined in the third paper were not able to be tested in the game that was developed due to constraints on time and resources. These advantages may also be limited by the challenges in analysing the data generated, and while it was suggested in the final paper that data mining techniques could be used to extract meaningful results from the potentially enormous volume of data generated in games, this was not explored further, partly due to the fact that the field is in its infancy (Drachen, Thurau, Togelius, Yannakakis, & Bauckhage, 2013). This further highlights the need for a greater investment in resources and a greater collaborative effort in developing the digital and human resources required to realise the potential of the design sciences approach.

However, taken together these papers illustrate the utility of the CAS approach in recasting concepts that are already familiar to researchers so that questions regarding bidirectional relationships and dynamic social interactions can be addressed using design sciences. This approach can shed light on the mechanisms generating relationships between variables, both within individuals, as was done in the final paper, or between interacting actors as illustrated in Papers 1 and 2. This not only allows for more granular explanations of

how relationships are generated, but also provides a means of addressing questions of dependence and contingency related to the circumstances under which these relationships occur, and how they can be encouraged or prevented. Paper 3 argued that the ability to introduce subtle variations to games and ABMs would provide an efficient way of addressing these questions. However, the experience of developing the game in Paper 4 added showed that meeting the requirements of both validity and player engagement outlined in the third paper is a labour-intensive task involving many skills and successive iterations of development and playtesting. Furthermore, in order to provide the flexibility in varying models and games, a modular approach to development where elements of one project can be reused or easily modified for use in another, indicates that a broader, organisational approach is needed.

This broader organisational approach to applying design sciences signals opportunities to invest in "virtual labs" as part of the viable, long-term research strategy. This would include resources for producing more conventional studies, as well as developers and researchers skilled in the production and use of computational models and games. Given an area of research in social psychology where a range of studies could be employed in investigating a set of phenomena, teams could provide a framework of applications from which numerous interrelated games, versions of games, models, and simulations could be produced. An example of a model for these teams is the MIT Media Lab ("MIT Media Lab," 2018), a research facility that brings together researchers and developers to create technological solutions to various problems. The potential advantages of maintaining a laboratory of this kind would extend not only to answering questions that remain beyond the scope of conventional approaches, but also to producing cross-validated studies with a higher degree of reliability and replicability than is available through conventional means alone. This is not to say that conventional approaches would be excluded from such an environment, as the essential role played by these approaches in the use of design sciences is evident in this thesis, and has been suggested in previous studies incorporating both approaches (Van Rooy, Wood, & Tran, 2016).

In conclusion, this thesis has shown that relationships between variables established through conventional approaches can be understood broadly in terms of behavioural transitions. The first paper showed how familiar theoretical concepts, such as individual differences, can be recast as coconstitutive processes occurring at the individual and social levels, where individual responses to situations collectively result in cyclical phase transitions. A more detailed examination of this process was conducted in a narrower context

in the second paper, where individual transitions between adaptive behaviours contributed to belief persistence. The final paper then examined a transition between exploration and exploitation among human participants in relation to dispositional measures of personality based on a methodological approach presented in the third paper. In doing so, these studies provide support for existing theories and offer additional insights, while showing how these approaches can be used to start testing theoretical statements in a practical and controlled way. Furthermore, although it is clear that the theoretical and artefactual tools associated with the CAS approach can provide insights that are unavailable through the use of conventional methods alone, they complement these methods in a way that can potentially increase validity, and provide more robust explanations for the complex relationships found in personality and social psychology.

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Appendices

The following .txt files are associated with this thesis:

ABM Classes: A list of the main Java classes defining the model in Paper 2.

Full-factorial Analysis Results: Results of the full-factorial analysis conducted on the model in Paper 2.

Market Farmer: The Javascript code for the game Market Farmer in Paper 4

Market Farmer Data: The JSON data file for the game Market Farmer in Paper 4

Ethics Application Form: The completed ethics application form submitted for the Market Farmer study in Paper 4.

Ethics Approval Email: Email from the Human Ethics Officer at the ANU approving the Market Farmer study in Paper 4.