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OPENING THE BLACK BOX: COMBINING AGENT BASED SIMULATION AND REALISM IN INTERVENTION DEVELOPMENT

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ABSTRACT

Interventions in healthcare seek to make a change to service provision or behaviour in order to improve health of individuals and populations. An intervention is usually designed and developed by experts using the available research findings in a given area. Prior to the piloting phase of intervention the effectiveness of the intervention design is not normally tested. Simulation methods provide a way to test and refine changes to a system before they are implemented in the real world.
The use of Agent Based Simulation (ABS) using a realist approach is presented as a method for the rapid development of complex behavioural simulations which can be used to inform the design and development of interventions. The complementarity between ABS and realism will be discussed and an example of this approach being used presented.

Keywords: Healthcare, agent based simulation, intervention development, realism

1 INTRODUCTION

Currently missing from the intervention development process is a platform on which to test and refine intervention effectiveness prior to any implementation in the real world. Intervention, process change and behaviour change are the labels given to the use of research findings to make some change to a system and/or process. These systems and processes are often individual, group, or physical (Argyris, 1970), although the differences between them are often blurred. An intervention is typically developed using the available research literature, piloted on a small scale and then implemented on a larger scale. Classic interventions were often described as 'black box' interventions. The change or new process would be implemented and observed, but the explanation of the mechanisms responsible for the change would be limited simply to a description of the intervention (Harachi et al., 1999, Tulsky et al., 1998).

The process of moving from using the literature to inform the intervention design to piloting and then large scale implementation challenges the researcher in terms of evidence synthesis, theory development, research design and evaluation. All of these stages and aspects of the intervention process must be considered while trying to produce and implement a useful and effective intervention (Craig et al., 2008).

The realist approach is being increasingly applied to intervention development (Pawson et al., 2005, Connelly et al., 2007). The realist approach is driven by theory and seeks to understand the interplay of context, mechanisms and outcomes in systems and processes (Chen and Rossi, 1980). Theory is developed from data and previous literature to produce an explanatory account of the system or process under investigation, Pearson et al. (2015) have used realist review techniques for understanding collaborative care for offender mental health prior to the development of an intervention. As demonstrated by Pearson et al. such explanatory accounts can be used to develop interventions, it is also possible to use realist methods to inform the implementation of interventions and evaluate them (Pawson et al., 2004, Pawson, 2013). This is the process of 'opening the black box' of an intervention so that the individual mechanisms responsible for producing a change in an intervention can be studied, understood and replicated.

Simulation methods can provide a test bed for intervention development which would support the design process. Agent Based Simulation (ABS) is a method by which the behaviour of individuals can be simulated within a given environment using sets of rules applied to the agents. The resulting behaviour and outcomes emerge from the interaction of the agents within the bounds of their rules and environment (Šalamon, 2011).

This paper will argue that realist methods of inquiry can be used to inform simulation models of the proposed intervention, which in turn could improve the overall effectiveness of an intervention. Brief introductions to realist inquiry, ABS and interventions will be given in order to set out the scope of this approach. The complementarity between realist inquiry and ABS will then be examined and the similarities between the two approaches discussed. An example of the development process for a complex behavioural simulation which uses a realist approach will be given to demonstrate how this process can be practically implemented. The final discussion will look at the advantages and disadvantages of this approach to intervention development and highlight the technical difficulties that will need to be overcome.

2 REALISM

Modern realist inquiry has its roots in the works of Roy Bhaskar and Donald Campbell such as "A Realist Theory of Science" (Bhaskar, 1979) and "Methodology and Epistemology for Social Sciences: Selected Papers" (Campbell, 1988). When broken down to its most simple tenements, realism espouses the use of all types of data. Whether qualitative or quantitative, all data relating to a phenomenon aids in its description and our understanding of it (Campbell, 1988). The goal of realist enquiry is normally explanation, it seeks to go beyond description and provide insight into the cause. This is achieved by a focus on the context, mechanism and outcome of the phenomena under investigation (Pawson, 2013).

Through the utilisation of multiple data types detailed information can be collected on the context in which the phenomena occurs, mechanisms which are thought to be at work within that context and the outcomes that can be observed, enabling the development of explanatory theory which is what makes the realist approach so powerful. Two modern applications of the realist approach which have become somewhat formalised in their application are realist synthesis and realist evaluation.

Realist synthesis and evaluation both seek to use evidence, whether from the literature or primary data sources, to develop explanatory accounts of the phenomena under investigation. When utilising one of these realist methods or a more general realist methodology, the realist approach brings a depth and breadth of evidence use which can inform the creation of an agent based simulation when developing an intervention which has a large behavioural component.

3 AGENT BASED SIMULATION

Agent based simulation (ABS) is a method which uses the individual as the main building block of the simulation. Typically it is the complexity that arises from the interaction of multiple individuals over time which is of interest, which represent the emergent properties of the system (Chen et al., 2007). This simulation method has been successfully applied in many different disciplines most prolifically ecology for the study of animal behaviour (Chalk, 2009, Bryson et al., 2007) and epidemiology for the study of disease outbreak and transmission (Eubank et al., 2004). In operational research (OR) this method is beginning to gain traction as its use for the study of behaviour in relation to behavioural OR becomes apparent (Escudero-Marin and Pidd, 2011), along with its usefulness in multimethod modelling to support discrete event simulation and system dynamics modelling (Flynn et al., 2014).

The agents in a simulation are programmed with a set of rules which often operate stochastically to mimic the variation seen in the real world. In this respect the behaviour and experiences of each agent differ over time. Agents can be programmed to learn and adapt based on their interaction with the environment and/or other agents. It is these properties of variation, individuality and learning which make ABS a suitable method for modelling social phenomena (Šalamon, 2011).

4 INTERVENTIONS

Interventions are programmes of change designed to improve the functioning of a system. They are commonly associated with health sciences where the system undergoing the change can vary from a ward or department in a hospital to national scale health process and from the individual person to whole populations. The main guidelines for the development and evaluation of complex interventions comes from the United Kingdom Medical Research Council (Craig et al., 2008) and as highlighted by (Anderson, 2008) the use of new methodological advances is encouraged especially those of realist synthesis and evaluation. In general there are four stages to an intervention: Development, feasibility and piloting, evaluation and implementation.

The development process of an intervention seeks to understand the existing literature around the process to be changed, a theory about how the change can be achieved is developed and the expected processes and outcomes mapped out (Richards and Rahm Hallberg, 2015). Realist synthesis can be used to aid in the process of developing interventions as it provides a relatively systematic approach to achieving each of these development steps (Pawson, 2006). The second stage is feasibility and piloting, this is where the intervention procedures are tested on a small scale. The feasibility and pilot studies carried out are evaluated to refine the intervention process and understand the mechanisms responsible for causing the changes in measured outcomes observed during the studies (Craig et al., 2008). It is at this stage that the use of ABS could be most effective.

The evaluation stage of the intervention process seeks to understand how the intervention was or was not producing the desired change. The implementation phase of an intervention is more long term than the

feasibility and piloting phases. Once the intervention has been refined to the point that confidence is high in the positive value of the changes produced by it, the intervention can be rolled out on a larger scale.

5 COMPLIMENTARITY OF ABS AND THE REALIST APPROACH

There are a number of similarities between ABS and realism which make them suitable for use together.

5.1 Emergent behaviour

The outcomes of an ABS model are the result of the emergent behaviour produced by the behavior of individual agents and their interactions with their environment and other agents. This can be likened to Archer's (1995) realist social theory of behaviour, in which behaviour is the result of the individuals' intentions. The emergent behaviour of the system does not confirm the intentions of any one individual in the system but instead produces "Unavoidable, unplanned, self-generated, morphogenetic change" in behaviour (Archer, 1995). In this way, ABS produces the same naturally generated behaviour from system component interaction as seen in the real world through the realist lens.

In the realist approach, reliability is determined through testing and re-testing of hypotheses. When modelling, various scenarios can be explored using "what if" analysis and simulations are run many times to determine the variation within the system. It is often difficult to test and re-test hypotheses developed through realist synthesis and evaluation due to the complexity of the studies that would be required, the cost of running such studies and the resource use that would be required. The ethical issues associated with running such studies over and over again are also prohibitive. ABS provides an ethical and cost-effective environment in which to test the hypotheses arising from realist synthesis and evaluation used for intervention development and evaluation.

5.2 Theory driven approach

The realist approaches to evidence synthesis and evaluation are both driven by the use of existing theory and the development of theory (Chen and Rossi, 1983). For an ABS, the rules which are ascribed to the agents and the environment are derived from existing theory or the simulation is being used to test a theory about the functioning of a system. The need to at once develop and test theory is common to both ABS and realism for without it both approaches have no substance or use.

The role of context in the development and testing of theory in the realist approaches is also a central tenant of the realist philosophy. The context in which behaviour takes place can impact on the mechanisms responsible for producing the behaviour (Elster, 2007). In an ABS the environment in which the agents interact impact the behaviour of the agents. Therefore, the environment of an ABS can be used to model the context of real world behavior which is central to the realist approach.

5.3 Use of data

The realist approach is one of the few philosophical schools of thought that does not place restrictions of the type of data that should be used under its banner (Campbell, 1988). Many methodological approaches require the use of either qualitative data or quantitative data but do not support the integration of both data types (Bryman, 2012). To enable the researcher to capture data about the context, mechanisms and outcomes in the situation under investigation both qualitative and quantitative data are necessary and valid. Qualitative data adds description, detail and insight to the study while quantitative data adds specificity, objectivity and comparability (Olsen, 2010).

ABS models can be informed by both quantitative and qualitative data. Behaviour in ABS models is represented using a series of rules, typically following an "if-then" format. Qualitative data can be used to inform the development of such rules (unlike in purely mathematical models) allowing behavioural aspects to be captured even where quantitative data is lacking.

6 AN EXAMPLE OF BEHAVIOURAL SIMULATION DEVELOPMENT – POLYPHARMACY MEDICATION ADHERENCE

When people are taking more than one medication on a regular basis this is referred to as polypharmacy. An ABS tool was developed as part of a wider programme of work which is investigating peoples adherence to multiple medications. When taking multiple medications people have been observed to change their prescribed drug regimen, but this process is not well understood. Understanding how people change and self-optimize their medication under conditions of polypharmacy is a topic of interest in relation to person-centred healthcare and medication prescribing practice (Anthierens et al., 2010).

Many different factors influence whether or not somebody will take their medication as prescribed, and this represents a complex behavioural phenomenon where a change in behaviour and practice is required. The number of medications, how often they have to be taken and the complexity of taking them all add to the treatment burden the patient has to deal with. In the case of polypharmacy, one set of medications for a condition may also adversely interact with the medications for another condition. Both high treatment burden and adverse drug interactions are more likely to result in divergence from prescribed treatment regimens.

The ABS for this project was developed using a realist inspired approach which is outlined in Figure 1 and described in detail below.

The first stage of the project was to determine the research question, this was achieved through collaboration between experts in the area of polypharmacy research and the simulation team. By working together the scope of the project could be constrained to make it practical for simulation while still being useful for the intervention development process. The research question was: "Can ABS be used as a means of determining the optimal set of medications to prescribe to adults with type 2 diabetes (T2D) and asthma, such that their treatment burden is minimised, the clinical benefit of the medication maximised and any wasted cost from unused medication or additional hospital visits minimised?"

To narrow the scope further for a preliminary exploratory investigation, the team focused on a population of interest of adults with both Type 2 Diabetes and asthma. The key outcome measures were the percentage of total medications prescribed being taken by the patient and their average state of health, as if a patient takes fewer medications than prescribed there are potential wastages involved, along with potential safety issues. The population of interest was chosen because insulin medications for diabetes are known to produce negative side effects when taken with some asthma medications. In addition, diabetes and asthma are common co-morbidities found within the UK population making this a useful study population. The wider project is seeking to understand polypharmacy from a patient perspective with the idea that more effective medication use can be achieved by understanding how the patient uses their medication, which in turn could help to inform prescribing practice.

Once the research question and study population were determined the next stage of the process was to map the relevant potential proximal and distal factors which could influence someone not to take their medication as prescribed. To draw comparison with the realist approach, this is the stage at which the theoretical framework, on which the simulation would be based, starts to be developed. The mapping process included engaging with current patients who have multiple comorbidities, experts in the field of polypharmacy, pharmacists and a General Practitioner. Through extensive discussion, an influence map was developed (see snapshot in Figure 1).

The influence map enabled a focused search of the literature to find both quantitative and qualitative data that could be used to represent and parameterise such relationships within the mathematical modelling environment of an Agent Based Simulation. Relevant journal articles were identified and entered into a table of the relationships with a brief summary of the useful findings. While this was a labour-intensive process with over 150 relationships to find evidence for, by creating the influence map first the search of the literature could be focused only on those relationships which had been identified.

The next stage of the simulation development process was to extract the data and develop rules based on that data to parameterise the simulation. Both qualitative and quantitative findings were included in the literature search; the qualitative data was used primarily to develop rules for the simulation while

quantitative data was used to assign probability distributions and weightings within the rules from the qualitative data. The use of a realist approach to this project allowed multiple research methods (focus groups and evidence synthesis) and data types (qualitative and quantitative) to be used. It also enabled these data to be interpreted and used in the context of each other to produce a more complete picture of the phenomena under investigation. The process of mapping the relationships between the factors influencing adherence gave a basic structure to the programmatic rules for the agents. This process made the inclusion of the evidence informed rules easier as they could be fitted into the structure of the relationships.

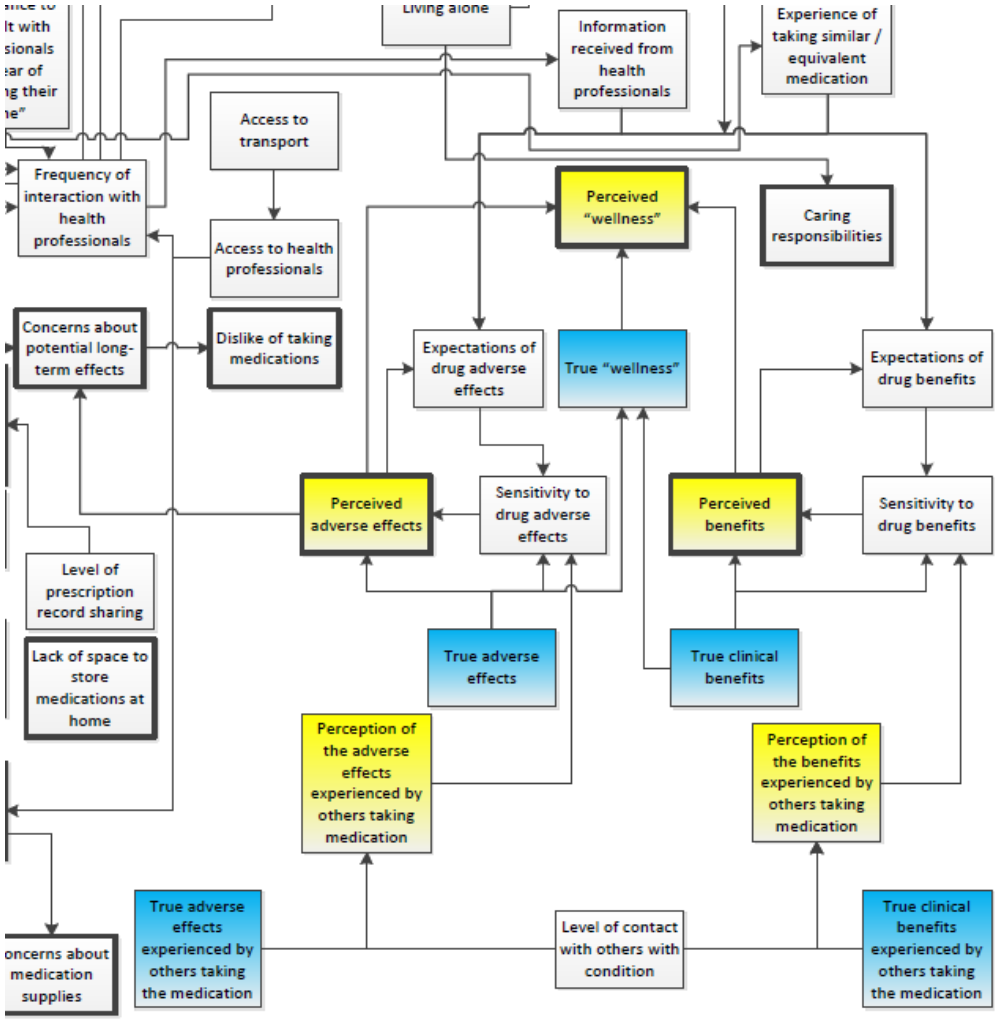

Figure 1 *Snapshot of the polypharmacy influence map*

Once all of the information required to build the simulation had been collated, the build process could begin. The simulation was built using Anylogic 6.71 multimethod simulation software. The model was structured such that each general factor that directly influenced adherence resolved to a boolean proposed action – to either adhere or not to adhere. In addition, a modified Linear Operator Learning Rule was implemented to model the impact of patient wellness and perceived wellness on the self-optimisation process. Each patient maintains a perception of how well they feel with their current medication, as well as a memory or estimate of how well they would feel for each other combination of medications. The perception of their wellness with their current medication combination is updated each simulated day

based on how well they actually are, their sensitivity to the effects of the medication, and the importance they place on how they feel now compared with how they felt before. If their perception of how well they are with their current medication falls a user-defined percentage below that of an alternative medication combination, the proposed action will be for them to switch to that medication combination. The action that a patient undertakes each day (to stick with their current medication or switch to an alternative combination) is selected at random, with different weightings for the proposed action derived from the patients wellness, and the proposed actions derived from the other more general factors.

Currently, the simulation is structured as a tool that allows users to explore the impact of different prescribed medication combinations and different population demographics on adherence to prescribed medication and levels of health, with treatment burden of a medication combination judged by the user. In time, it is hoped that this tool can be used to aid the development of an intervention to improve prescribing practice for those with Type 2 Diabetes and Asthma.

This simulation development process was facilitated by the use of information from a range of sources including; expert patients, expert researchers, primary research and secondary/review literature, to develop a theory of polypharmacy medication adherence behaviour on which to base the simulation. Being able to bring together qualitative and quantitative data not just in the theory development stage of the project but also in the creation of the rules and parameters for the model enabled a more complete picture of the relevant behavioural systems to be understood and implemented in the simulation.

The relative speed with which this type of simulation can be developed would likely not interfere with the normal intervention development process and provides a way to more completely study complex behavioural phenomena which maybe disparate in the literature, but can be studied in conjunction with one another in the simulated virtual environment.

7 DISCUSSION

The aim of this paper was to make the argument for the use of a realist approach to the design of ABS models to support the intervention development process. The level of complementarity between the realist approach and ABS would enable each approach to inform the other leading to more rigorous, reliable and valid theory. Both approaches acknowledge social behaviour to be greater than the sum of its parts, as it is the emergent quality of the behaviour that both approaches seek to understand and capture in the theory from which they are developed and seek to develop.

The data types required by both approaches and their use of this data to find explanatory sequences of behaviour are also unified. Realist methods of enquiry can provide the rules and theory for developing a model of phenomena of interest while ABS provides a technical platform in which to test that theory and hypotheses. Being able to study complex and even ethically difficult situations in detail beyond that which could realistically be captured in the real world provides researchers and particularly social scientists with a new and potentially useful approach to scientific investigation.

With the integration of realist approaches and ABS comes the opportunity to apply their complementarity to an important area of research; interventions. As described in Section 6, ABS modelling informed by a realist approach can be used to support and improve intervention development. Financial support for research is becoming increasingly scarce and competition increasing, and it would be timely to support intervention programmes with ABS to reduce the pressure on pilot studies which could reduce costs and potentially improve the effectiveness of the intervention and increase its subsequent impact.

There are challenges to be met when using ABS and realist approaches in support of intervention development. As with all interdisciplinary research, the level of understanding between ABS practitioners, social scientists and healthcare researchers about the language being used and the capabilities of each approach will have to be addressed. This is something that takes time and communication, but being aware of this issue from the start of a project will aid in overcoming any difficulties (Wear, 1999). A limitation of ABS as with all simulation and modelling approaches is that models and simulations are simplifications of reality providing only an estimate of what might occur in

reality (Law, 2006). However, as long as the results are communicated and understood in this context, the outputs of models can still be very useful in providing some evidence to help inform a decision.

A final challenge will be to ensure that ABS and realist approaches are truely applicable to the intervention being planned. Successful application of this approach will come from ensuring that ABS is used in situations where a key component of the proposed intervention is individual-level behaviour, and that the realist approach is correctly applied to produce sufficient data on which to build a model.

The integration of ABS and possibly other modelling and simulation approaches along with realist approaches in the support of intervention design has huge potential. These methods work best when applied to real world problems, and it is our hope that impactful applications of these methods will help to prove the effectiveness of this combined methodology.

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REFERENCES

Anderson R (2008). New MRC guidance on evaluating complex interventions. *BMJ* **337**: a1937.

Anthierens S, Tansens A, Petrovic M and Christiaens T (2010). Qualitative insights into general practitioners views on polypharmacy. *BMC Family Practice* **11(1)**: 1-6.

Archer M S (1995). *Realist social theory: The morphogenetic approach*. Cambridge university press: Cambridge.

Argyris C (1970). *Intervention Theory & Method: A Behavioral Science View*.

Bhaskar R (1979). *A realist theory of science*. Routledge: London.

Bryman A (2012). *Social research methods*. Oxford university press: Oxford.

Bryson J J, Ando Y and Lehmann H (2007). Agent-based modelling as scientific method: a case study analysing primate social behaviour. *Philosophical Transactions of the Royal Society B: Biological Sciences* **362(1485)**: 1685-1699.

Campbell D T (1988). *Methodology and epistemology for social sciences: Selected papers.* University of Chicago Press: Chicago.

Chalk D (2009). *Artificially Intelligent Foraging*. PhD thesis, University of Exeter.

Chen C C, Nagl S B and Clack C D (2007). Specifying, detecting and analysing emergent behaviours in multi-level agent-based simulations. *Paper presented at the Proceedings of the 2007 Summer Computer Simulation Conference*. San Diego, California.

Chen H T and Rossi P H (1980). The Multi-Goal, Theory-Driven Approach to Evaluation: A Model Linking Basic and Applied Social Science. *Social Forces* **59(1)**: 106-122. doi: 10.2307/2577835

Chen H T and Rossi P H (1983). Evaluating with sense the theory-driven approach. *Evaluation review* **7(3)**: 283-302.

Connelly J B, Duaso M J and Butler G (2007). A systematic review of controlled trials of interventions to prevent childhood obesity and overweight: A realistic synthesis of the evidence. *Public Health* **121(7)**: 510-517, doi: http://dx.doi.org/10.1016/j.puhe.2006.11.015.

Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I and Petticrew M (2008). Developing and evaluating complex interventions: the new Medical Research Council guidance. *BMJ* 337.

Elster J (2007). *Explaining social behavior: More nuts and bolts for the social sciences.* Cambridge University Press: Cambridge.

Escudero-Marin P and Pidd M (2011). Using ABMS to simulate emergency departments. *Paper presented at the Proceedings of the 2014 winter simulation conference*.

Eubank S, Guclu H, Kumar V A, Marathe M V, Srinivasan A, Toroczkai Z and Wang N (2004). Modelling disease outbreaks in realistic urban social networks. *Nature* **429(6988)**: 180-184.

Flynn T, Tian Y, Masnick K, McDonnell G, Huynh E, Mair A and Osgood N (2014). Discrete choice, agent based and system dynamics simulation of health profession career paths. *Paper presented at the Proceedings of the 2014 Winter Simulation Conference*.

Harachi T, Abbott R, Catalano R, Haggerty K and Fleming C (1999). Opening the Black Box: Using Process Evaluation Measures to Assess Implementation and Theory Building. *American Journal of Community Psychology* **27(5)**: 711-731, doi: 10.1023/A:1022194005511.

Law A (2006). *Simulation modeling and analysis (4 ed.)*. McGraw-Hill.

Olsen W (2010). *Realist Methodology (Vol. 2)*. SAGE Publications Ltd: London.

Pawson R (2006). *Evidence-based policy: A realist perspective*. SAGE Publications Ltd: London.

Pawson R (2013). *The science of evaluation: a realist manifesto*. SAGE Publications Ltd: London.

Pawson R, Greenhalgh T, Harvey G and Walshe K (2004). *Realist synthesis: an introduction*. ESRC Research Methods Programme, University of Manchester: Manchester.

Pawson R, Greenhalgh T, Harvey G and Walshe K (2005). Realist review – a new method of systematic review designed for complex policy interventions. *Journal of Health Services Research & Policy* **10(suppl 1)**: 21-34, doi: 10.1258/1355819054308530.

Pearson M, Brand S L, Quinn C, Shaw J, Maguire M, Michie S, Briscoe S, Lennox C, Stirzaker A, Kirkpatrick T and Byng R (2015). Using realist review to inform intervention development: Methodological illustration and conceptual platform for collaborative care in offender mental health. *Implementation Science* **10**:134.

Richards D and Rahm Hallberg I (2015). *Complex Interventions in Health : An overview of research methods*. Taylor and Francis: Oxford.

Šalamon T (2011). *Design of agent-based models*. Tomáš Bruckner: Řepín - Živonín.

Tulsky J A, Fischer G S, Rose M R and Arnold R M (1998). Opening the Black Box: How Do Physicians Communicate about Advance Directives? *Annals of Internal Medicine* **129(6)**: 441-449. doi: 10.7326/0003-4819-129-6-199809150-00003.

Wear D N (1999). Challenges to Interdisciplinary Discourse. *Ecosystems* **2(4):** 299-301. doi: 10.2307/3659022.

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