Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Behavioral Sciences

Review

Impactful environmental psychology needs formal theories

Anne E Urai[1], Fabian Dablander[2] and Jan Willem Bolderdijk[3]

Changing individual and collective behavior is critical to addressing the climate and ecological crisis. Environmental psychology is thus well-positioned to contribute knowledge to guide impactful climate action. However, we argue that it is not living up to its full potential, partly because its theories often remain verbal. Formalizing theories — expressing them in the precise language of mathematics or computer code — is especially important to give substance to thinking about complex systems, where nonlinearities and feedback loops make the effect of interventions hard to predict. Formal theories increase conceptual clarity and mechanistic understanding, advance cumulative science, enable '*in silico*' intervention testing, and improve integration into policy-relevant models. We illustrate how environmental psychologists can start incorporating theory formalization in their work.

Addresses
[1] Cognitive Psychology, Institute of Psychology, Leiden University, the Netherlands
[2] SEVEN, University of Amsterdam, the Netherlands
[3] Amsterdam Business School, Section Marketing, University of Amsterdam, the Netherlands

Corresponding author: Urai, Anne E (a.e.urai@fsw.leidenuniv.nl),
Urai, Anne E (@anne-urai.bsky.social),
Dablander, Fabian (@fdabl.bsky.social)

Current Opinion in Behavioral Sciences 2025, **66**:101619

This review comes from a themed issue on **Behavioral Science for Climate Change**

Edited by **Madalina Oana Vlasceanu** and **Grace Lindsay**

Available online xxxx

Received: 26 May 2025; Revised: 3 November 2025; Accepted: 4 November 2025

https://doi.org/10.1016/j.cobeha.2025.101619

Introduction

Understanding and changing human behavior is crucial to addressing the climate and ecological crisis. Environmental psychology can help us understand how individuals can be encouraged to act more pro-environmentally and engage in collective climate action [1]. To increase its impact, environmental psychology has recently been called to focus on high-impact behaviors and individuals [1,2]; develop, curate, and analyze large-scale datasets [3,4]; improve measurement practices [5,6]; and improve the theoretical basis for interventions [7,8].

Here, we argue that to further increase its impact, environmental psychology needs formal theories. This is especially crucial as behavioral science increasingly takes a 'systems view', explicitly conceptualizing behavior as arising from interactions between individual, social, and environmental factors [9,10]. *Complex systems*, which consist of multiple interacting components characterized by nonlinear relationships, *feedback loops*, and *emergent properties*, are notoriously difficult for humans to understand and predict [11,12] (see Box 1 for glossary). Without the help of formal theories, systems thinking thus risks remaining a vague collection of concepts rather than a powerful way to understand, predict, and influence behavior.

In this article, we explain what formal theories are, how to build them, and their many benefits for impactful environmental psychology. These include increasing mechanistic understanding, advancing cumulative science, enabling '*in silico*' intervention testing, and improving integration into policy-relevant models.

What are formal theories?

Environmental psychology is rife with theories [13,14], including the Theory of Planned Behavior, Value Belief Norm theory, and Protection Motivation Theory. Virtually all these are *verbal theories*, which use natural language (such as English or Dutch) to explain how various components (e.g. values, beliefs, norms) together produce some behavior (e.g. buying 'green' products or joining the climate movement). Psychology at large has long been criticized for being dominated by such 'soft', verbal theories, leading to a fragmented empirical literature that is difficult to integrate across domains [15–18]. In many fields of study, including cognitive science, physics, and biology, verbal theories are therefore considered only the first step towards a *formal theory* expressed in the language of mathematics, formal logic, or computer models.

Formalization starts with a candidate verbal theory. As familiar to most environmental psychologists, theory-building involves identifying all relevant parts of a target system and specifying their interrelationships. These can be represented in a conceptual box-and-arrow diagram that captures the theory's assumptions [19,20] (Box 1).

Box 1 Glossary.

- **Verbal theory**: a theory expressed in natural language (such as English) that aims to explain phenomena in the world.
- **Formal theory**: a theory expressed in the precise language of mathematics, logic, or computer code.
- **Formal or computational model**: a (often simplified) instantiation of a theory that specifies its components and their interrelationships, typically implemented in computer code that can generate predictions through simulation.
- **Complex system**: a system with multiple interacting components characterized by nonlinear relationships and feedback loops.
- **Feedback loop:** a process where the output of a system is fed back as an input; can be positive (reinforcing) or negative (balancing).
- **Emergent properties**: properties that parts of a system do not display on their own, but emerge when they interact in a system.
- ***In silico***: experiments performed using computer models. In biology, this is contrasted with '*in vitro*' studies of biological samples in a dish or '*in vivo*' experiments in live organisms.

Implementing the parts and their relationships in mathematical equations and/or computer code results in a formal model that instantiates the theory (see Box 2 for the different steps, and the paper by Fried [21] for a discussion on the definition of theories vs. models). This formalization process makes the model *generative* [22]. We can now use computer simulations to generate theory-implied data [16]: synthetic, quantitative data that reflect the theory's predictions. This is a crucial advantage over verbal theories, enabling us to more precisely deduce the predictions that the theory and its assumptions imply. Importantly, formalization often reveals predictions that were not clear from the verbal theory (see Robinaugh et al. [16] Figure 1, for a clear illustration of this point).

The process of formalization is often accompanied by the uncomfortable realization that one's verbal theory is vague on what the relevant components exactly are and how they precisely influence each other [17,23]. Since natural language is imprecise, formalizing one's assumption tests logical consistency and conceptual

Box 2 Formalizing theories: a very short primer.

What does it take to build formal theories? Many types of models exist. Particularly relevant to environmental psychology may be systems dynamics models [48] and agent-based models [23,49].

Here, we largely follow Borsboom's '*theory construction methodology*' [22] but expand on step 3.

1. The best start of a formal theory is to choose a phenomenon of interest and a 'soft theory' that explains it (also called verbal theory or prototype theory). This stage will be familiar to many environmental psychologists.
2. ***Design the model.*** This can be done on paper or with dedicated software, such as M-tool [20]. A common starting point for models of system dynamics is box-and-arrow diagrams.Define and visualize the components or constructs that make up the model.

   a. Determining the right level is crucial: are the components individual humans (with beliefs, behaviors, or emotions), groups, or societies [23]? Models with few components can be a good starting point to build intuition.
   b. Articulate how the various components interact. For each link, do we know, for example, the direction (uni- or bidirectional), weight (high/low), and functional form (linear, sigmoidal) [16]? Do the interactions include feedback loops, temporal dynamics (e.g. delays), or a spatial structure (e.g. a social or physical network)?

3. ***Construct the model, now with code*.**

   a. For systems modeling and basic simulation, VenSim can be freely downloaded for educational purposes. For agent-based modeling specifically, NetLogo is a good software [43]. Coding up your own model from scratch is a powerful way to inspect all the choices that may or may not be relevant. A good textbook to start coding models in R is provided in Ref. [50].

4. ***Verify and validate*** the model against data. This can be done by simulating the model's predictions ('theory-implied data') and by inspecting (visually or using statistical tests) if these produce reasonable behavior, and specifically the patterns that you are interested in understanding.

   a. Check the model's robustness using sensitivity analyses: how do predictions depend on the modeling choices you made? This stage often shows surprises and is important for building intuition for the effects of our assumptions.
   b. In some cases, we can *calibrate* parameters of the model using empirical data (also called 'model fitting'): tuning the model elements so they match certain phenomena in our data. The model's predictions should then be tested on new data.

5. Lastly, step back from your model and assess its overall worth. What aspects of the model could be simplified, or expanded? Which range of phenomena can your model explain, and which alternative model variants may be informative? Does the model predict new phenomena that could be experimentally tested? The scientist now enters a spiral of iterative theory development [22].

   a. Open science practices, especially sharing of well-documented code to accompany a paper's methods section, are crucial to make formal theory building truly cumulative.

clarity [12]. The process of formalization often reveals the source and extent of imprecision in verbal theories. It also helps with specifying what empirical data would be needed to arbitrate between different modeling choices, for example, whether relationships are linear or not, or how individual characteristics are distributed across a population (see Ref. [24] for an example of formalizing the 'extinction of experience' theory). Importantly, formalization is only as useful as the initial verbal theory is appropriate, valid, and empirically supported [19]. To avoid a false impression of mathematical precision that might come with abstract formalization, formal theories need to be grounded in real-world phenomena and data (Box 2).

Formal theories for grounded systems thinking

Formalizing theories often brings to light counterintuitive predictions that quickly surpass human capabilities of mental simulation [11,12]. Complex systems, where feedback loops, delays, nonlinearities, and emergent properties mean that the net effect of interventions becomes hard to predict, are especially difficult for humans to understand and intuit [11]. Behavioral science, including environmental psychology, is increasingly drawn to concepts from complex systems theory [9,10], including the notions of 'tipping points' [25] and 'attractor landscapes' [26], to conceptualize behavior change as a system moving between alternative states over time. This move towards systems thinking risks remaining vague when not grounded in formalized theories.

The most common theories in environmental psychology often (implicitly) assume that relationships between constructs are static and linear — they lack crucial elements that characterize complex systems. The Theory of Planned Behavior [27], for instance, is an example of a box-and-arrow diagram that implicitly assumes a one-directional relationship between antecedents of a behavior (e.g. attitudes, subjective norms, perceived behavioral control) and their outcome (e.g. pro-environmental behavior). Such a theory can be thought of as the representation of a simple system with unidirectional, linear effects. However, this overlooks crucial elements of complex systems such as feedback loops: what the theory considers outcomes may also influence antecedents. For instance, a positive experience with some pro-environmental behavior (e.g. taking the bus instead of the car) can lead to more positive attitudes towards that behavior [28], and one's publicly visible pro-environmental actions can influence other people's perception of the social norm [29], which in turn influences individual behavior. Formal modeling can help researchers simulate the effects of such *reinforcing feedback loops* and thus help to understand how behavior evolves over time, within individuals, and across groups.

Formal models are especially helpful to predict the sometimes counterintuitive effects of interventions. Interventions such as disruptive climate protests may trigger a host of feedback effects across different timescales, making the ultimate effect hard to predict. Formalization of these can help to anticipate whether well-intentioned interventions may backfire.

Benefits of formal theories

There is, simply put, nothing quite so practical as a good (formal) theory. Here, we list some benefits for environmental psychology, which can ultimately advance its real-world impact.

Increasing mechanistic understanding

Formal theories can increase understanding of the psychological mechanisms that give rise to behavior. They allow us to go beyond statistically describing patterns observed in data towards providing a working model of the mechanisms and processes that explain how and why a behavior came about and changes over time. In many fields, mechanistic insight has been key towards greater understanding and ultimately intervention in a system. For instance, knowing the structure of the DNA molecule allowed us to precisely understand the molecular mechanism behind long-known patterns of inheritance. For environmental psychology, such mechanisms may range from individual cognition to the spread of behaviors through social networks.

At the cognitive level, for instance, Liu et al. [30] showed that people perceive a greater impact of climate change when presented with binary data (history of lake freezes: yes or no) as opposed to continuous data (history of average winter temperatures). A formal Bayesian model was able to reproduce this phenomenon. Crucially, the model also gives insight into why humans behave this way: binary data points create an illusion of sudden shifts, even when underlying changes are gradual. The model provides an explanation of the behavioral effect in terms of fundamental, well-studied cognitive processes, and allows predicting people's perception of shifts in new data [30].

Formal models can also provide a mechanistic understanding of interactions between individuals. In well-studied laboratory coordination games, seemingly stable social conventions can undergo sudden 'tipping points': once a convention starts shifting, it tends to become self-reinforcing and changes quickly to a new stable convention [31]. These patterns can be simulated using formal models of interacting agents who aim to coordinate. This shows how — close to the system's tipping point — just a few additional people adopting a new convention can tip the whole group towards a new convention. Importantly, formal modeling can explain the behavioral mechanisms that determine why social tipping happens: only when individuals aim to coordinate on a shared convention (conformity), stick with habits (status quo bias), and follow trends (sensitivity to dynamic norms) does the game's group dynamics display classic tipping points [32].

Going beyond surveys and laboratory tasks, formal models can also be used to explore what mechanisms give rise to real-world behavior and the impact of policies. In an example from public health, between-country differences in mask-wearing behavior during COVID-19 could only be explained when simulating the interaction between disease progression, policy signals, and socio-cultural and economic factors such as risk perception and social norm adherence [33,34]. This shows how even under simplified assumptions (e.g. that all people in a country can be represented by an idealized average), formal models can explain between-country differences in aggregate behavior that may otherwise seem hard to understand.

While formal theories can help us understand the mechanisms giving rise to behavior, they are not necessarily the best tools for prediction. If prediction is the primary goal, tools from machine learning are likely better suited [35], especially in combination with large-scale, well-curated datasets of environmentally relevant behavior [3]. However, recent work has started to use 'deep learning' approaches, especially large language models, for theory development in psychology ([36], but see Ref. [37]).

Advancing cumulative science

Formal theories advance cumulative science by providing precise, testable predictions, making it possible to unambiguously identify whether a theory is supported or contradicted by empirical data. If a theory stays verbal, it makes imprecise or even ambiguous predictions, and it can often be reinterpreted to accommodate conflicting findings [38]. This makes verbal theories difficult to falsify, and they continue to stick around or 'fade away as people lose interest' [39]. Choosing a verbal theory comes down to personal preference, and theories become like toothbrushes:no researcher wants to use anybody else's [40]. In contrast, the precision of formal theories leads to risky predictions, allowing researchers to rigorously test theories across diverse contexts, leading to refinements, extensions, or even rejection of the theory in light of contradictory evidence. In this way, formalization is crucial for cumulative science [41,42].

Formal theories also provide a structured framework for generating 'risky' predictions. This makes research more targeted and systematic, ensuring that new studies directly contribute to theory refinement. For instance, the idea of the 25% 'social tipping point' (stating that a quarter of a population adopting a new convention can cause the whole group to change to the alternative) was first derived from a simple computational model [31]. The model made the risky prediction that tipping points would lie around 25% of a population (depending on both population size and individuals' memory length), which was later confirmed by empirical data [31].

Enabling '*in silico*' intervention testing

Formal models enable simulating how different interventions might play out in the real world, given our best understanding of the system under study. Such '*in silico*' intervention testing is an efficient way to assess the effectiveness, cost, or speed of different interventions. It also helps clarify the robustness of these estimates and their sensitivity to assumptions and modeling decisions [24,43]. This can help in selecting, evaluating, and adjusting interventions for impactful behavior change, before testing them in costly field studies.

For example, Hoffmann et al. [44] used an agent-based model, parameterized with survey data, to study how pro-environmental behavior (e.g. avoiding car use, installing solar panels, or urban greening) spreads across neighborhoods. In their model, pluralistic ignorance (a shared misperception of others' opinions) can keep a social system stuck in a norm everybody dislikes, such as front yards covered in concrete tiles. They then simulated the effects of two interventions, finding that whereas increased communication between neighbors has only a short-lasting effect on behavior, enhanced visibility of the same behavior leads to higher adoption rates. This suggests that improving visibility (e.g. signs or stickers) may be an effective intervention target to boost the spread of pro-environmental behavior through neighborhoods, setting the stage for testing this in a field study ([45] chapter 4).

Improving integration into policy-relevant models

Formal theories can help integrate insights from environmental psychology into policy-relevant Integrated Assessment Models (IAMs), which combine narratives of how society will develop in the future with coupled components that include climate, energy, and the economy. However, IAMs often include extremely crude assumptions about how humans make environmentally relevant decisions [46,47]. Currently, many common theories in environmental psychology are neither precise nor unified enough to be easily integrated into IAMs [13]. Formalization is thus an important step to be able to integrate (environmental) psychological theory into policy-relevant models.

Conclusion

As the climate and ecological crisis worsen, environmental psychologists are increasingly focused on real-world impact. Formal theories can improve the field's impact by increasing conceptual clarity and mechanistic understanding, advancing cumulative science, enabling '*in silico*' intervention testing, and allowing for better integration into policy-relevant models. Formalization is especially critical to give proper substance to reasoning about complex systems, where nonlinearities and feedback loops make the effect of interventions hard to predict. We hope that this short piece provides a starting point for environmental psychology to move towards a stronger focus on formal theories, ultimately increasing its real-world impact.

Author contributions

AEU and JWB conceptualized the project. AEU wrote the first draft. AEU, FD, and JWB together discussed the ideas and wrote the paper.

Data Availability

No data were used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Amelie Halstenberg for an excellent MSc thesis on formal models of social tipping points, which started the conversations that led to this paper. We thank Cameron Brick, Maien Sachisthal, Kristian Nielsen, and Vítor Vasconcelos for helpful feedback on the manuscript. AEU is supported by a Veni grant from the Dutch Research Council,The Netherlands VI.Veni.212.184.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Gurtner LM, Moser S: **The where, how, and who of mitigating climate change: a targeted research agenda for psychology**. *J Environ Psychol* 2024, **94**:102250, https://doi.org/10.1016/j.jenvp.2024.102250

2. Nielsen KS, Cologna V, Bauer JM, Berger S, Brick C, Dietz T, Hahnel UJJ, Henn L, Lange F, Stern PC, Wolske KS: **Realizing the full potential of behavioural science for climate change mitigation**. *Nat Clim Change* 2024,322-330, https://doi.org/10.1038/s41558-024-01951-1

3. Jenny MA, Betsch C: **Large-scale behavioural data are key to climate policy**. *Nat Hum Behav* 2022, **6**:1444-1447, https://doi.org/10.1038/s41562-022-01479-4

4. Vlasceanu M, Doell KC, Bak-Coleman JB, Todorova B, Berkebile-Weinberg MM, Grayson SJ, Patel Y, Goldwert D, Pei Y, Chakroff A, Pronizius E, van den Broek KL, Vlasceanu D, Constantino S, Morais MJ, Schumann P, Rathje S, Fang K, Aglioti SM, Van Bavel JJ: **Addressing climate change with behavioral science: a global intervention tournament in 63 countries**. *Sci Adv* 2024, **10**:eadj5778, https://doi.org/10.1126/sciadv.adj5778

5. Dablander F, Lange F, Brick C, Aron AR: **Expressing intentions is not climate action**. *Proc Natl Acad Sci USA* 2025, **122**:e2512457122, https://doi.org/10.1073/pnas.2512457122

6. Lange F: **Measurement approaches in climate action research**. *Curr Opin Behav Sci* 2025, **63**:101510, https://doi.org/10.1016/j.cobeha.2025.101510

7. Lange F, Nielsen KS, Cologna V, Brick C, Stern PC: **Making theory useful for understanding high-impact behavior. A response to van Valkengoed et al. (2021)**. *J Environ Psychol* 2021, **75**:101611, https://doi.org/10.1016/j.jenvp.2021.101611

8. van Valkengoed AM, Steg L, Perlaviciute G, Schultz PW, Brosch T, Gatersleben B, Nordlund A, Pahl S, Whitmarsh L: **Theory enhances impact. Reply to: 'The case for impact-focused environmental psychology'**. *J Environ Psychol* 2021, **75**:101597, https://doi.org/10.1016/j.jenvp.2021.101597

9. •• Hallsworth M: **A manifesto for applying behavioural science**. *Nat Hum Behav* 2023, **7**:310-322, https://doi.org/10.1038/s41562-023-01555-3.

A manifesto for including more systems thinking into applied behavioral science.

10. Dupoux M, Gaudeul A, Baggio M, Bruns H, Ciriolo E, Krawczyk M, Kuehnhanss C, Nohlen H: **Unlocking the Full Potential of Behavioural Insights for Policy: From Influencing the Individual to Shaping the System**. Publications Office of the European Union; 2025, https://doi.org/10.2760/7367599

11. •• Meadows DH: **Thinking in Systems: A Primer**. Chelsea Green Publishing; 2008.

A crucial guide for systems thinkers.

12. •• Smaldino PE: **Models are stupid, and we need more of them.** Computational Social Psychology. Routledge; 2017:311-331.

Guidance for scientists interested in formalizing their verbal theories, including insights on the philosophy of modelling and the need for collaborations between modellers and domain experts. Includes many references on the philosophy of formal modeling.

13. •• van Valkengoed AM, Perlaviciute G, Steg L: **Representing the drivers of lifestyle change in Integrated Assessment Models using theories from environmental psychology: introducing the Motivation, Agency, and Past Behaviour (MAP) framework**. *Environ Res Commun* 2025, **7**:032001, https://doi.org/10.1088/2515-7620/adb9bf.

Details why current theories in environmental psychology are insufficient to be useful in Integrated Assessment Models that are used in climate science and policy-making, and offers concrete suggestions for improving psychological models to this end.

14. • Brick C, Nielsen KS, Berger S, Henn L, Wolske KS, Lange F, Hanss D, Bauer JM, Aldoh A, Sachisthal MSM, Johnsen SÅK, Cologna V: **Current research practices on pro-environmental behavior: a survey of environmental psychologists**. *J Environ Psychol* 2024, **97**:102375, https://doi.org/10.1016/j.jenvp.2024.102375.

Survey of environmental psychologists, with one question about the theories used in their work. The most common response was 'no theory', and most of the theories listed are verbal theories (although no question mentioned formal theory or modeling). This work nicely represents the state of the field at this moment, from which we can chart a path towards improvement in the future.

15. Muthukrishna M, Henrich J: **A problem in theory**. *Nat Hum Behav* 2019, **3**:221-229, https://doi.org/10.1038/s41562-018-0522-1

16. •• Robinaugh DJ, Haslbeck JMB, Ryan O, Fried EI, Waldorp LJ: **Invisible hands and fine calipers: a call to use formal theory as a toolkit for theory construction**. *Perspect Psychol Sci* 2021, **16**:725-743, https://doi.org/10.1177/1745691620974697.

Clearly spells out the importance of formal theory in making verbal theories more concrete, explained using simple systems that show surprising behaviors. They outline how formal theories are tools for thinking, for evaluating explanations, for guiding future measurement, for further theory development, and for integration and collaboration.

17. van Rooij I, Blokpoel M: **Formalizing verbal theories**. *Soc Psychol* 2020, **51**:285-298, https://doi.org/10.1027/1864-9335/a000428

18. Proulx T, Morey RD: **Beyond statistical ritual: theory in psychological science**. *Perspect Psychol Sci* 2021, **16**:671-681, https://doi.org/10.1177/17456916211017098.
•• Special issue on theory development in psychology.

19. Gray K: **How to map theory: reliable methods are fruitless without rigorous theory**. *Perspect Psychol Sci* 2017, **12**:731-741, https://doi.org/10.1177/1745691617691949

20. van den Broek KL, Klein SA, Luomba J, Fischer H: **Introducing M-Tool: a standardised and inclusive mental model mapping tool**. *Syst Dyn Rev* 2021, **37**:353-362, https://doi.org/10.1002/sdr.1698

21. Fried EI: **Theories and models: what they are, what they are for, and what they are about**. *Psychol Inq* 2020, **31**:336-344, https://doi.org/10.1080/1047840X.2020.1854011

22. Borsboom D, van der Maas HLJ, Dalege J, Kievit RA, Haig BD: **Theory construction methodology: a practical framework for building theories in psychology**. *Perspect Psychol Sci* 2021, **16**:756-766, https://doi.org/10.1177/1745691620969647

23. Smaldino PE: **How to translate a verbal theory into a formal model**. *Soc Psychol* 2020, **51**:207-218, https://doi.org/10.1027/1864-9335/a000425

24. Reintgen Kamphuisen FM, Joye Y, Bolderdijk JW: **An agent-based model of the extinction of experience: how nature availability and connectedness to nature co-evolve over time**. *J Environ Psychol* 2025, **106**:102629, https://doi.org/10.1016/j.jenvp.2025.102629

25. Pizziol V, Tavoni A: **From niches to norms: the promise of social tipping interventions to scale climate action**. *NPJ Clim Action* 2024, **3**:1-8, https://doi.org/10.1038/s44168-024-00131-3

26. Heino MTJ, Proverbio D, Marchand G, Resnicow K, Hankonen N: **Attractor landscapes: a unifying conceptual model for understanding behaviour change across scales of observation**. *Health Psychol Rev* 2023, **17**:655-672, https://doi.org/10.1080/17437199.2022.2146598.
• Proposed attractor states and dynamics as a conceptual framework for viewing behavior change.

27. Ajzen I: **The theory of planned behavior**. *Organ Behav Hum Decis Process* 1991, **50**:179-211, https://doi.org/10.1016/0749-5978(91)90020-T

28. Thøgersen J: **Promoting public transport as a subscription service: effects of a free month travel card**. *Transp Policy* 2009, **16**:335-343, https://doi.org/10.1016/j.tranpol.2009.10.008

29. Kashima Y, Wilson S, Lusher D, Pearson LJ, Pearson C: **The acquisition of perceived descriptive norms as social category learning in social networks**. *Soc Netw* 2013, **35**:711-719, https://doi.org/10.1016/j.socnet.2013.06.002

30. Liu G, Snell JC, Griffiths TL, Dubey R: **Binary climate data visuals amplify perceived impact of climate change**. *Nat Hum Behav* 2025,1355-1364, https://doi.org/10.1038/s41562-025-02183-9

31. Centola D, Becker J, Brackbill D, Baronchelli A: **Experimental evidence for tipping points in social convention**. *Science* 2018, **360**:1116-1119, https://doi.org/10.1126/science.aas8827

32. Ye M, Zino L, Mlakar Ž, Bolderdijk JW, Risselada H, Fennis BM, Cao M: **Collective patterns of social diffusion are shaped by individual inertia and trend-seeking**. *Nat Commun* 2021, **12**:5698, https://doi.org/10.1038/s41467-021-25953-1

33. Yang L, Constantino SM, Grenfell BT, Weber EU, Levin SA, Vasconcelos VV: **Sociocultural determinants of global mask-wearing behavior**. *Proc Natl Acad Sci USA* 2022, **119**:e2213525119, https://doi.org/10.1073/pnas.2213525119

34. Mittal D, Constantino SM, Levin SA, Sloot P, Weber EU, Vasconcelos VV: **Policy, risk, and norms shape collective behaviors worldwide**. *arXiv* 2025, arXiv:2508.15098.

35. Breiman L: **Statistical modeling: the two cultures (with comments and a rejoinder by the author)**. *Stat Sci* 2001, **16**:199-231, https://doi.org/10.1214/ss/1009213726

36. Binz M, Akata E, Bethge M, Brändle F, Callaway F, Coda-Forno J, Dayan P, Demircan C, Eckstein MK, Éltető N, Griffiths TL, Haridi S, Jagadish AK, Ji-An L, Kipnis A, Kumar S, Ludwig T, Mathony M, Mattar M, ... Schulz E: **A foundation model to predict and capture human cognition**. *Nature* 2025, **644**:1002-1009, https://doi.org/10.1038/s41586-025-09215-4

37. I. van Rooij and O. Guest, Combining psychology with artificial intelligence: what could possibly go wrong?, Philpapers, 2025, ⟨https://philpapers.org/rec/VANCPW⟩.

38. Gigerenzer G: **Surrogates for theories**. *Theory Psychol* 1998, **8**:195-204, https://doi.org/10.1177/0959354398082006

39. Meehl PE: **Theoretical risks and tabular asterisks: Sir Karl, Sir Ronald, and the slow progress of soft psychology**. *J Consult Clin Psychol* 1978, **46**:806-834, https://doi.org/10.1037/0022-006X.46.4.806

40. Mischel W: **The toothbrush problem**. *APS Observer*; 2008: 21. ⟨https://www.psychologicalscience.org/observer/the-toothbrush-problem⟩.

41. Forscher BK: **Chaos in the brickyard**. *Science* 1963, **142**:339, https://doi.org/10.1126/science.142.3590.339.a

42. Newell A: **You can't play 20 questions with nature and win**. *Visual Information Processing*; 1973.

43. Smaldino PE: **Modeling Social Behavior: Mathematical and Agent-Based Models of Social Dynamics and Cultural Evolution**. Princeton University Press; 2023.

44. Hoffmann T, Ye M, Zino L, Cao M, Rauws W, Bolderdijk JW: **Overcoming inaction: an agent-based modelling study of social interventions that promote systematic pro-environmental change**. *J Environ Psychol* 2024, **94**:102221, https://doi.org/10.1016/j.jenvp.2023.102221

45. Hoffmann T: **From Your Frontyard to the Block: Pathways to Widespread Pro-Environmental Change** (PhD thesis), University of Groningen, FEB Research Institute; 2025, https://doi.org/10.33612/diss.1281652742

46. Mercure J-F, Pollitt H, Bassi AM, Viñuales JE, Edwards NR: **Modelling complex systems of heterogeneous agents to better design sustainability transitions policy**. *Glob Environ Change* 2016, **37**:102-115, https://doi.org/10.1016/j.gloenvcha.2016.02.003

47. Donges JF, Heitzig J, Barfuss W, Wiedermann M, Kassel JA, Kittel T, Kolb JJ, Kolster T, Müller-Hansen F, Otto IM, Zimmerer KB, Lucht W: **Earth system modeling with endogenous and dynamic human societies: the copan:CORE open World–Earth modeling framework**. *Earth Syst Dyn* 2020, **11**:395-413, https://doi.org/10.5194/esd-11-395-2020

48. Crielaard L, Uleman JF, Châtel BDL, Epskamp S, Sloot PMA, Quax R: **Refining the causal loop diagram: a tutorial for maximizing the contribution of domain expertise in computational system dynamics modeling**. *Psychol Methods* 2024, **29**:169-201, https://doi.org/10.1037/met0000484

49. Jager W, Ernst A: **Introduction of the special issue "Social simulation in environmental psychology"**. *J Environ Psychol* 2017, **52**:114-118, https://doi.org/10.1016/j.jenvp.2017.07.002

50. van der Maas HLJ: **Complex-Systems Research in Psychology**. SFI Press; 2024, ⟨https://santafeinstitute.github.io/ComplexPsych/⟩.
• This textbook is a great resource for those who already know a bit of R programming and want to dive deeper into complex systems models (and even fit them to their data).