An Abductive Methodology for Psychological Theory Construction

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Abstract

Current psychological research primarily employs the hypothetico-deductive method, which emphasizes the collection of empirical data to verify theories but neglects the process of theory (hypothesis) construction. In contrast, the abductive methodology not only focuses on detecting phenomena through empirical data but also emphasizes constructing explanatory theories for these phenomena. This methodology holds that scientific inquiry should be oriented toward research questions and comprises two main stages: first, phenomenon detection, which detects phenomena in the form of empirical generalizations through inductive methods; second, theory construction, which generates theories through existential abduction, develops theories through analogical abduction, and evaluates theories through inference to the best explanation. The abductive methodology provides a systematic explanatory framework and methodological guidance for theory construction in psychology.

Full Text

The Abductive Theory of Method for Psychological Theory Construction

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Abstract

Current psychological research primarily employs the hypothetico-deductive method, which emphasizes collecting empirical data to verify theories but neglects the process of theory (or hypothesis) construction. In contrast, the abductive theory of method (ATOM) focuses on both detecting phenomena through empirical data and constructing explanatory theories for those phenomena. This methodology posits that scientific inquiry should be problem-driven and consists of two main stages: first, phenomenon detection, which identifies phenomena in the form of empirical generalizations through induction; and second, theory construction, which generates theories through existential abduction, develops them through analogical abduction, and evaluates them through inference to the best explanation. ATOM provides a systematic interpretive framework and methodological guidance for theory construction in psychology.

Keywords: abductive theory of method, theory construction, psychology

Psychology as a science frequently encounters theoretical dilemmas in its development. First, the scientific methods currently in common use are not fully adequate for theory construction. Of the two scientific methods commonly used in psychological research, the hypothetico-deductive method tests existing hypotheses or theories through large amounts of data and evidence, a process that does not encompass theory construction. The inductive method distills general laws from observed facts, phenomena, and research findings; however, this process from particular to general suffers from logical incompleteness. These two scientific methods—one limited to verifying existing theories, the other constrained by the incompleteness of deriving universal laws from limited instances—may lead researchers to neglect or be unclear about how to systematically construct theories if psychology relies primarily on them. With the development of artificial intelligence and big data technologies, researchers increasingly depend on bottom-up, data-driven approaches (Liu et al., 2024), potentially exacerbating this dilemma.

Second, even when psychology has numerous theories, it rarely emphasizes theoretical unification. For example, Eronen and Bringmann (2021), in arguing that psychology lacks good theories, note that there are over 30 constructs related to perceived control alone, with researchers continuously introducing new related constructs. Consequently, Borsboom et al. (2021) metaphorically describe psychological theories as "small but abundant bubbles," suggesting that while psychology has many theories, they are small-scale and lack holism and unity. In this situation, there is a need to systematically compare and evaluate existing theories to screen and integrate them.

Third, the logical connection between theories and the facts used to test them is often weak. Regarding the causes of this theoretical dilemma, Oberauer and Lewandowsky (2019) suggest incomplete theory development and insufficient theory validation, which result in empirical observations that cannot effectively verify or falsify theories or hypotheses during empirical testing. The primary cause of all these theoretical dilemmas may be the lack of systematic methodological guidance for theory construction. As Borsboom et al. argue, psychology does not lack theories but rather a systematic theory construction program. In other words, more theories are not necessarily better; what matters is how to make theories more integrated and systematic.

How can these theoretical dilemmas be resolved? The abductive theory of method (ATOM) offers psychology researchers a new perspective. First, ATOM advocates that scientific inquiry should be a bottom-up process that begins with detecting new phenomena and proceeds to theory construction. This process integrates two forms of reasoning—induction and abduction—along with multiple research methods and strategies, forming a relatively systematic scientific research framework. To some extent, this framework compensates for the problem of the hypothetico-deductive method' s emphasis on hypothesis verification at the expense of theory construction, as well as the logical limitations of induction. Second, ATOM provides systematic methods and procedures for theory construction, covering the entire process from discovering new phenomena through various quantitative and qualitative data analyses to cross-validating explanatory theories through multiple methods, offering guidance for building unified psychological theories. Finally, ATOM emphasizes the theoretical explanation of detected phenomena, arguing that explanatory theories should be constructed more systematically through a series of steps including theory generation, theory development, and theory evaluation. In this process, continuous iteration of theory development and evaluation enables researchers to construct more robust and reliable theories. Thus, ATOM provides a systematic framework for psychological theory construction.

2 Background of ATOM' s Proposal

The proponent of ATOM is Brian Douglas Haig. Haig, a New Zealander, earned his Ph.D. in philosophy from the University of Alberta, Canada, in 1975 and subsequently worked in the Department of Psychology at the University of Canterbury, New Zealand. His research focuses primarily on theoretical psychology, research methodology, and educational theory. To date, Haig has published over 160 high-quality papers and books and was elected a Fellow of the New Zealand Psychological Society and a Fellow of the Association for Psychological Science in 2008 and 2010, respectively. Haig (2023) maintains a scientific realist stance, emphasizing that applying scientific realism in psychology requires a more local perspective—evaluating and understanding theories within specific scientific domains and empirical contexts—to better accommodate psychology' s distinctive nature. Scientific realism is a philosophical position holding that scientific theories can truly reflect the real world (Haig, 2014). However, antirealism holds different positions on scientific theories; for instance, instrumentalism views theories merely as tools for predicting observable phenomena, while social constructivism regards knowledge (including theoretical knowledge) as a product of social negotiation rather than a simple reflection of objective reality (Chakravartty, 2017). The abductive reasoning employed in ATOM presupposes the existence of theoretical entities, aligning with the scientific realist perspective. Scientific realism guides ATOM to adopt methods that can effectively reveal underlying mechanisms during theory construction, such as exploratory factor analysis.

Abductive reasoning is a crucial form of inference in ATOM, with its origins traceable to American philosopher and scientist Charles Sanders Peirce (1839–

1914). Abductive reasoning attempts to explain a surprising or unexpected event (C) by providing a possible explanation (A) for a new discovery or phenomenon that does not fit existing knowledge systems. The logical pattern of this reasoning is as follows (cited from Wible, 2023): (1) A surprising fact C is observed; (2) If A were true, then the occurrence of C would be a matter of course; (3) Therefore, we have reason to suspect that A is true.

The internal logic of abductive reasoning differs from both hypothetico-deductive and inductive reasoning. The hypothetico-deductive process derives directly testable research hypotheses about empirical facts from a theory or hypothesis, then verifies or falsifies these hypotheses through experiments or other research methods. Although this reasoning process is relatively rigorous logically, its limitation lies in that formal logical deductive reasoning only tests preset hypotheses, neglecting the generation of new phenomena and new theories, and thus does not actually produce new knowledge. Induction is generally considered a scientific research method that operates in the opposite direction to the hypothetico-deductive method. Induction is the process of finding consistency from observed facts or phenomena and deriving universal laws, emphasizing the importance of forming empirical generalizations in scientific inquiry. However, strictly speaking, this process is merely a descriptive summary of the external characteristics of things (Haig, 2014), and the conclusions of induction cannot yet be regarded as "theories." For example, we observe that when a bear appears before people, they exhibit behavioral responses such as fleeing and trembling, along with emotional responses such as fear. We then summarize the external characteristics of such phenomena: behavioral and emotional responses occur simultaneously when facing dangerous situations. However, conclusions drawn from induction are based on limited observations or instances, making inductive results uncertain and refutable. For instance, some people do not exhibit the aforementioned emotional and behavioral responses when seeing a bear because the bear is caged and poses no threat to them.

In contrast to inductive and deductive reasoning, abductive reasoning can creatively generate new knowledge. It starts from observed new phenomena and attempts to find the best explanatory theory for that phenomenon. For example, water marks on the road in the early morning might lead us to speculate that it rained last night or that other causes are responsible; through this speculative process, a possible explanation for the phenomenon is found. Since abductive reasoning speculates about possible causes of new phenomena, its conclusions are also not necessarily certain and require further empirical validation.

These three forms of reasoning together constitute the complete process of knowledge acquisition (Minnameier, 2004; see Figure 1 [Figure 1: see original paper]): In the first stage, after observing new facts, abductive reasoning yields a possible explanatory theory about the phenomenon; in the second stage, the proposed theory is verified through hypothetico-deductive reasoning; in the third stage, induction is used to summarize whether the research results from the previous stage are consistent with the original empirical facts. If new facts emerge, a new round of exploratory theory construction must begin with abductive reasoning, and so on in a cyclical manner. This process of knowledge acquisition is also the process of scientific inquiry, reflecting the complementarity of the three forms of reasoning.

Unfortunately, previous methodology textbooks in psychology and other disciplines have mostly mistakenly assumed that deductive and inductive reasoning represent all forms of inference, rarely mentioning abductive reasoning. Of course, no single form of reasoning can "stand alone."

Haig (2005) argues that while induction plays an important role in discovering phenomena in the form of empirical generalizations, theory construction is equally important. Although the hypothetico-deductive method plays a key role in theory testing, it only involves one part of theory construction (Simon, 1977). While abductive reasoning moves from phenomenon identification to theory construction, it lacks a process for how to discover phenomena. Evidently, each of these three methods only involves one or several stages of scientific inquiry, and only when combined can they comprehensively cover the scientific inquiry process. In traditional philosophy of science theories, inductivism emphasizes that scientific theories are induced from empirical facts, while deductivism emphasizes that theories are derived through logical reasoning and a priori principles —one valuing facts, the other valuing deductive derivation. However, there has previously been no philosophy of science theory specifically emphasizing the abductive reasoning process, unable to effectively explain how to ascend from observed facts or phenomena to theories. Therefore, Haig proposed the abductive theory of method (ATOM), which not only concerns how to operationalize the detection of empirical facts through induction but also explores how to proceduralize the construction of scientific theories through abductive reasoning, thereby providing a more systematic methodological framework for behavioral science research. Although both induction and abductive reasoning play important roles in the ATOM theoretical framework, the latter occupies a dominant position, hence the name "abductive theory of method."

ATOM' s proposal was a process. Ward and Haig (1997) first employed abductive methods in the psychological assessment of clinical patients to help clinicians more effectively reason about the causes of problems at each assessment stage, providing a relatively systematic assessment framework that includes four stages: phenomenon detection (identifying and describing patients' psychological problems), theory generation (forming preliminary conjectures about the underlying mechanisms producing psychological problems), theory development (building conceptual models of problems based on existing psychological theories and experience), and theory appraisal (evaluating the adequacy of theories or hypotheses). Subsequently, Ward et al. (1999) more comprehensively outlined the application of abductive reasoning in clinical psychological assessment and first used the concept of ATOM. By 2005, Haig expanded the application of abductive reasoning to the entire field of behavioral science research, no longer limited to clinical psychological assessment, and formally proposed ATOM for behavioral science, which had by then become a scientific philosophy theory of general significance.

3 Main Arguments of ATOM

From ATOM' s perspective, scientific inquiry is a process: under the guidance of research problems, researchers reveal specific phenomena through systematic data analysis and subsequently construct explanatory theories for these phenomena. According to the constraint-inclusion view (Haig, 1987, 2005, 2014), research problem formulation should include all constraints on problem solutions and requirements for finding solutions, encompassing empirical, theoretical, and methodological constraints, which constitute the problem itself. For example, a researcher investigating the effect of a teaching method on student learning outcomes might face empirical constraints from previous research findings, theoretical constraints from different schools of learning theory, and methodological constraints regarding experimental design and sample selection. By integrating these constraints, researchers can more systematically define research problems. Clearly defining and formulating a research problem is equivalent to solving half of it. However, since many important research problems are typically unstructured, Haig argues that the fundamental purpose of scientific research is to better define research problems by introducing various required constraints during the research process. Different stages of scientific inquiry may require clarifying and solving problems to varying degrees. For instance, when researchers discover a new phenomenon, that phenomenon becomes one of the constraints for further constructing an explanatory theory—that is, constructing an explanatory theory for Phenomenon A rather than Phenomenon B. Subsequently, when constructing a theory for Phenomenon A, methodological constraints (such as prioritizing theories that are parsimonious and have broader explanatory power) come into play. After clarifying the research problem, researchers first analyze data to discover stable empirical regularities or phenomena. Once these phenomena are identified, scientists use abductive reasoning to infer the underlying causes of these phenomena, thereby constructing explanatory theories. Therefore, ATOM's scientific inquiry process mainly includes two stages: phenomenon detection and theory construction (see the overall framework in Table 1), which we elaborate on below.

3.1 Phenomenon Detection Stage

Phenomena are relatively stable, recurrent general features that exist in the world, typically appearing in the form of empirical generalizations (including generalizations about states, objects, processes, events, and other difficult-to-classify features) (Haig, 2013b). There are two common types of phenomena. The first is effects—specific phenomena caused by certain factors. Effects focus on describing phenomena under specific conditions and may be named after their discoverers, such as the Rosenthal effect in psychology, the Doppler effect in physics, and the Baldwin effect in biology. The second is laws–generalizations of objective regularities between things. Laws focus on describing universally applicable regularities, such as the law of effect in psychology (describing the association between individual behavior and its consequences), the law of universal gravitation in physics, and the law of conservation of mass in chemistry. By understanding these phenomena, people can gain deeper insights into the fundamental rules governing the natural world and the complexity of human behavior. For example, the Rosenthal effect has been widely applied in education because it generalizes the impact of teacher and parent expectations on student academic achievement (Ma & Wei, 2017; Sakar, 2023). These phenomena not only help us understand past events but also provide a basis for predicting future events.

However, phenomena may not be directly observable but must be abstracted from data through analysis and interpretation. Therefore, data serve as evidence and tools for understanding phenomena. In psychology, researchers collect large amounts of data to discover and describe phenomena. These data include two major categories: first, subjective measurements of psychological feelings, cognitions, and concepts, such as self-reports of emotional experiences; and second, objective measurements of the external conditions, behavioral and physiological manifestations of psychological activities, such as stimulus intensity, reaction time, and EEG data (Xin, 2024). Through data collection, analysis, and discussion, researchers can extract phenomena from data, thereby gaining deeper understanding of human behavior and psychological processes.

How can phenomena be detected through data? ATOM summarizes the phenomenon detection process as a statistics-oriented, multi-stage data analysis (see Table 1 , Phenomenon Detection Stage), employing various strategies and statistical methods to explore and reconstruct phenomena. The first stage is initial data analysis. The main task at this stage is data cleaning and preparation to ensure data quality, including checking data accuracy, handling missing and outlier values, and assessing whether data meet statistical assumptions. The second stage is exploratory data analysis. This stage aims to reveal data structure and patterns through various intuitive, simple statistical methods (such as stem-and-leaf plots and box plots), helping researchers promptly identify anomalous data. The third stage is approximate replication. This stage uses computer-intensive resampling methods, such as bootstrap, jackknife, and cross-validation, to verify the robustness of data patterns discovered in the second stage. These methods allow researchers to conduct thousands or even millions of computations across multiple data points to assess the consistency and reliability of sampling results. The fourth stage is constructive replication. In the process of confirming the existence of phenomena, researchers need not only to test the consistency of data patterns through approximate replication but also to test the generalizability of results through constructive replication. The latter demonstrates the universality and replicability of results across different methods, treatment levels, and contexts by varying key variables. However, the above data analysis strategies are not the only way to discover phenomena; meta-analysis is also a common method for discovering phenomena. The entire phenomenon detection process is a process of enumerative induction, whether through statistics-oriented multi-stage data analysis or meta-analysis.

3.2 Theory Construction Stage

Discovering phenomena is not only crucial for scientific inquiry, but constructing explanatory theories for phenomena is equally important. ATOM argues that the important function of phenomena is to motivate people to explore explanatory theories for them, as this not only helps us understand the mechanisms behind phenomena but also promotes the deepening and expansion of scientific knowledge. The entire theory construction process includes three stages: theory generation, theory development, and theory appraisal (see Table 1 , Theory Construction Stage). Each stage corresponds to a form of abductive reasoning: existential abduction, analogical abduction, and inference to the best explanation (IBE). Although theory generation precedes theory development, theory appraisal begins with theory generation, accompanies the theory development process, and finally extends to the comparative evaluation of mature theories. Therefore, these three stages do not occur in strict chronological order. Generally, theory generation and theory development follow a temporal sequence, while theory appraisal runs throughout the entire theory construction process. This dynamic theory construction process ensures continuous optimization and improvement of theories.

First, the theory generation stage. Theory generation is the initial phase of theory construction, involving the formation of preliminary explanatory theories through existential abduction. Existential abduction refers to hypothesizing the existence of unknown entities in the absence of direct evidence (Thagard, 1988) to construct causal explanations. For example, when Spearman proposed his two-factor theory, he inferred the existence of a general factor (g factor) and multiple specific factors (s factors) by observing correlations between different intelligence tests. This process is similar to the logic of existential abductive reasoning: inferring the most likely explanation (hypothesizing the existence of g and s factors) from a phenomenon (correlations among multiple intelligence test results). This reasoning mode encourages researchers to transcend existing knowledge boundaries and explore potentially new areas, facilitating the acquisition of new scientific theories beyond current frameworks. The general logical pattern of existential abductive reasoning can be summarized as: (1) A surprising empirical phenomenon P is observed; (2) If hypothesis H is approximately true and relevant auxiliary knowledge A is invoked, then P would naturally occur; (3) Therefore, we have reason to believe that H is initially plausible and worthy of further investigation.

The logical form of theory generation emphasizes the reasoning process from phenomena to theories. However, this scientific inquiry process requires attention to several points: First, the facts requiring explanation in science are not single specific events but empirical generalizations or phenomena. Second, within the philosophy of science, phenomena or facts can be explained not only by proposed theories but also discovered through auxiliary knowledge. For example, Spearman used the g factor (general intelligence) to explain the positive correlation phenomenon between different intelligence or cognitive ability tests, and this phenomenon can be discovered whether using the Wechsler Intelligence Scale or other intelligence tests, where intelligence tests serve as auxiliary knowledge. Third, existential abduction does not guarantee discovery of absolute truth. In scientific inquiry, researchers pursue plausibility—that is, whether a hypothesis is reasonable within the current knowledge system and can be temporarily accepted. Fourth, the conclusion of the reasoning cannot assert that the hypothesis is true but only provides a preliminary plausibility judgment, indicating that the hypothesis is worthy of further investigation. Fifth, the existential abductive reasoning pattern only concerns logical form; however, the theory generation process needs to incorporate a series of normative constraints (such as heuristics, rules, and principles) to ensure that the generated theory has preliminary credibility and plausibility.

In the theory generation process, ATOM employs an operational abductive method: exploratory factor analysis. It hypothesizes the existence of latent variables (i.e., common factors) by discovering correlation patterns among variables and uses the principle of the common cause to generate theories during this process. Haig (2014) argues that theories initially formed in this way can be understood as genuine theoretical entities. Exploratory factor analysis shares similar characteristics with existential abductive reasoning: the former assumes the existence of latent variables (such as the "two factors" in Spearman' s intelligence model), while the latter assumes the existence of unknown entities. Therefore, exploratory factor analysis can serve as a concrete method for operationalizing abductive reasoning. Although exploratory factor analysis well reflects the characteristics of abductive reasoning, it focuses on common factors and thus can appropriately function as a theory generator only in multivariate contexts where a common causal structure exists (i.e., where multiple variables share common latent factors). Moreover, theories generated through existential abduction only possess preliminary plausibility because they represent only initial understanding and explanation of phenomena. For example, exploratory factor analysis simply delineates factor structure and requires empirical evidence to fully verify its validity and reliability.

Second, the theory development stage. Theories generated in the theory generation stage typically have a tentative nature (i.e., hypothesizing the existence of theoretical entities) and preliminary plausibility. Therefore, to more deeply understand the nature of these theoretical entities, we need to adopt appropriate research strategies to develop theories. Analogical modeling is a research strategy recommended by ATOM that develops explanatory theories by establishing analogical relationships between the modeling subject and source models (Haig, 2013a). This analogical relationship includes positive analogy (similar attributes between source model and modeling subject), negative analogy (different attributes between source model and modeling subject), and neutral analogy (lack of reliable knowledge about matching attributes between source model and modeling subject). When considering the plausibility of analogical modeling, positive analogy is the core: by identifying similarities between source models and modeling subjects, it provides a foundation for theory development. Negative analogy is irrelevant to the purpose of analogical modeling but helps clarify differences between source models and modeling subjects, thereby avoiding over-analogy. Neutral analogy, where the similarity or difference of certain features remains undetermined, provides space for further research and exploration of analogical models, maintaining their openness. Moreover, the selection of source models in analogical modeling is crucial: priority should be given to well-studied source models with mature theories, while requiring obvious similarities in key attributes between source models and modeling subjects. For example, Darwin used artificial selection as a source model because it was highly similar to natural selection in the core attribute of "selection mechanism." The logic of this method is analogical abduction, whose general reasoning pattern is: (1) In scenario S1, hypothesis H about attribute Q is correct; (2) In terms of attribute Q, scenario S1 is similar to scenario S2; (3) Therefore, an analogy of H may also apply to scenario S2.

Through this reasoning mode, researchers can apply known hypotheses or theories to new situations, thereby expanding understanding and knowledge of unknown hypotheses or theories. For example, Skinner observed animal behavior in experimental boxes (scenario S1), discovered that animal behavior could be shaped through rewards or punishments (hypothesis H), and thus proposed the theory of operant conditioning. Later, he analogized this discovery to human behavior (scenario S2), arguing that human behavior could similarly be changed through reinforcement (rewards) or punishment. Analogical abduction plays an important creative role in theory development, as it can generate new theories through analogy with old theories. Its creativity is precisely manifested in the difference between source models and modeling subjects during the analogical modeling process. For example, although the computer operation process is widely used to simulate and understand human cognitive processes, human cognitive apparatus (the modeling subject) is not actually equivalent to computers (the source model). Despite their fundamental differences, this analogy helps us understand complex cognitive processes. Analogical abduction helps researchers understand and develop theories by comparing entities from known domains with entities from unknown domains, making it considered an indispensable cognitive tool in scientific practice.

Finally, the theory appraisal stage. For a potential theory to achieve genuine knowledge status, it requires further theoretical evaluation. ATOM employs another form of abductive reasoning for theory appraisal: inference to the best explanation (IBE). This reasoning mode is based on the recognition that our understanding of the world largely depends on considerations of explanatory value (Haig, 2009). For example, if theory A can better explain a phenomenon than its competing theory B, then theory A should be prioritized. Initially, the IBE reasoning pattern was used to infer explanatory hypotheses for a set of data (Josephson & Josephson, 1994). However, the facts that science seeks to explain are empirical phenomena rather than data; what needs to be inferred is the best explanatory theory rather than a hypothesis; and when arguing conclusions, the focus should be on whether the theory is better than other competing theories rather than whether the hypothesis is true. Therefore, Haig (2009) revised Josephson and Josephson' s IBE reasoning pattern and proposed the IBE reasoning pattern for the theory appraisal process within the ATOM framework: (1) P1, P2, etc., are surprising empirical phenomena. (2) Theory T explains P1, P2. (3) No other theory can explain P1, P2, etc., better than T. (4) Therefore, T is accepted as the best explanatory theory.

Since IBE' s evaluation criteria can reliably identify the best explanatory theory, ATOM adopts it as the preferred method for theory appraisal. According to the principle of explanatory coherence (Thagard, 1992), the core of inferring the best explanation is to establish explanatory coherence—that is, to infer whether a theory is the best explanatory theory depends on whether it is more coherent in explanation than competing theories. Whether a theory is coherent can be judged by three criteria: explanatory breadth, simplicity, and analogy (Thagard, 1978). Explanatory breadth is the most important criterion for selecting the best explanatory theory. If a theory can explain a broader range of facts, it demonstrates higher theoretical coherence. Simplicity favors theories that use fewer special or ad hoc assumptions, while also imposing constraints on the explanatory breadth criterion—namely, that enhancing theoretical breadth should not come at the expense of simplicity. Analogy enhances the explanatory power of new theories through analogy with known theories. For example, Darwin' s theory of natural selection increased its explanatory value through analogy with the known process of artificial selection. These three criteria work together in the theory appraisal process to help researchers determine which theory provides a better explanation.

In summary, ATOM's theory construction process is a rigorous and coherent logical system. It generates a preliminary plausible theoretical explanation through existential abduction, then develops the theory through analogical abduction, and finally evaluates the theory through inference to the best explanation. In the theory construction process, the three forms of abductive reasoning complement each other. The role of existential abduction is to infer possible explanations from new phenomena. However, since it cannot assess whether this explanation is reasonable, inference to the best explanation can be used to initially select the best explanation from multiple possible explanations through theoretical analysis. At this point, the explanatory theory is still initial and requires further development through analogical reasoning. Finally, multiple competing theories developed through this process undergo evaluation of explanatory coherence. By clarifying this iterative theoretical process, ATOM provides a relatively comprehensive and systematic methodological framework for theory construction in psychology and the behavioral sciences.

4 Application of ATOM in Psychology

The following section illustrates how ATOM can be applied to psychological research using specific examples. Borsboom et al. (2021) tailored a theory construction framework for psychology based on ATOM—the theory construction methodology—which includes five steps (see Figure 2 [Figure 2: see original paper]).

Step 1: Identify new empirical phenomena. Researchers observe and discover certain phenomena, and after repeated summarization, confirm that these phenomena are stable and reliable. For example, Kahneman and Tversky (1979) discovered the phenomenon of loss aversion in risky decision-making through extensive experimental evidence. This phenomenon refers to people' s greater aversion to losses compared to their pleasure from equivalent gains.

Step 2: Form a prototype theory. The process of forming a prototype theory involves proposing a preliminary explanatory model through abductive reasoning after identifying a phenomenon. Initially, theories typically only generally express that if the theory or hypothesis were true, the corresponding phenomenon would occur. Researchers can then use analogical abduction to analogize explanatory principles from other domains to better construct explanatory theories for phenomena. Kahneman and Tversky' s prospect theory can be used to explain the aforementioned phenomenon in risky decision-making, using a value function to explain loss aversion—the value function is concave for gains and convex for losses, here analogizing mathematical concave and convex functions.

Step 3: Develop a formal theory. This process does not involve fitting data models through statistical methods such as ANOVA or regression analysis but rather employs formal theory—that is, capturing the principles of explanatory theories through a set of equations, computational programming languages, or logical rules. Formal theory expresses theoretical structures through more precise language, enabling researchers to derive precisely the behaviors predicted by the theory (Robinaugh et al., 2021). Combining formal theory with ATOM' s theory development stage can enhance theoretical precision and predictive power. For example, prospect theory uses a value function to express psychological feelings toward gains and losses and decision weights to describe subjective perception of probabilities, mathematically and intuitively explaining human decision-making behavior under risk and uncertainty.

Step 4: Check the adequacy of the formal theory. This step requires conducting simulation studies or analytical derivations to verify whether the formal model can explain empirical phenomena. Computer simulation methods, such as Agent-Based Modeling, can be used to test formal models. This method constructs virtual worlds where individuals interact according to set rules, simulating micro-level individual behaviors and their interaction patterns to reproduce macro-level complex phenomena and predict their development trends (Yang et al., 2024). This facilitates more detailed testing during theory appraisal in ATOM by simulating different situations and conditions to test theoretical robustness. Continuing with the above example, if repeated data simulations and mathematical analyses show that the combination of the value function and decision weights can explain the previously demonstrated empirical phenomena, this indicates that prospect theory has adequacy.

Step 5: Evaluate the value of the constructed theory. The final step primarily involves theoretical analysis to examine whether prospect theory can explain a broader range of risky decision-making phenomena, whether its expression is parsimonious, and whether it can better explain risky decision-making phenomena compared to other theories. By following these five steps, researchers can construct a relatively complete explanatory theory for observed phenomena. Based on the ATOM template, the theory construction methodology not only provides a structured approach for constructing psychological theories but also offers new perspectives and methodological tools for solving psychology' s theoretical dilemmas, helping to promote theoretical development across the discipline.

5.1 Scientificity and Rationality of ATOM

Since the ATOM for scientific inquiry was formally proposed in 2005, twenty years have passed. During this period, Haig and his collaborators have extensively argued for ATOM through numerous theoretical articles. Haig has not only conducted theoretical analyses of ATOM (Haig, 2005, 2008a, 2014) but also compared it with the hypothetico-deductive method, induction, and inference to the best explanation, which hold pivotal positions in science (Haig, 2008b, 2019). As mentioned earlier, some existing scientific inquiry methods have limitations in theory construction. Induction yields conclusions that remain descriptive empirical generalizations rather than theories, while the hypothetico-deductive method completely skips theory construction. Compared with induction, inference to the best explanation does not summarize facts descriptively but rather infers the best explanation for facts in theoretical form; compared with the hypothetico-deductive method, inference to the best explanation views the relationship between theory and phenomenon as explanatory rather than logically necessary. Although inference to the best explanation is useful for evaluating the value of different competing theories, it cannot cover the entire theory construction process. Undeniably, these methods have played important roles in specific domains—for example, induction is important for discovering phenomena, hypothetico-deductive reasoning for hypothesis testing, and inference to the best explanation for theory appraisal. However, scientific inquiry is a continuous process that may require using different scientific methods. Therefore, Haig integrated multiple research methods and strategies to form the ATOM model. He did not incorporate the hypothetico-deductive method into ATOM but instead used induction to detect phenomena and abductive reasoning to construct theories (including using inference to the best explanation to evaluate the value of competing theories). Thus, the scientificity and rationality of

ATOM lie in that researchers can combine the advantages of different scientific methods under the ATOM framework—for example, integrating induction and abductive reasoning (including existential abduction, analogical abduction, and inference to the best explanation)—and apply them to multiple domains rather than just specific domains.

Additionally, ATOM incorporates grounded theory, a relatively mature method in qualitative research, for theory generation (see Table 1), thereby providing strong support for theory construction in qualitative research. Grounded theory, as a commonly used theory construction approach in qualitative research, typically collects data through interviews and field observations, then codes the data and conducts theoretical sampling, finally generating theories (Glaser & Strauss, 1967). ATOM and grounded theory share both similarities and differences (Haig, 2018). The similarities are that both emphasize a "facts before theory" and "bottom-up" scientific inquiry process—that is, generating theories from data or phenomena—and both emphasize that theory construction is not accomplished in one step but is a dynamic process of continuous development. The differences are mainly reflected in three aspects.

First, regarding the philosophical foundation of methodology, ATOM explicitly elaborates phenomenon detection and theory construction based on realism and emphasizes that theories should be based on genuine understanding of phenomena. However, grounded theory' s philosophical stance is not unified: some researchers lean toward realism, believing that grounded research should "discover" theories rooted in empirical data; others adhere to anti-realism (such as social constructivism), viewing theories as merely interpretive analyses (Wu et al., 2016), a kind of "invention" or "construction." Second, in terms of theory construction, ATOM uses different forms of abductive reasoning to generate and develop theories, then evaluates theories through inference to the best explanation. Grounded theory, however, focuses on generating theories through the method of constant comparison and does not provide a systematic theory construction method. Finally, regarding application, ATOM, as a methodological framework, can be used for both qualitative and quantitative research, providing a more general and structured framework for scientific research (including problem representation, phenomenon detection, theory generation, theory development, and theory appraisal). Grounded theory is typically regarded as a specific qualitative research method, focusing more on qualitative analysis and the gradual development of theories. In summary, ATOM is a universal philosophy of science theory that elaborates the general process of theory construction. Grounded theory is only a specific qualitative research method used to inductively generate theoretical frameworks from empirical data and is therefore used by ATOM as a specific technique for theory generation.

5.2 Advantages and Value of ATOM

First, ATOM holds that phenomenon detection and theory construction are equally important. From the perspective of philosophy of science, this bridges the long-standing disconnect between scientific practice and philosophical reflection. Xu (2019) argues that ATOM strengthens the advantages of abductive reasoning and balancedly addresses two key stages of scientific inquiry: on the one hand, it focuses on the creative context of scientific discovery—the context of discovery; on the other hand, it maintains rigorous standards in the process of scientific theory or hypothesis verification—the context of justification. This dual-pronged methodology overcomes the past defect of overemphasizing the context of justification while neglecting the context of discovery. Simultaneously, this helps ameliorate the problem that because the hypothetico-deductive method has become mainstream in psychological research, researchers overly focus on hypothesis testing while neglecting theory construction.

Second, ATOM is a comprehensive framework that integrates multiple research methods, enabling researchers to combine and apply different research methods and strategies according to research goals and needs during scientific exploration, demonstrating high flexibility and applicability. For example, researchers conducting quantitative studies can choose exploratory factor analysis for theory generation, while those conducting qualitative studies can choose grounded theory for theory generation. Thus, ATOM can adapt to different research needs.

Third, ATOM provides a series of followable steps for phenomenon detection and theory construction, demonstrating strong operability and wide applicability across multiple domains. It not only offers a valuable methodological framework for philosophy of science and psychology but has also been applied in artificial intelligence. For example, Thagard (2024) proposed a set of evaluation criteria to test the ability of generative AI programs to perform explanatory reasoning and used these criteria to determine the extent to which ChatGPT can conduct explanatory reasoning, clearly employing some concepts and ideas from ATOM.

5.3 Limitations of ATOM

First, ATOM provides limited argumentation regarding data acquisition methods in the phenomenon detection process. As Haig (2005) notes, although ATOM provides detailed data processing and analysis strategies in the phenomenon detection stage, it neglects key aspects such as research design, data measurement, and collection.

Second, ATOM provides insufficient elaboration on guiding norms for theory construction. Romeijn (2008) argues that ATOM is too permissive in using exploratory factor analysis for theory generation and analogical modeling for theory development. Exploratory factor analysis has uncertainty in model selection, and in analogical modeling, any formal structure with the same number of objects can be mapped onto another, generating numerous candidate theories. However, both approaches lack clear guiding norms for theory selection. Although ATOM adopts the principle of explanatory coherence to evaluate theories, Romeijn believes this cannot effectively resolve ATOM' s permissiveness in theory generation and theory development. Moreover, the theory of explanatory coherence relies on specific criteria such as explanatory breadth, simplicity, and analogy, but the selection of these criteria is relatively subjective and lacks quantitative rules, potentially leading to different theory evaluation results. Later, Haig (2008c) responded to Romeijn' s concerns about guiding norms, arguing that ATOM' s normativity is relative and that many specific research methods used in ATOM have already been validated by empirical research.

Third, ATOM' s theory generation component does not adequately consider the diversity of theory generation methods, which may hinder the construction of complex theories. Within the ATOM framework, although it includes both qualitative research methods for theory generation (such as grounded theory) and quantitative research methods (i.e., exploratory factor analysis), there are clearly many more methods available for generating psychological theories. Moreover, ATOM's most emphasized theory generation method—exploratory factor analysis—only delineates dimensions and types of latent relationships among observed variables and is suitable for simple theories related to dimensions or types. In fact, beyond these theories, psychology has many other types of complex theories, such as process theories (e.g., Dodge' s social information processing theory), structural theories (e.g., Kohlberg' s theory of moral development), and functional theories (e.g., Baddeley' s multi-component model of working memory) (Xin, 2024), which are generated through different methods.

Fourth, the hypothetico-deductive method is a very important scientific method for hypothesis testing; however, ATOM does not adequately address its role in theory development. Peirce argued that knowledge should be acquired through the three logics of scientific discovery—abduction, deduction, and induction (Minnameier, 2004). Hypothetico-deductive reasoning is the intermediate link in knowledge acquisition and plays an important role in theoretical derivation or theory testing. Similarly, Kardes et al. (2021) note that abduction alone may be insufficient to produce replicable new theories, while the application of the hypothetico-deductive method can demonstrate the generalizability of theories (external validity). Therefore, in the development of the ATOM framework, consideration might be given to how to incorporate the hypothetico-deductive method.

Despite these limitations, ATOM still provides a valuable overarching framework for theory construction in psychology. We acknowledge that no methodology or theory can be perfect and requires continuous development and improvement by successive generations of scholars.

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Note: Figure translations are in progress. See original paper for figures.