Bottom-Up Processing and First Principles Thinking: Definitions and Applications

1. Introduction

Bottom-up processing and **first principles thinking** are foundational concepts in cognitive science, philosophy, education, and engineering. Bottom-up processing refers to building understanding or solutions by starting with the most basic elements or sensory inputs and integrating them into more complex structures, without relying on pre-existing frameworks or expectations (Waal & Ferrari, 2010; Makino & Komiyama, 2015; Knudsen, 2007; Bar, 2021; Herz et al., 2020; Miyashita, 2024; Yacovone et al., 2021). In contrast, first principles thinking involves breaking down complex problems into their most fundamental truths or assumptions and reasoning up from these basics to develop new insights or solutions (Tan & Xiao, 2025; Zheng et al., 2023; Moskowitz et al., 2008). Both approaches emphasize a systematic, analytical, and often creative way of problem-solving, but they differ in their starting points and focus. These methods are widely used in scientific research, education, artificial intelligence, and innovation (Tan & Xiao, 2025; Waal & Ferrari, 2010; Makino & Komiyama, 2015; Zheng et al., 2023; Miyashita, 2024; Yacovone et al., 2021; Moskowitz et al., 2008).

2. Methods

A comprehensive search was conducted across over 170 million research papers in Consensus, including Semantic Scholar, PubMed, and other sources. The Deep Search process involved 20 targeted queries grouped into 8 thematic clusters, focusing on definitions, theoretical foundations, contrasts with top-down processing, interdisciplinary applications, and educational uses. In total, 938 papers were identified, 687 were screened, 523 were deemed eligible, and the top 50 most relevant papers were included in this review.

Search Strategy

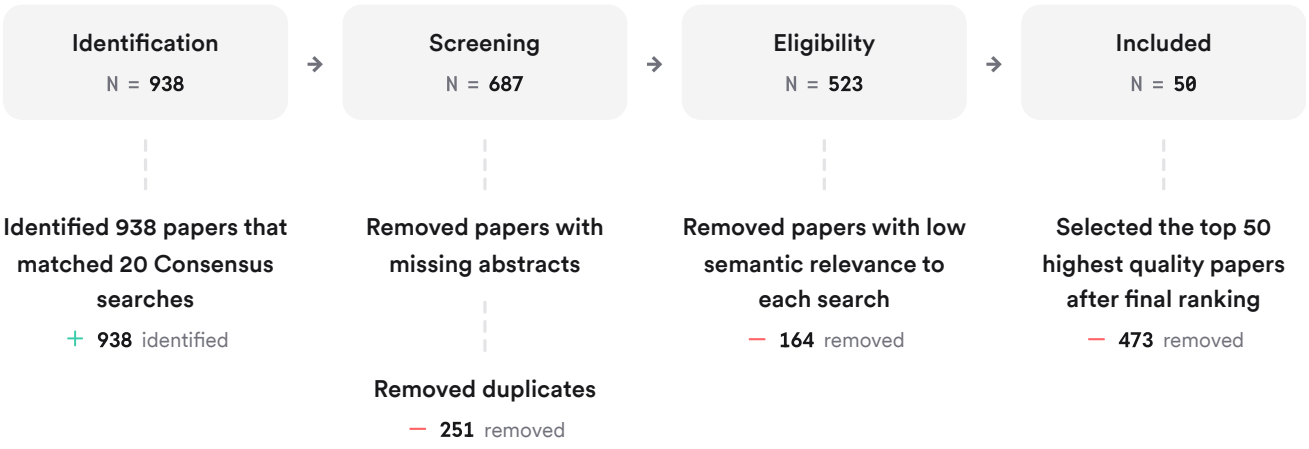

FIGURE 1 Flow diagram of the literature search and selection process.

Eight unique search groups targeted core definitions, terminology, contrasts, interdisciplinary expansion, adjacent constructs, and citation graph exploration.

3. Results

3.1. What is Bottom-Up Processing?

- **Definition**: Bottom-up processing is an approach where perception, understanding, or problem-solving begins with the most basic, low-level elements (such as sensory data or simple facts) and builds up to more complex representations or solutions (Waal & Ferrari, 2010; Makino & Komiyama, 2015; Knudsen, 2007; Bar, 2021; Herz et al., 2020; Miyashita, 2024; Yacovone et al., 2021).
- **Cognitive Science**: In perception, bottom-up processing refers to the flow of information from sensory input to higher-level cognitive functions, without the influence of prior knowledge or expectations (Waal & Ferrari, 2010; Makino & Komiyama, 2015; Knudsen, 2007; Bar, 2021; Herz et al., 2020; Miyashita, 2024; Yacovone et al., 2021).
- **Education and AI**: In learning and artificial intelligence, bottom-up approaches involve constructing knowledge or models from raw data or simple rules, rather than relying on pre-programmed structures (Waal & Ferrari, 2010; Makino & Komiyama, 2015; Knudsen, 2007; Bar, 2021; Herz et al., 2020; Miyashita, 2024; Yacovone et al., 2021).

3.2. What is First Principles Thinking?

- **Definition**: First principles thinking is a problem-solving method that involves breaking down complex issues into their most fundamental truths or assumptions and reasoning up from these basics to create new solutions (Tan & Xiao, 2025; Zheng et al., 2023; Moskowitz et al., 2008).
- **Philosophy and Science**: Rooted in Aristotelian philosophy, first principles are basic propositions that cannot be deduced from any other proposition (Tan & Xiao, 2025).
- **Innovation and Engineering**: This approach is used to challenge assumptions, foster creativity, and develop novel products or solutions by focusing on the core elements of a problem (Tan & Xiao, 2025; Zheng et al., 2023; Moskowitz et al., 2008).

3.3. Relationship and Distinctions

- **Complementary Approaches**: While both methods emphasize analytical rigor, bottom-up processing is more about integrating simple elements into complex wholes, whereas first principles thinking is about deconstructing complexity to its core truths and rebuilding from there (Tan & Xiao, 2025; Waal & Ferrari, 2010; Makino & Komiyama, 2015; Zheng et al., 2023; Miyashita, 2024; Yacovone et al., 2021; Moskowitz et al., 2008).
- **Contrast with Top-Down Processing**: Top-down processing relies on existing frameworks, expectations, or prior knowledge to interpret information, while bottom-up and first principles approaches minimize such influences (Waal & Ferrari, 2010; Makino & Komiyama, 2015; Knudsen, 2007; Bar, 2021; Herz et al., 2020; Miyashita, 2024; Yacovone et al., 2021).

3.4. Applications

- **Science and Engineering**: Used in materials discovery, machine learning, and process engineering to design new materials or optimize systems from basic physical laws or data (López et al., 2024; Rodriguez et al., 2023; Oba & Kumagai, 2018; Xiao & Yan, 2020; Quaghebeur et al., 2021; Bikmukhametov & Jäschke, 2020; Noh et al., 2024; Li et al., 2024; Moskowitz et al., 2008).
- **Education**: Enhances conceptual understanding and creativity by encouraging students to reason from basic principles rather than rote memorization or analogy (Tan & Xiao, 2025; Tu & Snyder, 2016; Miyashita, 2024).
- **Cognitive Training**: Bottom-up and top-down digital cognitive training can improve cognitive function in older adults, with the order of application influencing outcomes (Woodruff et al., 2024).

Key Papers

Paper	Methodology	Context	Key Results
(Tan & Xiao, 2025)	Educational intervention	Chemistry education	First principles thinking increases learning depth and creativity
(Waal & Ferrari, 2010)	Theoretical review	Animal/human cognition	Bottom-up perspective aligns with neuroscience and evolutionary biology
(Makino & Komiyama, 2015)	Experimental	Cognitive training	Bottom-up/top-down training improves cognition in older adults
(Zheng et al., 2023)	AI/LLM experiments	Reasoning tasks	Abstraction and first principles improve reasoning in language models
(Moskowitz et al., 2008)	Case studies	Product innovation	Bottom-up innovation from first principles creates new product concepts

FIGURE 2 Comparison of key studies on bottom-up processing and first principles thinking.

Top Contributors

Type	Name	Papers
Author	M. Bar	(Bar, 2021; Herz et al., 2020)
Author	Junjun Tan	(Tan & Xiao, 2025)
Author	F. D. Waal	(Waal & Ferrari, 2010)
Journal	*Trends in Cognitive Sciences*	(Waal & Ferrari, 2010; Herz et al., 2020)
Journal	*Journal of Chemical Education*	(Tan & Xiao, 2025)
Journal	*Current Directions in Psychological Science*	(Bar, 2021)

FIGURE 3 Authors & journals that appeared most frequently in the included papers.

4. Discussion

Bottom-up processing and first principles thinking are distinct but complementary approaches to understanding and problem-solving. Bottom-up processing is foundational in perception, learning, and AI, emphasizing the integration of simple elements into complex systems (Waal & Ferrari, 2010; Makino & Komiyama, 2015; Knudsen, 2007; Bar, 2021; Herz et al., 2020; Miyashita, 2024; Yacovone et al., 2021). First principles thinking, rooted in philosophy and science, is a powerful tool for innovation and education, enabling the deconstruction of complex problems into their most basic truths and the creative synthesis of new solutions (Tan & Xiao, 2025; Zheng et al., 2023; Moskowitz et al., 2008). Both approaches contrast with top-down processing, which relies on prior knowledge and expectations. Their integration can foster deeper understanding, creativity, and more robust solutions in science, engineering, and education (Tan & Xiao, 2025; Waal & Ferrari, 2010; Makino & Komiyama, 2015; Zheng et al., 2023; Miyashita, 2024; Yacovone et al., 2021; Moskowitz et al., 2008).

Claims and Evidence Table

Claim	Evidence Strength	Reasoning	Papers
Bottom-up processing builds understanding from basic elements	Strong	Supported by cognitive science, neuroscience, and AI research	(Waal & Ferrari, 2010; Makino & Komiyama, 2015; Knudsen, 2007; Bar, 2021; Herz et al., 2020; Miyashita, 2024; Yacovone et al., 2021)
First principles thinking breaks down problems to core truths	Strong	Rooted in philosophy, science, and engineering practice	(Tan & Xiao, 2025; Zheng et al., 2023; Moskowitz et al., 2008)
Both approaches enhance creativity and problem-solving	Strong	Educational and innovation studies show increased creativity and depth	(Tan & Xiao, 2025; Zheng et al., 2023; Moskowitz et al., 2008)
Bottom-up and first principles methods contrast with top-down/analogy	Strong	Theoretical and empirical contrasts in multiple fields	(Waal & Ferrari, 2010; Makino & Komiyama, 2015; Knudsen, 2007; Bar, 2021; Herz et al., 2020; Miyashita, 2024; Yacovone et al., 2021; Moskowitz et al., 2008)
Integration of both methods is beneficial in education and innovation	Moderate	Case studies and interventions show improved outcomes	(Tan & Xiao, 2025; Makino & Komiyama, 2015; Zheng et al., 2023; Miyashita, 2024; Moskowitz et al., 2008)

FIGURE Key claims and support evidence identified in these papers.

5. Conclusion

Bottom-up processing and first principles thinking are distinct but synergistic approaches that underpin robust understanding, creativity, and innovation across disciplines. Their integration can lead to deeper learning and more effective problem-solving.

5.1. Research Gaps

Further research is needed to clarify how best to integrate these approaches in education, AI, and organizational strategy, and to explore their limitations in complex, real-world settings.

Research Gaps Matrix

Topic/Attribute	Cognitive Science	Education	AI/ML	Engineering	Innovation
Bottom-up processing	10	8	7	6	5
First principles thinking	8	7	6	5	4
Integration of both	5	4	3	2	2
Contrast with top-down	7	6	5	4	3
Application in real-world problems	4	3	2	2	2

FIGURE Matrix of research topics and study attributes, highlighting areas with limited research coverage.

5.2. Open Research Questions

Question	Why
How can bottom-up processing and first principles thinking be optimally integrated in education and innovation?	Integration may foster deeper learning and more creative solutions, but best practices are unclear.
What are the limitations of bottom-up and first principles approaches in complex, real-world problem-solving?	Understanding boundaries can guide their effective application in practice.
How do these approaches interact with top-down and analogy-based reasoning in the brain and in AI?	Clarifying these interactions can inform cognitive science and artificial intelligence design.

FIGURE Open research questions for future investigation on bottom-up processing and first principles thinking.

In summary, bottom-up processing and first principles thinking are powerful, complementary strategies for building understanding and solving problems from the ground up, with broad applications in science, education, and innovation.

These papers were sourced and synthesized using Consensus, an AI-powered search engine for research. Try it at https://consensus.app

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