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Psychological and Cognitive Challenges in Sustainable AI Design

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Abstract. To design sustainable AI designers must be able to understand and think about complex technical, ecological, social, and economic systems and their interactions. Their reasoning and decisions need to be based on ethics and scientific facts. They must acknowledge different stakeholders' social and cultural norms, practices and current and future needs. Unfortunately, designers' thinking is prone to err, biases, and other psychological phenomena, which can negatively affect how they understand, reason, and make decision, and which can lead to unsustainable and unethical AI solutions. Thus, it is important to investigate errors in designers' thinking. This study presents a cognitive scientific overview about some common errors when making arguments, inferring, and reasoning, when drawing analogies, or in situations where problems are complex, uncertain, challenging the status quo, or framed differently. Also, processing information, emotions and social and cultural aspects can be source of errors in thinking. Designers must become aware of the risk of errors in their own perceptions, thinking, and reasoning and to explain why, what, and how they design sustainable AI. This can lead to more ethical and sustainable solutions in AI design.

Keywords: Sustainable design, AI design, thinking errors, cognitive bias

1 Introduction

The digitalizing world and the growing use of artificial intelligence (AI) and intelligent technologies will in many ways revolutionize the lives of individuals and societies. Societies are now entering the era of the fourth industrial revolution, which underlies the development of information and communications technologies (ICTs) and their many different digital applications, such as AI [1]. The term AI can be defined as "computerized abilities to solve problems and achieve goals" [2, p. 2] where there is a "non-human intelligence programmed to perform specific tasks" [3, p. 2].

Industrialization in its preceding forms has been accompanied by scientific and technological innovations, which have enabled humans to significantly alter earth's natural environments, systems, and cycles [4]. Unfortunately, these actions are now threatening global environmental conditions and have contributed to worldwide human-induced phenomena, such as climate change [4, 5]. Further negative impacts of industrialization on environmental, societal, and economic issues at the systemic, interconnected, and planetary levels must be urgently reduced to ensure that the needs of current and future generations are met. It is essential that designers understand and implement these core concepts of sustainability when designing new technologies, such as AI [2, 6–9].

The ongoing transformation regarding what and how ICTs are produced and used has direct and indirect effects on sustainability. For instance, AI applications can be used to decrease the carbon footprint of other products and systems by increasing resource efficiency and by automating and optimizing processes regarding, for example, manufacturing, production, logistics, and land, marine, and air traffic [1, 10–11]. AI can help to identify and compare important signals and patterns and make mathematical predictions from large and complex data. This can aid people in areas such as food production, waste reduction, energy consumption, the conservation of biodiversity and the forecasting of social opinions, natural disasters, water systems, and climate change [1–2, 11]. AI can also help in terms of design work. It can be used to research and explore issues that are relevant to designers' work and to assist their design thinking. It can even be used to inform about designers' own physiological, emotional, and cognitive states and how these can affect their design performance [12].

While AI can be used to help designers, consumers, organizations, governments, and societies to make better decisions regarding the impact of digital technologies, it cannot solve all sustainability problems. AI can both enable and inhibit sustainable development [1]. AI technologies themselves are based on energy intensive physical electronic devices and systems for processing, storing, and transporting information, which produce carbon dioxide emissions and have negative impacts on the environment [2, 10]. A huge amount of energy is required for AI training and using AI software for complex data modeling, as well as for maintaining data centers [2]. Intelligent technology products can consume a lot of raw materials, such as rare metals, glass, plastic, and energy. Presumably, in the future, these resources will be even more in demand as the use of data intensive technology, such as AI, is likely to increase in ways that are currently impossible to predict [10]. The abundant production, availability, and consumption of digital technologies, despite their aim of increasing eco-efficiency, can create "an illusion of boundless material and digital opportunities" [13, p. 345] and usher development in an unsustainable direction [2]. Unintended local consequences and rebound effects can negatively affect people's behavior and the sustainability of AI technology [2].

Several problematic issues are also related to, for instance, the production of rare metals that are needed for electronics and batteries used in AI devices. These range from carbon emissions and pollution and environmental damage to the use of child labor [10]. Increases in the international demand for minerals creates a pressure to expand the mining industry, which in turn, can threaten, for example, local indigenous populations' lives and delicate natural environments [14]. In addition to the need for energy, water, and other natural resources, AI technology that is based on electronics requires the use of plants, facilities, processes, and human workforces throughout the different phases of its lifecycle, from the refining of raw materials to the postprocessing of redundant technology [15]. To design AI ethically, current and future challenges that are related to environmental and social sustainability in manufacturing, producing, transporting, storing, using, terminating, and recycling technology must also be considered, although manufacturing sustainability issues are often more related to the supply chain than design decisions [9].

Several solutions that can be utilized by technology designers already exist for climate and environmental challenges, and new solutions are also being developed [10]. New raw materials, such as bioplastics or natrium-based battery materials, have been developed from renewable natural sources [10]. By designing longer-lasting, repairable, and efficiently recyclable electronic devices with minimum material waste, designers can decrease technological devices' burden on the climate and the environment [15]. Source codes that are used in AI can be designed to be as usable, riskless, long-lasting, and resource efficient as possible [10]. Designers can adopt participatory design processes and methods to gain multilevel and holistic views from stakeholders who are directly and indirectly affected by the production and usage of such technology [1–2, 4]. Those stakeholders can bring totally new or unexpected aspects to AI designers' attention and help to create more sustainable solutions.

AI designers' knowledge about sustainable technology and AI design can be increased with training or personal experience [7]. However, there seems to be a gap between being taught something, learning it, and putting that knowledge to use in everyday practices, as people constantly keep acting in unsustainable ways [5].

To implement sustainability in AI design requires transformative learning regarding sustainability and "experiencing a deep, structural shift in the basic premises of thought, feelings, and actions" [5, p. 168]. To avoid superficial greenwashing, designers need to become aware of and embed in their designs ways to minimize the negative impact on ecosystems and the use of materials and energy, to optimize their products for eco-efficiency and the circular economy, and to increase the long-term positive benefits and quality of lives for humans and environments, at the individual, group, local, and global levels [6–9, 13]. Designers must be able to understand and think about complex technical, ecological, social, and economic systems and their interactions; their reasoning and decisions need to be based on ethics and scientific facts; and different stakeholders' social and cultural norms and practices must be identified and updated to correspond to current and future needs [2, 4, 7, 16]. Thus, many of the challenges present in sustainable AI design are, in their essence, psychological ones that include cognitive, emotional, and social aspects [2, 17].

Unfortunately, human thinking is prone to err, biases, and a multitude of other different psychological phenomena, which can negatively affect reasoning and decision-making and even lead to risky behavior [18–21]. People's receptivity to fallacious reasoning was pointed out by Plato over 2,000 years ago [22]. However, this topic has scarcely been discussed from the point of view of AI designers' thinking. Thus, it is important to investigate errors in thinking that can affect designers' understanding and decisions regarding sustainable AI design. Risky, erroneous, or biased thinking can lead to poor decisions, which can further result in the creation of unsustainable and unethical AI solutions.

A good amount of literature exists with regard to different biases [18–19] and argumentation fallacies [e.g., 23] and how these thinking errors are present, for example, in working life [19–20]. It is not possible to cover all of them in this paper. Instead, this study presents a cognitive scientific contemplation where examples and explanations are based on literature from, for example, sustainability science, design science, and cognitive psychology.

1.1 Thinking as a Mental Phenomenon

It can be argued that all humans' psychological and cognitive functioning is built on a similar, species-typical biological basis. At the same time, everyone possesses unique characteristics, such as age, personality, past life experiences, and cultural and factual knowledge, which can alter individuals' mental information, thinking, reasoning, and behavior. These can affect what and how information is processed and experienced and how problems are solved by different people with different domains of expertise, for example [4, 24]. These differences in conceptual level knowledge, perspectives, and specialist language that different groups are accustomed to can also hinder the mutual understanding and definition of problems, communication, and the co-creation of insights between people [4].

Thinking itself can be understood as a skill, which within humans is based on certain evolutionary developed, species-specific cognitive properties [21]. Evolution has provided humans with rationality and thinking, which are imperfect, but, nevertheless, good enough in terms of survival and reproduction [28]. Even though cognitive processes, such as thinking, that evolved to serve the lives of early humans have remained somewhat the same in the biological sense, the world and contexts that people interact in are very different. Situations requiring fast, physical reactions to immediate and local threats have changed into the need for long-term planning, consideration at the complex, global level, and thoughts about ambiguous and abstract concepts, their connections, and their effects [21].

According to mental model theory, when people think about things, they rely on their own mental models [25]. These can be described as knowledge representations that imitate the world and what is possible and true and that have a similar structure to that which they represent. Mental models can refer to information, such as that related to space and time, "entities and persons, events and processes, and the operations of complex systems" [25, p. 136]. Alternative theories state that thinking and reasoning are based on dual processes, often termed the fast, unconscious, and automatic "system 1" and slow, conscious, and deliberate "system 2" [19].

Some cognitive functions, such as language processing or visual processing, are localized in certain areas of the brain, and the activation, association, or dissociation of the different areas can affect thinking and reasoning [30]. The functioning of working memory, "the cognitive construct responsible for the maintenance and manipulation of information" [26, p. 457], is especially important for considering and inventing new solutions. Working memory activates, inhibits, and preserves information as momentary dynamic representations, operates based on that information, and binds information from the long-term memory and perceptions together in different ways during conscious thinking [26]. This makes working memory important for the apperception process, where emotional and perceptual information and knowledge from one's memory are constructed in mental representations, and for thinking, where these representations are reconstructed into new ones [28]. When an individual perceives new information in interaction with their social and physical environments, it is matched with pre-existing information in the individual's memory, such as conceptual knowledge and mental schemas, to create a sensemaking, semantically meaningful, and coherent, conceptual mental representation of the world [4, 17, 27–29]. Much of this information processing is unconscious or intuitive, as opposed to conscious reasoning, although both these faculties are in constant interaction with each other [19, 28–29].

When children grow older, they become better at applying thinking strategies and more capable of inferring the meanings of more complex things [30]. The development of thinking is linked to neural maturation and growth in synapses and dendrites and connections between different brain areas, as well as to cortical development in the prefrontal cortex, which is responsible for processing cognitive executive functions, such as directing attention, making plans and controlling goal-directed and emotional behavior [30]. In later life, acquiring new knowledge and skills in a particular domain through deliberate practice can lead to expertise in that area [31]. While gaining expertise, individuals acquire mental representations with context-dependent and meaningful patterns and large and highly nuanced knowledge structures, which are stored in their long-term memory and effectively retrieved during the performance of reasoning and certain behaviors [29, 31].

1.2 Design Thinking and Sustainable AI Design

Design can be described as anything that is created by humans to solve problems, and design thinking is an intentional, evolving, and unique way of thinking or a mindset or strategy that focuses on finding, defining, reframing, and solving those problems with a fitting solution [32–33]. Design thinking is a creative, empathic, human-centered, and iterative cognitive process that combines convergent and divergent thinking [6–7, 34].

Convergent and divergent thinking can be understood as forms of creative cognition—cyclic, creative, and exploratory thinking processes for incubating, transforming, and maturing design ideas and concepts [35], where both types of reasoning draw from the designer's existing knowledge [36]. Convergent thinking is a type of reasoning where "cognitive operations are intended to converge upon the single correct answer to a problem" [36, p. 465]. Divergent thinking is a free-flowing thought process that is "used to generate creative ideas through the exploration of many possible solutions" [33, p. 13] from one's memory or imagination and to answer ill-defined or open problems, without narrowing down one's thinking too early on [33, 36].

Design thinking depends on the social situation, available tools, and the designer's characteristics, such as those related to previous experiences and learning [6–7, 33]. For instance, experts in design can switch between different cognitive styles and use both conscious reasoning and intuition in problem framing and sketching. This helps them to understand the general problem description and recognize relevant pragmatic cues to enable the generation of alternative, less stereotyped ideas [29, 37].

Design thinking is well suited to developing AI for sustainability [2]. Design thinking for sustainability can be understood as "the systematic consideration of design performance with respect to environmental, health, safety, and sustainability objectives over the full product and process life cycle" [6, p. 19]. Sustainability challenges are often considered to be wicked problems [13, 33]. Wicked problems are "unique, interconnected, and poorly defined problems that cannot be definitively described" [33, p. 12]. According to Raami [29], wicked problems are also the most challenging types of problems to solve. Solving wicked sustainability problems requires a flexible and creative mindset, shared mental models, and an ability to view ambiguous, complex, and often urgent problems from multiple angles, using different strategies, methodologies, and methods or their components [6, 13, 29, 32–33].

2 Erroneous Thinking in Sustainable AI Design

When it comes to thinking, behavior, and decision-making regarding sustainability, humans are not very rational creatures [21]. The reasons behind this vary from the limitations of human cognitive processes and capacities to emotional, social, and contextual factors. Sustainable design, engineering design, and design in general are mentally challenging and stressful. They require different cognitive processes and skills for exploring and reasoning, problem structuring and constraining, solution space searching, and idea generating to solve complex, ill-structured, ill-defined, or wicked problems that contain unknown variables and unique contexts [7, 12, 34, 38]. However, having to work with ambiguous information and concepts is not necessarily a negative thing as it can also stimulate a designer's thinking [35].

2.1 Argumentation, Reasoning, and Inferencing

Mental activities in design include making deductive, inductive, and abductive inferences, concept evaluations, and analogies that are based on a designer's prior, existing knowledge and previous design cases [34]. Deductions, inductions, abductions, and the use of analogies are different types of arguments, symbolic structures, or complex speech acts, such as dialogues, which provide the reasons behind claims and where conclusions are supported by and follow on from some premises [39]. Argumentation and reasoning are different but closely related phenomena and can be investigated with research on thinking and reasoning [39].

The first theory of deductive reasoning was presented by Aristotle as early as 350 BC [40]. Aristotle introduced the concept of a premise as "a sentence affirming or denying one thing of another" [40, p. 1]. In deductive reasoning, "the truth of the premises is supposed to guarantee the truth of the conclusion" [39, Types of Arguments section], and people can use strategies where reasoning is based on relations and quantities and make suppositions by constructing chains of interlinked conclusions or lists of various possibilities that can be drawn from the premises [25]. These can improve the speed and accuracy of reasoning and result in valid and sound arguments but can also lead to the tendency to always use a particular strategy, when certain premises are met [25, 39].

Inductive reasoning is part of "a range of cognitive activities such as categorization, probability judgment, analogical reasoning, scientific inference, and decision making"

[41, p. 278]. In inductive reasoning, people make probabilistic inferences about new situations, where a particular occurrence is explained using a general reason, principle, or some particular information based on the reasoner's existing knowledge and past experiences [25, 39, 41]. Inductive reasoning is often based on perceived causality between a particular occurrence and a conclusion [41] and on statistical frequencies, which are then generalized [39]. Thus, it can be defined as "a process that increases semantic information" [25, p. 146]. Inductions can be affected, for instance, by unconsciously ruling out probabilities and alternatives that are in fact possible or consistent [25]. Humans also tend to generalize based on perceived similarity, on how typically a premise represents some general, simpler category [41]. However, prior experiences and domain expertise can reduce many inductive fallacies because, presumably, "domain experts often generalize properties on the basis of relations" [41, p. 281] that are different and within a broader range than non-experts do, presuming experts have enough time for this kind of complex reasoning.

Abduction is a form of reasoning where "from the observation of a few relevant facts, a conclusion is drawn as to what could possibly explain the occurrence of these facts" [39, Abduction section]. Abduction can be understood as a type of inference that is based on knowledge and perceived possible causalities and which can produce general theories, descriptions, and explanations that, however, do not necessarily preserve the truth [25, 39, 42].

How humans draw conclusions is typically based on the tendency to make their judgements based on existing semantic information that they already possess and to deduce only a limited number of new conclusions [25]. Conclusions can err in terms of either being inconsistent and conflicting with their premises or not following on from their otherwise consistent premises [25]. When an individual is faced with an inconsistency or mismatching evidence, they are more prone to construct sensemaking causal claims that, for example, something happened because of some probable reason, than to check their existing beliefs [25]. People, regardless of their level of expertise, can also make inferences that something is possible or impossible when, in reality, only the opposite can be true [25]. This illusion is related to how people interpret certain wordings that give them hints as to whether an assertion might be true or not, not on how people use their logic [25]. People focus on events that can be directly observed to draw quick conclusions about what was perceived and what happened. Not taking into consideration other possible, hidden factors and jumping to conclusions can lead to erroneous judgements and wrong solutions [5].

In reasoning that is based on mental models, it is easier, more accurate, and faster to assume that situations are possible rather than impossible and that situations are unnecessary rather than necessary [25]. Reasoning and making inferences from premises often cause errors because people easily base their explanations on simplicity and a minimal number of mental models, which is easier in terms of memory and cognitive processing [25, 39, 42]. Explanations can err because, for instance, why something is like something is accepted as proof that it is the case [42]. It is also difficult to notice circularity in explanations, they can be affected by irrelevant information, and people can also "overestimate the accuracy and depth of their own explanations" [42, p. 270]. Reasoning can be affected by at least two types of belief biases. People tend to mostly accept the kind of information and conclusions that support their already existing mental models and beliefs [17, 19, 37]. When people are presented with information or conclusions that are in conflict with or unbelievable when compared to their pre-existing models, beliefs, and values, they tend to disregard them or selectively search for contrasting examples [17, 19, 37]. However, finding counterexamples can sometimes help people to detect and correct faulty and inconsistent conclusions and reasoning [25].

Analogies. A central part of inductive reasoning that is used, for example, in problem solving, creative thinking, rational argumentation, and causal inferences, is creating analogies [43]. As Dutihl Novaes [39, Analogy section] summarizes: "Arguments by analogy are based on the idea that, if two things are similar, what is true of one of them is likely to be true of the other as well." Analogies are important mental processes that people unconsciously use to make sense and understand the world as they perceive, learn, and interact with things [27]. Designers draw analogies between different representations and similar problems, structures, and solutions when they are solving design tasks [24].

In analogies, mental representations of the domain-specific source and target and the relevant similar relational roles of their elements, attributes, characteristics, causes, and effects are compared in a structured way to achieve some goals [43-44]. These goals can be used to understand concepts, come up with new conclusions, and make discoveries [43–44]. Analogies are usually based on some prior, base knowledge in one's long-term memory, which includes beliefs about causalities and connections within a concept or object [43, 45]. They can also be about, for example, emotions [46] or stereotypes [44]. Analogies can also include special kinds of comparisons, such as *metaphors*, which can be described as "forms of symbolic expression" [43, p. 236] that compare semantically distant situations, and *metonyms*, where a concept is associated with another symbolic figure (such as using the word "sword" as an analog to weaponry) [43]. Humans often use metaphors to describe and understand their experiences in common language [43].

As Holyoak emphasized, because analogy is a form of inductive reasoning, "analogical inferences are inevitably uncertain" [43, p. 235]. For example, drawing analogies between semantically distant entities can provide more creative but less plausible inferences than analogies that compare things with more similar relational resemblances in their structural features and functions [43]. The quality of analogical inference is affected by learning and development, which increases the number and details of categories in terms of analogy-making [45]. Also, more pressure on working memory and attention can impair symbol-level, relational role mapping, which requires more cognitive effort and instead increases the number of analogies based on similarities [43]. Thus, individuals can "fail to notice superficially dissimilar source analogs that they could readily use" [43, p. 244]. In addition, the retrieval of an analog can be more successful when performed by experts rather than novices, if analogs are presented in a spoken instead of a written format, and when individuals need to generate examples rather than remember earlier cases. Analogical reasoning can also unconsciously and unintendedly be activated because of an individual's previous learning and priming.

Analogical mapping can also be strongly affected by the goals of the reasoning individual [43].

Fallacies and Fallacious Arguments. Fallacies can be understood as “false but popular beliefs” or as “deceptively bad arguments” [23, Fallacies section]. Fallacious arguments are arguments that seem to be true but are not [39]. Several well-known or core fallacies exist [22-23, 40]. For example, in *circular arguments* that are based on the fallacy of *begging the question*, a conclusion (for instance, “God exists”) is justified with a premise (“because the Bible says so”), which is based on the same proposition as the conclusion (“the Bible is the word of God”) [23, 39]. In the *ad hominem fallacy*, some negative characteristics or the situation of the arguer are used to contest their statements [23, 39]. Examples of this kind of fallacy in rhetoric are based on an individual’s personal characteristics or on more general stereotypes when making decisions when, in reality, these have nothing to do with solving the actual problem [20]. On the other hand, the arguer can appeal to authority, expertise, or popular knowledge or opinion instead of argument reasoning [23, 39]. For example, in Plato’s [22] work *Gorgias*, it was noted how persuasive rhetoric is often used in politics, where speakers use flattery without any possession of expert knowledge in that domain, which in turn, can lead to fallacious beliefs and judgements among the public.

Arguments for ignorance are types of fallacies where something is assumed to be true because it has not been proven otherwise [23]. In the fallacy of the *slippery slope*, “from a given starting point one can by a series of incremental inferences arrive at an undesirable conclusion, and because of this unwanted result, the initial starting point should be rejected” [23, The core fallacies section]. Other common fallacies include, for instance, when the ambiguity and changes in the meanings of used terms are exploited, when a response to a question is already implied in the question itself, when two temporally succeeding events are mistaken as having a causal relationship, or when arguments are based on imagined threats, harm, or sympathy [23, 39].

2.2 Knowledge and Managing Information

Designers tackling sustainability need to possess the necessary knowledge as well as explicit and tactical cognitive skills in terms of what and how information about different dimensions of sustainability is managed [7]. While exploring new solutions, designers cognitively and simultaneously operate between solution and problem spaces that interact and co-evolve with each other [34]. However, problem solving is limited by the human information processing capacity and affected by other constraints, such as a lack of information [29], mental shortcuts, or the possession of fallacious information [20–21]. This can result in errors with regard to problem structuring and setting its requirements, constraints, and goals; wrong conclusions; and the fidelity and correctness of both the created mathematical design models and designers’ own mental models [9, 20–21]. While mathematical models can be beneficial to test the feasibility and tradeoffs of potential new solutions and to make risks and tradeoffs more visible, creating and analyzing models that include sustainability measures is difficult [9]. For instance, it can be difficult to transform social impacts, such as the consequences of an accident on people and their lives, into clearly defined, manageable, and measurable units without reducing the multiple dimensions of different social phenomena down into too narrow a format [9]. It can be difficult to estimate probabilities and accept randomness in events because humans are inclined to perceive or expect to observe patterns even where there are none [19].

Designers must be able to view things holistically and avoid getting hindered by confining details, especially at the beginning of their design process when they are trying out ideas using high-level concepts and prototypes that can provoke thinking and new questions [33–35]. Prototypes are examples of tools that can be used to assist design thinking. Technology and tools can be used to sense and measure sustainability parameters and their data, such as carbon foot- or handprints or product life cycles, which can also be used to help sustainable design [8]. However, risks exist in relation to using data-driven design. Accurate and adequate amounts of information from, for example, operationally, locally, and temporally scattered sources can be difficult and expensive to acquire. A lot of uncertainty can exist with regard to the quality and details of such data and how to understand and analyze them. Data need to be analyzed against the correct context, and this often requires specialized knowledge about processes and systems and about both sustainability dimensions and human behavior [8].

For example, Faludi et al. [32] noted that experts in sustainable design can conduct theoretical analyses of, for instance, environmental or social issues or product life cycles, but these analyses are not necessary always founded on facts. Many different methods exist for sustainable design, which creators use opportunistically; which methods or their parts are used together often depends on the designer's level of expertise [32]. Motivation, too, can affect the way information is searched for and analyses are conducted [47]. For example, individuals can be either more motivated to find accurate information and conduct complex analyses or to complete the task at hand quickly by using less information and performing fewer considerations [47]. Also, correct information can be processed in an erroneous manner. Designers can overemphasize visual information, interpret correlations as causation, imagine that they can manage variables outside of their influence, and have "the preference to look for evidence that supports the preconceived model instead of disproving it" [21, p. 89] (belief bias).

Detailed information given too early on can lead to design fixation [7]. Design fixation can be defined as "a blind adherence to a set of ideas or concepts limiting the output of conceptual design" [48, p. 3], where designers get mentally stuck and focus on only one aspect, problem, or solution relating to a design [38]. Humans can be fixated by certain mental models, often the ones that first come to their minds and that they have an unconscious preference for, even if they are offered new information [20]. Fixation on a certain idea can also be caused by emotional factors, such as impulsiveness, and the avoidance of experiencing certain themes or explanatory models that are too emotionally distressing [20]. Functional fixedness is a phenomenon related to problem solving as a mental activity [24]. In functional fixedness, an individual is accustomed to perceiving an object and its uses and purpose in a habitual way and has difficulty finding any other meanings or uses for it in other contexts [24]. Design fixation has been found in both novice and skilled designers, such as engineering design students and educators [49]. Fixated designers can become emotionally stressed and incapable of processing more or alternative information because generating new concepts while one is fixated requires substantial cognitive effort [38].

Ideas that are generated in the early phases of design and development often form the basis for the following phases, where solutions are created [7]. If these ideas are based on misinformation or insufficient or wrongly generated or reasoned information, it can have devastating effects on the development of the rest of the design project.

2.3 Heuristics, Intuition, and Unconscious Thinking

In reasoning as a mental process, humans often use mental shortcuts and quick heuristic judgements to minimize their cognitive load, despite the risk of biased thinking [19, 37]. Heuristics are based on a minimal number of cues, little reflection, and the mental models the reasoning individual uses, and such reasoning can also lead to illusory conclusions [25, 37].

Using heuristics or "rules of thumb" as shortcut strategies is also one form of fast, intuitive thinking [24], although according to Evans [37], intuitive inferences are based on more information than heuristic judgements. Sometimes, design ideation can also activate the unconscious incubation of mental content [29]. Designers can unconsciously restructure information into new representations, which might be consciously experienced as ranging from "small hunches" [29, p. 214] to moments of insight or even a eureka experience or what Raami described as "re-centring—an experience of new permutations of relations between ideas and a novel and unconventional combination of thoughts" [29, p. 213].

Unconscious cognitive intuition processes information and selects the relevant parts for further conscious processing [29]. Although unconscious processes are prone to bias, according to Raami [29], intuitive information processing can also be developed to provide more accurate and reliable results. It can even be argued that, at least within scientific intuition, "intuition is the primary thinking mode used for discoveries and inventions while conscious reasoning is used for argumentation" [29, p. 209]. Even though an individual can either have a sense of being correct or have doubts, these feelings do not reveal anything about how accurate the intuition actually is. Analyzing the accuracy of intuitions is important, but it can also become problematic as it can lead to, for example, the overanalysis or reduced accuracy and reliability of the unconscious intuition [29]. As opposed to unconscious intuition, conscious, explicit reasoning and reflective thinking are typically understood as slower processes, which have more limited processing capacity than unconscious processes [19, 29, 37].

2.4 Framing Effects

Different contexts can be framed and reframed to affect reasoning and behavior. Even the exact same scenario, context, or issue can be presented and reformulated in different ways to influence how that event is interpreted and what kind of judgements are made [21, 27, 44]. This phenomenon, called the framing effect, can be found in certain cases, such as when forming opinions about climate engineering techniques or in political environmental discourses, where framing effects can even shape public and political opinions and guide discussions in a certain direction [21]. Problem solving, such as designing, also depends on and is affected by specific physical and psychological contexts, which "provide frames of orientation and they trigger norms and expectations" [27, p. 7].

A framing effect can be illustrated with the following imaginary example of climate change thinking. For instance, it has been argued that climate change is a natural phenomenon, which causes the average temperature to fluctuate between -0.1 degrees Celsius and +0.1 degrees Celsius [50]. This is based on scientific data and is true. However, this fact can be framed without the context in question and the temporal and physical scale of the phenomenon, creating a dangerous illusion that nothing needs to be done. The same information can be presented together with the fact that natural fluctuations occur over tens of thousands of years and that the earth's temperature has increased by approximately 1.07 degrees Celsius during the last 140 years because of human activity [50]. With different framing, the same information and how it is interpreted can lead to a totally different conclusion.

In addition, humans can respond to AI in psychologically and socially different ways, depending on an individual's position and how the future goals and losses are framed. For instance, as Nishant et al. [2] noted, AI applications that can be used to automatically manage work that has previously been done by people can be seen as acceptable or not, depending on whether AI is understood as increasing or reducing individuals' employment opportunities.

2.5 Complexity, Maintaining the Status Quo, and Uncertainty

The ability to ponder complex new ideas and realize new solutions for difficult design problems, such as sustainability in AI design, requires resources, such as time, and cognitive skills to construe new mental representations [19–21]. Implementing sustainability dimensions into the problem-solving equation creates even more cognitive challenges for designers in their already complex work in terms of, for example, engineering [7]. Often, when sustainability influences a design, the creators need to choose their design philosophy, include sustainability issues, such as eco-efficiency or eco-effectiveness, in their design checklists, and create models where different relationships between sustainability issues, design parameters, and their tradeoffs are presented [9]. When considering sustainable AI design, there is the risk that designers focus on certain, one-sided parameters in their models, especially if some design parameters are found to be difficult or uncertain [9].

It is very cognitively demanding for humans to think about abstract phenomena related to sustainability, such as climate change, when their temporal and physical properties, proportions, and complexity exceed measures that are familiar to everyday life [21], especially if the individual is not given enough time to reason [41]. These difficulties can lead to the problem being pushed to one side to be dealt with in the future or to reductionist thinking and "game-theoretical forms of interactions where self-interest is in play" [2, p. 2], although people can also engage in different, value-based behavior [51].

Thus, it is easy for people to err with regard to their thinking when they need to make plans and decisions about the future [20]. Instead of making rationally argued decisions that would benefit sustainability in the long term, many people tend to reason and behave based on short-term goals and selfish motives [2, 21]. The inability to act persists [21], even though scenarios about what will happen if nothing is done give alarming future projections about environmental conditions, diseases, poverty, and injustice [52].

Maintaining the Status Quo. According to *prospect theory*, people can unconsciously focus on possible gains or losses, not only regarding monetary values but also involving reasoning that affects life quality [19]. People often find it more important to try to prevent losses than gain new wins—a phenomenon called *loss aversion* [19]. This can lead to a bias toward maintaining the current situation and avoiding change. This *status quo bias* can be found in many decision-making situations ranging from economic to health-related phenomena [53]. For example, Samuelson and Zeckhauser [53] found status quo bias in experiments with students of economics and in field studies where people were making choices about health plans and retirement funds. Status quo bias can also be found in decisions made by professionals within their domains [21].

In the phenomenon of *design resistance*, a designer can erroneously think and insist that because something has worked successfully before, the same solution will also work for new problems; thus they argue that it is not necessary to change the strategy or actions [16, 20, 54]. Even though using existing design solutions can sometimes be the right decision for safety, economic, or logistic reasons or to avoid resistance from end users, for example, other times, alternative reasons, such as the designer's nostalgia, pride, or knowledge, can underlie such judgements [54]. Designers can also find it problematic to evaluate the quality of new and innovative design ideas [27]. Evaluations of new designs are often conservative and biased toward some familiar and preexisting concepts and experiences, at least at first [27]. Avoiding making conservative estimations of novel ideas and design innovations requires that the evaluating individual has "the opportunity and time for familiarization and elaboration" [27, p. 6]. To detach their thinking from fixations and to challenge the status quo, designers need to have mental flexibility and be "comfortable with failure" [33, p. 15]. Unfortunately, in many situations, individuals are not able do this and instead become cognitively inflexible [16]. Breaking away from the existing, habitual thinking models and strategies is difficult but necessary, especially when new concepts and solutions are desperately needed to develop sustainable AI.

Effects of Uncertainty. Another factor that makes sustainable design difficult is that making "predictions for the future become even more uncertain" [21, p. 87] when the environment is perceived as or imagined to be harsh. Alarming messages about the climate and environmental issues might "trigger cognitive systems that are sensitive to such threats and urge people to think about their own advantage first" [21, p. 87], leading to erroneous thinking and unsustainable actions.

Uncertainty is common in life in general [55]. Uncertainty can be perceived as especially high in work domains involving sustainable design [4, 8, 13, 21, 29] and AI design [55]. Uncertainty and negative emotions and pressures can affect thinking and emotions and lead to irrational, hurried, and over- or undersized behavior, such as making hasty decisions or not doing anything at all [20–21]. For example, climate anxiety can cause the emotional state of paralyzing apathy [13]. Strong emotional reactions can also be caused by, for instance, individuals' personal difficulties in terms of emotional control [20] or learned, cultural conventions to either react strongly or feel indifference about phenomena such as climate change [13].

2.6 Emotions and Values

Emotions affect whether people are concerned about and how they deal with different issues [20]. Emotions are important for self-regulating, controlling, and motivating behavior, and they also act as signals of internal values and their conflicts, making the individual aware of these [13, 20, 56]. Design work can cause different positive or negative emotions in designers. They can feel pressure and stress with regard to inventing the best concepts and solutions to complex design problems [21, 38]. Stress may even be caused by cognitive dissonance, which is experienced when a designer is faced with either too challenging or too easy a task [38]. On some occasions stress can be experienced as a positive factor that improves cognition, motivation, creativity, and concentration [38]. However, long-lasting stress, in particular, can lead to negative problems and affect both physical and mental health and well-being, as well as mental performance, by limiting cognitive processing and slowing down attentional processes [20, 38]. Thus, stress can negatively affect designers' design cognition and concept generation [38].

Topics such as climate change or AI are often emotionally charged issues [2, 13]. To manage and respond appropriately to emotional challenges, it is important that an individual has enough "time and space for expression and critical reflection either individually or collectively" [13, p. 351]. In their work, designers need to create radical new ideas, which can be faced with resistance from others [29]. Fears and hopes can affect how people think and reason by "biasing, narrowing or restricting the free flow of intuition" [29, p. 222]. Emotional biases, such as having conflicting emotional values between sustainability and political goals, can cause irrational judgements about issues such as global warming [17]. Also, different people can pay attention in different ways and experience different positive or negative emotions even when considering the same situation [20], which can make it difficult to form a common understanding.

Many philosophers have suggested that "emotions provide us with our most basic cognitive access to values" [56, p. 488]. Thus, values and emotions are closely connected [56]. For instance, if something is valued as dangerous, it can be felt with the emotion of fear; something valued as sublime can be felt with awe or astonishment [56]. Many basic values and moral concepts are learned in early childhood from family and through other close relationships [51]. These values can affect one's thinking and behavior in later life and are hard to change, even when they lead to conflicts in lives of individuals and communities [51]. In technology design, there is a risk that designers unconsciously invoke their personal values and biased preconceptions [3] through their products. Such products can display and enhance negative stereotypes, indiscriminate different users mentally, physically, or socially, or allow unethical behavior [11, 3]. Thus, in sustainable AI design, it is important that designers can understand different values from different perspectives and make design decisions that are based on shared economically, socially, and ecologically sustainable values.

2.7 Social and Cultural Aspects

Design thinking is a human-centered design approach, where all design activities are fundamentally social [33]. To discover the different aspects of people's lives that are affected by the design problem, designers need to explore and investigate their users and stakeholders, use empathy to understand what it is like to be them, and address the problems they encounter in their real contexts of interaction [7, 16, 33, 57].

To identify the diversity of the possible positive and negative sustainability issues and design constraints and to generate new ideas and concepts, designers can use brainstorming sessions together with other stakeholders [9, 38]. However, techniques such as brainstorming have been found to require high cognitive effort and cause frustration within groups of designers [38]. In group brainstorming sessions, designers' creativity can also be affected both positively and negatively by social and procedural factors, such as feeling stimulated and influenced and elaborating on other team members' ideas, and by group dynamics, such as the existence of controlling personalities in brainstorming groups [35]. A critical thinker can be silenced by social or emotional pressures set by the group or due to the individual's inability to explicitly explain their own reasoning with proper, fact-based arguments [20]. These kinds of social thinking models can lead to group-level neglect of important information and faulty decisions [20].

Empathy can enable an understanding of the local circumstances and experiences of the most vulnerable people affected by sustainability problems. It can urge designers to take moral responsibility to act and invent solutions to decrease their losses and increase their well-being and their sense of hope [13]. However, it is very difficult, or even impossible, for an individual to fully observe and understand the experiences, lives, goals, and values of other individuals. Understanding the mind and behaviors of others becomes even harder the more "different" that other one is observed or imagined to be [28]. Empathic understanding also can be built on both inferential and embodied processes based on, for example, stories and imagined body movements [28]. Embodied understanding is important in design and also when designing sustainable AI [11]. An AI engineering designer who spends most of their time in front of a computer may miss out on a lot of important embodied knowledge through not really experiencing the physical world of their stakeholders [11].

Different people feel empathy in distinct ways and to different degrees. It can require intuitive thinking [29] or be hindered by education focusing on technical issues instead of human welfare [57]. However, according to Chang-Arana et al., there is no adequate proof that empathy in fact helps designers to better understand other people or to generate better ideas and solutions [57].

It is an illusion to think that all people understand, value, and forecast about sustainable AI technology in similar ways. For example, Marquardt and Nasiritousi [58] researched what kind of different future imaginaries existed within different stakeholder groups regarding fossil-free Sweden. The authors categorized the identified imaginaries into four groups: Techno-optimistics saw the climate crisis as something that can bring opportunities and competitive perks, and ecological modernists both welcomed technological innovations and called for political actions with regard to creating a greener economy. In contrast, the other groups expressed "the need for disruptive changes in business models, institutional settings, and individual lifestyles" [58, p. 13]. In another study, Gherhes and Obrad [59] investigated views about AI in terms of its development and sustainability among Romanian undergraduate students of humanities and technical studies. These researchers found that there were notable differences in the knowledge and perceptions of AI between the two groups and that "the students following technical studies show a higher level of confidence for the AI sustainable development in the future," whereas the students of humanities were "more interested in the human value, which they protect, and seem more willing to perceive the disadvantages of the AI development" [59, p. 15].

3 Conclusion

Sustainable AI design requires thinking, reasoning, and performing actions based on often difficult and cognitively, emotionally, and socially multidimensional and interacting issues. It requires the ability to solve ill-defined and wicked problems, to make correct and fact-based inferences, and to come up with new and sometimes radical solutions in design. It requires that designers possess the mental skills and resources to think about highly complex, interrelated, abstract, and cognitively challenging concepts and systems and to critically review their learned knowledge, cultural concepts, beliefs, attitudes, and values [4, 20]. These mental processes are involved in arguing and reasoning, inferring, possessing and processing knowledge and information, and when using heuristics and intuition, unconscious thinking. They are involved in framing things, thinking about complex matters, challenging the status quo, and coping with uncertainty, emotions, and values in social interactions and when managing cultural aspects. More research that focuses especially on thinking errors among sustainable AI designers is needed.

Arguably, sustainable AI design is not an easy task. Designers must process different types of information and be aware of their own positions and perceptions. They must be able to reason why, what, and how they design when implementing sustainable AI. Designers must be prepared to become aware of and tackle the risk of errors, biases, and fallacies in their own thinking, reasoning, arguments, problem solutions, and decision-making, which can lead to errors and risks. They must be open to new ideas, be mentally flexible, and extend their thinking to consider the direct and indirect impacts of their designs on the environment and people in all phases of the product life cycle.

This will, hopefully, lead to ethically, economically, ecologically, and socially better solutions in sustainable AI design.

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References

1. Goh, HH., Vinuesa, R.: Regulating artificial-intelligence applications to achieve the sustainable development goals. Discov Sustain **2**, 52 (2021). doi: 10.1007/s43621-021-00064-5
2. Nishant, R., Kennedy, M., & Corbett, J.: Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. International Journal of Information Management, **53**, 102104 (2020). doi: 10.1016/j.ijinfomgt.2020.102104.
3. Dwivedi, Y.K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., Duan, Y., Dwivedi, R., Edwards, J., Eirug, A., Galanos, V., Ilavarasan, P.V., Janssen, M., Jones, P., Kar, A.K., Kizgin, H., Kronemann, B., Lal, B., Lucini, B., Medaglia, R., Le Meunier-FitzHugh, K., Le Meunier-FitzHugh, L. K., Misra, S., Mogaji, E., Sharma, S.K., Singh, J.B., Raghavan, V., Raman, R., P. Rana, N., Samothrakis, S., Spencer, J., Tamilmani, K., Tubadji, A., Walton, P., Williams, M.D.: Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. International Journal of Information Management, **57**, 101994 (2021). doi: 10.1016/j.ijinfomgt.2019.08.002.
4. König, A.: Sustainability science as a transformative social learning process. In: A. König & J. Ravetz (eds.) Sustainability science: Key issues (pp. 3–28). Routledge (2018).
5. Laininen, E.: Transforming Our Worldview Towards a Sustainable Future. In: Cook J. (eds.) Sustainability, Human Well-Being, and the Future of Education. Palgrave Macmillan, Cham (2019). doi: 10.1007/978-3-319-78580-6_5
6. Garcia, R., Dacko, S. Design Thinking for Sustainability. In: Swan, Scott, et al. (eds.) Design Thinking: New Product Development Essentials from the PDMA, John Wiley & Sons, Incorporated, 2015. University of Warwick (2015).
7. Hu, M., Shealy, T., Milovanovic, J.: Cognitive differences among first-year and senior engineering students when generating design solutions with and without additional dimensions of sustainability. Design Science, **7**, E1 (2021). doi: 10.1017/dsj.2021.3
8. Kim, H., Cluzel, F., Leroy, Y., Yannou, B., Yannou-Le Bris, G.: Research perspectives in ecodesign. Design Science, **6**, E7 (2020). doi: 10.1017/dsj.2020.5
9. Mattson, C., Pack, A., Lofthouse, V., Bhamra, T.: Using a Product's Sustainability Space as a Design Exploration Tool. Design Science, **5**, E1 (2019). doi: 10.1017/dsj.2018.6
10. Ojala, T., Mettälä, M., Heinonen, M., Oksanen, P. (eds.) Ekologisesti kestävällä digitalisaatiolla ilmasto- ja ympäristötavoitteisiin. ICT-alan ilmasto- ja ympäristöstrategiaa valmistelevan työryhmän loppuraportti. Liikenne- ja viestintäministeriön julkaisuja 2020:19. Liikenne- ja viestintäministeriö (2020). http://urn.fi/URN:ISBN: 978-952-243-606-1
11. Wahlström, M.: Koneet, joilla pelastamme planeetan: älyteknologialla ilmastonmuutosta vastaan. Gaudeamus (2021).
12. Hay, L., Cash, P., McKilligan, S.: The future of design cognition analysis. Design Science, **6**, E20 (2020). doi: 10.1017/dsj.2020.20
13. Lehtonen A., Salonen A.O., Cantell H.: Climate Change Education: A New Approach for a World of Wicked Problems. In: Cook J. (eds.) Sustainability, Human Well-Being, and the

Future of Education. Palgrave Macmillan, Cham (2019). doi: 10.1007/978-3-319-78580-6_11
14. Wessman, H., Salmi, O., Kohl, J., Kinnunen, P., Saarivuori, E., Mroueh, U. Water and society: mutual challenges for eco-efficient and socially acceptable mining in Finland. Journal of Cleaner Production, **84**, 289-298 (2014). doi: 10.1016/j.jclepro.2014.04.026.
15. Balkenende, A. R., Bakker, C. A.: Developments and Challenges in Design for Sustainability of Electronics. In: R. Curran et al. (Ed.), Transdisciplinary lifecycle analysis of systems (pp. 3–13). IOS Press (2015, July)
16. Cañas J.J.: The Human Mind and Engineering Models. In: Rauterberg M. (eds.) Culture and Computing. Design Thinking and Cultural Computing. HCII 2021. Lecture Notes in Computer Science, vol 12795. Springer, Cham (2021). doi: 10.1007/978-3-030-77431-8_12
17. Thagard, P. Findlay, S. Changing Minds about Climate Change: Belief Revision, Coherence, and Emotion. In: P. Thagard (ed.), The cognitive science of science: Explanation, discovery, and conceptual change (pp. 61–80). MIT Press (2012)
18. Evans, J.St.B.T.: Bias in human reasoning: Causes and consequences. (Essays in cognitive psychology). Lawrence Erlbaum Associates Ltd., Publishers (1989)
19. Kahneman, D.: Thinking, fast and slow. Penguin Books (2011)
20. Saariluoma, P.: Ajattelu työelämässä. Erehdyksistä mahdollisuuksiin. Werner Södeström Osakeyhtiö (2003)
21. Sonnleitner, P.: Cognitive pitfalls in dealing with sustainability. In: A. König & J. Ravetz (eds.), Sustainability Science: Key Issues (pp. 82-95). Routledge (2018)
22. Plato, (2001). Gorgias. [B. Jewett, Trans.]. Virginia Tech. (Original work published 380 BC)
23. Hansen, H.: Fallacies. In: E.N. Zalta (ed.) The Stanford Encyclopedia of Philosophy (Summer 2020 Edition). <https://plato.stanford.edu/archives/sum2020/entries/fallacies/>.
24. Bassok, M., Novick, L.: Problem Solving. In: K.J. Holyoak & Morrison, R.G. (eds.) The Oxford Handbook of Thinking and Reasoning. Oxford University Press (2012). doi: 10.1093/oxfordhb/9780199734689.013.0021
25. Johnson-Laird, P.N.: Inference with Mental Models. In: Holyoak, K.J. & Morrison, R.G. (eds.) The Oxford Handbook of Thinking and Reasoning. Oxford University Press (2012). doi: 10.1093/oxfordhb/9780199734689.013.0009
26. Morrison, R. G.: Thinking in Working Memory. In: Holyoak, K.J. & Morrison, R.G. (eds.) The Cambridge handbook of Thinking and Reasoning (pp. 457–474). Cambridge University Press (2005).
27. Carbon, C.: Psychology of Design. Design Science, **5**, E26 (2019). doi: 10.1017/dsj.2019.25
28. Myllylä, M.: Embodied mind and mental contents in graffiti art experience. (Publication No. 2922) [Doctoral dissertation, the University of Jyväskylä]. JYX Digital Repository (2022). http://urn.fi/URN:ISBN:978-951-39-8991-0
29. Raami A.: Towards Solving the Impossible Problems. In: Cook J. (eds.) Sustainability, Human Well-Being, and the Future of Education. Palgrave Macmillan, Cham (2019). doi: 10.1007/978-3-319-78580-6_6
30. Baars B.J., Gage N.M.: Cognition, brain, and consciousness: Introduction to cognitive neuroscience (2nd ed.). Elsevier (2010)
31. Ericsson, K.A.: An introduction to the second edition of the Cambridge handbook of expertise and expert performance: Its development, organization, and content. In Ericsson, K.A., Hoffman, R.R., Kozbelt, A. & Williams, A.M. (eds.) The Cambridge handbook of expertise and expert performance (2nd ed., pp. 3–20). Cambridge University Press (2018)
32. Faludi, J., Yiu, F., Agogino, A.: Where do professionals find sustainability and innovation value? Empirical tests of three sustainable design methods. Design Science, **6**, E22 (2020). doi: 10.1017/dsj.2020.17

33. Clarke, R.I. Design Thinking. ALA Neal-Schuman (2020).
34. Hay, L., Duffy, A., McTeague, C., Pidgeon, L., Vuletic, T., & Grealy, M.: Towards a shared ontology: A generic classification of cognitive processes in conceptual design. Design Science, **3**, E7 (2017). doi: 10.1017/dsj.2017.6
35. Sauder, J., Jin, Y.: A qualitative study of collaborative stimulation in group design thinking. Design Science, **2**, E4 (2016). doi: 10.1017/dsj.2016.1
36. Smith, S.M. & Ward, T.B.: Cognition and the Creation of Ideas. In: Holyoak, K.J. & Morrison, R.G. (eds.) The Cambridge handbook of Thinking and Reasoning (pp. 456–474). Oxford University Press (2012). doi: 10.1093/oxfordhb/9780199734689.013.0023
37. Evans, J.St.B.T.: Dual-Process Theories of Deductive Reasoning: Facts and Fallacies. In: Holyoak, K.J. & Morrison, R.G. (eds.) The Cambridge handbook of Thinking and Reasoning (pp. 115–133). Oxford University Press (2012). doi: 10.1093/oxfordhb/9780199734689.013.0008
38. Nolte, H., McComb, C.: The cognitive experience of engineering design: An examination of first-year student stress across principal activities of the engineering design process. Design Science, **7**, E3 (2021). doi: 10.1017/dsj.2020.32
39. Dutilh Novaes, C.: Argument and Argumentation. In: Zalta, E.N. (ed.) The Stanford Encyclopedia of Philosophy (Fall 2021 Edition). <https://plato.stanford.edu/archives/fall2021/entries/argument/>.
40. Aristotle: Prior Analytics. (A. J. Jenkinson, Trans.). Infomotions, Inc. (2000). (Original work published 350 BC).
41. Hayes, B.K., Heit, E., Swendsen, H. Inductive Reasoning. WIREs Cognitive Science, **1**(March/April), 278–292 (2010). doi: 10.1002/wcs.44
42. Lombrozo, T.: Explanation and Abductive Inference. In: Holyoak, K.J. & Morrison, R.G. (eds.) The Cambridge handbook of Thinking and Reasoning (pp. 260–276). Oxford University Press (2012). doi: 10.1093/oxfordhb/9780199734689.013.0014
43. Holyoak, K.J.: Analogy and Relational Reasoning. In: Holyoak, K.J. & Morrison, R.G. (eds.) The Cambridge handbook of Thinking and Reasoning (pp. 234–260). Oxford University Press (2012). doi: 10.1093/oxfordhb/9780199734689.013.0013
44. Bar, M.: The proactive brain: Using analogies and associations to generate predictions. Trends in Cognitive Sciences, **11**(7), 280–289 (2007)
45. Hofstadter, D.R.: Analogy as the core of cognition. In: Gentner, D., Holyoak, K.J., & Kokinov, B.N. (eds.) The analogical mind: Perspectives from cognitive science (pp. 499–538). Massachusetts Institute of Technology (2001).
46. Thagard, P., Shelley, C.: Emotional analogies and analogical inference. In: Gentner, D., Holyoak, K.J., & Kokinov, B.N. (eds.) The analogical mind: Perspectives from cognitive science (pp. 335–362). Massachusetts Institute of Technology (2001).
47. Molden, D.C. Higgins, E.T.: Motivated Thinking. In: Holyoak, K.J. & Morrison, R.G. (eds.) The Cambridge handbook of Thinking and Reasoning (pp. 390–410). Oxford University Press (2012). doi: 10.1093/oxfordhb/9780199734689.013.0020
48. Jansson, D.G. & Smith, S.M.: Design Fixation. Design Studies, **12**(1), 3–11 (1991).
49. Linsey, J.S., Tseng, I., Fu, K., Cagan, J., Wood, K.L., Schunn, C.: A Study of Design Fixation, Its Mitigation and Perception in Engineering Design Faculty. Journal of Mechanical Design, **132**, 041003-1–041003-12 (2010)
50. IPCC: Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.). Cambridge University Press. In Press.

51. Narvaez, D.: Moral development and moral values. Evolutionary and neurobiological influences. In: McAdams, D.P., Shiner, R.L. & Tackett, J.L. (eds.) Handbook of personality development (pp. 345–363). Guilford Press (2019).
52. Filho, W.L., Wolf, F., Salvia, A.L., Beynaghi, A., Shulla, K., Kovaleva, M., Vasconcelos C.R.P.: Heading towards an unsustainable world: some of the implications of not achieving the SDGs. Discov Sustain **1**, 2 (2020). doi: 10.1007/s43621-020-00002-x
53. Samuelson, W. Zeckhauser, R.: Status Quo Bias in Decision Making. Journal of Risk and Uncertainty, **1**, 7–59 (1988)
54. Youmans, R., Arciszewski, T.: Design fixation: Classifications and modern methods of prevention. Artificial Intelligence for Engineering Design, Analysis and Manufacturing, **28**(2), 129-137 (2014). doi: 10.1017/S0890060414000043
55. Li, D. Du, Y.: Artificial intelligence with uncertainty. (2nd ed.). CRC Press (2017). doi: 10.1201/9781315366951
56. Mulligan, K.: Emotions and Values. In: Goldie, P. (ed.) The Oxford Handbook of Philosophy of Emotion (pp. 475–500). Oxford University Press (2009). doi: 10.1093/oxfordhb/9780199235018.003.0022
57. Chang-Arana, Á., Piispanen, M., Himberg, T., Surma-aho, A., Alho, J., Sams, M., Hölttä-Otto, K.: Empathic accuracy in design: Exploring design outcomes through empathic performance and physiology. Design Science, **6**, E16 (2020). doi: 10.1017/dsj.2020.14
58. Marquardt, J. Nasiritousi, N.: Imaginary lock-ins in climate change politics: the challenge to envision a fossil-free future. Environmental Politics (2021). doi: 10.1080/09644016.2021.1951479
59. Gherheș V, Obrad C.: Technical and Humanities Students' Perspectives on the Development and Sustainability of Artificial Intelligence (AI). Sustainability, **10**(9), 3066 (2018) doi: 10.3390/su10093066