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Cognitive Psychology

The TECo Database: Ecological and Technological Concepts at the Interface Between Abstractness and Concreteness

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Ecology and *Technology* are two keywords of the era we inhabit. Knowing how people represent these domains is essential to inform adequate interventions aimed at promoting conscious behaviors. Here we investigated this aspect by taking insights from the literature on conceptual organization. Specifically, we hypothesized Ecological and Technological concepts might have a "hybrid" nature, at the edge between Abstract and Concrete concepts. We asked a sample of Italian participants to rate 200 concepts pertaining to Ecological (e.g., *deforestation*), Technological (e.g., *Internet*), Natural (e.g., *water*), and Geographical/Geopolitical domains (e.g., *mountain*, *city*) on 39 semantic dimensions, some of which traditionally investigated (e.g., Context Availability), and others completely new (e.g., Political Relevance). Results indicate that Ecological and Technological concepts, despite having concrete referents, were more similar to Abstract than Concrete concepts in Concreteness~Abstractness and other semantic dimensions (e.g., Interoception, Social Valence). Interestingly, for some dimensions, they displayed a "more abstract" pattern than that of more typical Abstract concepts—e.g., later and more linguistic acquisition, higher need of others to be understood. Moreover, a Principal Component Analysis revealed three major components that explained overall the conceptual organization of our set of concepts. The first component complements the rating results, with the opposition between concreteness~abstractness, where Ecological and Technological concepts lie in the most abstract extreme. A further Hierarchical Cluster Analysis supported this distinction. Overall, our results have a twofold relevance. On a theoretical side, they contribute to enrich theories on concepts, suggesting Ecological and Technological concepts are special conceptual domains questioning the *concrete-abstract* dichotomy; on a more pragmatic side, they might inform societal politics on these timely themes.

1. Introduction

Over the last few decades, the world has experienced rapid scientific advancements, which are generating deep transformations in our lifestyle and environment, deeply affecting both our well-being and that of our planet.

One of the most impactful phenomena has been the advent of the Internet along with technological progress. Starting from the end of the 19th century, with the invention of the telephone, and passing through the middle of the 20th century, with the construction of *Eniac*, i.e., the first computer, and the implementation of the first Internet line, we have witnessed a rapid increase in the use of technology in our daily life. According to recent international reports, nowadays around 47.1% of the global population owns a personal computer (Statista Search Department, 2022), and 93% a mobile phone (statistics related to Europe - ITU, 2022). The Global Connectivity Report of the International Communication Union shows that the number of Internet users worldwide has increased over years, passing from 16% (1.0 billion of people) in 2005 to 66% (5.3 billion of people) in 2022 (ITU, Jolliffe, 2010). We live constantly immersed in technology, and its advance has offered

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new forms of entertainment, information, and communication, promoting global interconnectedness.

Besides these benefits, technological progress is also generating several negative consequences, both for humans and for the planet. Indeed, technological advancements enhanced social isolation and led to the progressive detachment from unmediated forms of relation with nature (Torales et al., 2020), resulting in the manifestation of many chronic stress syndromes (Rampelli et al., 2016; Tong et al., 2013) and psychological affections (Krabbendam & van Os, 2005). Furthermore, according to some estimates, the carbon footprint of our gadgets, the Internet, and their supporting systems accounts for about 3.7% of global greenhouse emissions. This is comparable with the number of emissions produced by the airline industry globally, and these emissions are predicted to double by 2025 (Griffiths, 2023).

Nowadays, the consequences of global warming, climate change, and the human indiscriminate exploitation of the planet's resources are manifesting with increasing force, generating considerable concerns for the future (Gooch, 1995; Hodgkinson & Innes, 2000). Phenomena such as biodiversity loss, catastrophic floods, melting glaciers, and rising of seas levels have a catastrophic impact on many domains, from food production (Parry et al., 2004) to the health of both ecosystems (IPCC, 2007) and people (EPA, 2010; Patz et al., 2005).

Taken together, this evidence unmasks a paradox of our historical time: while humans are evolving, the earth is exhausted, and our overall well-being is at risk.

Environmental psychology studies show that people are aware of the most correct ways to behave toward the planet (McKenzie-Mohr, 2002; Vorkinn & Riese, 2001). Despite this, the limits of the earth are repeatedly exceeded (Berenguer, 2007). Similarly, although school children are aware of the risks associated with screens and technology overusing (e.g., computer vision syndrome, worst communication skills - Sarvasri et al., 2020), they spend more time in front of a screen than in any other activity besides sleeping—with an average of 7 hours and 38 minutes a day, seven days a week (Rideout et al., 2010). Some of the reasons underlying this incongruence might lie in the insufficient understanding of how people represent reality. Indeed, actions are influenced not only by emotional, personological, and contextual aspects but also by cognitive representations (Myers, 2008).

The very first step to promote a course reversal might be thus to understand how humans cognitively represent technological and ecological issues. Indeed, although technology and ecology can be considered two separate domains, they are deeply intertwined, and our future depends on their most optimal balance.

While several studies investigated the impact of these domains in our life, focusing for instance on emotional aspects (e.g., digital emotion regulation - Wadley et al., 2020; eco-anxiety - Clayton, 2020; Pihkala, 2020), the way in which people cognitively represent these domains has not been studied yet. Specifically, research on the conceptualization of technological devices is limited to the assessment of differences between artificial (i.e., technological) and natural entities (e.g., Keil, 1989; Olivero & Carrara, 2021). Notably, here, we will access concepts and their properties, focusing on the words that express them. In addition, while many studies focused on the conceptualization of natural kinds like animals, plants (e.g., Berlin, 2014), and geographical entities (for a review, see Falcinelli et al., 2024), to the best of our knowledge no studies until now focused on how people conceptualize ecological issues caused by scientific and technological progress. This is a crucial point to understanding context-situated behaviors of human beings toward themselves, other people, and the natural environment. Understanding what words such as *nature, forest, climate change, sustainable development, pollution*, but also *Internet, technology,* and *connection* mean for people might indeed shed light on the cognitive representations driving human behaviors.

Studies on conceptual organization offer an interesting point of view to deepen aspects related to the representation of meaning, for example through the investigation of differences in the acquisition, use, and elaboration of concepts/words with differing levels of abstractness (Borghi et al., 2017; Brysbaert et al., 2014; Paivio, 1986). Compared to more Concrete concepts (e.g., *dog*), more Abstract concepts (e.g., *democracy*) generally do not refer to single and well-defined objects, but most often to complex situations with multiple entities in interaction. Moreover, they seem to be more detached from sensorimotor experience and more divergent in their meaning across individuals than Concrete concepts, being more strongly affected by contextual factors such as social (Barsalou & Wiemer-Hastings, 2005; Borghi, 2022; Catricalà et al., 2020; Diveica et al., 2023; Fini et al., 2021, 2023; Pexman et al., 2023), linguistic and cultural backgrounds (Borghi & Mazzuca, 2023; Gentner & Boroditsky, 2001; Mazzuca & Majid, 2023), expertise (Villani et al., 2022), and life experiences (Borghi & Binkofski, 2014; Mazzuca et al., 2020, 2021). This research field has been recently expanded by an exploration of the semantic properties of specific sub-kinds of Abstract (e.g., philosophical, spatio-temporal, emotional, social, numerical, moral, and mental states concepts - see Conca et al., 2021; Desai et al., 2018; Villani et al., 2019) and Concrete (e.g., food, tools, artifacts and natural kinds - see Keil, 1989; Rumiati & Foroni, 2016; Warrington & Shallice, 1984) concepts. Many efforts have also been devoted to exploring domains for which the concreteness~abstractness distinction might be problematic—because it might shift depending on the context—such as the ones of gender (Mazzuca et al., 2020; Mazzuca & Majid, 2023) and olfaction (Majid et al., 2018). In this framework, Ecological (e.g., *climate change, deforestation, ozone hole*) and Technological concepts (e.g., *connection, computer, Internet*) have been mostly overlooked.

Although Ecological and Technological concepts usually refer to concrete events, i.e., phenomena, objects, or entities that can be directly and first-hand experienced, at the same time, they seem to possess characteristics typically assigned to Abstract concepts, such as their strong social (Borghi, 2018a), emotional (Kousta et al., 2011), and political (Mazzuca & Santarelli, 2022) character. For example, thinking about the concept of *climate change* might evoke images of *flooding, blazes,* and *smoking industries*, which are all concrete entities. However, their emotionally charged nature is undoubted—eliciting negative emotions such as fear, uncertainty, and anxiety—as well as their high societal impact, and politicized character, being frequently at the forefront of public debates (e.g., COP26, 2021) and of awareness initiatives enacted to cope with climate change consequences (e.g., *Fridays for Future* - https://fridaysforfuture.org/). Likewise, the concept of the *Internet* might bring to our mind physical objects such as *computers, mobile phones, and screens*. At the same time, it might also be highly emotionally and socially charged, representing an important tool for socialization and communication with others.

Assessing Ecological and Technological concepts' abstractness and related semantic properties could help explain how individuals act towards the entities they refer to. People typically judge Abstract concepts as difficult to imagine and weakly linked to contexts (Paivio, 1990; Paivio et al., 1988; Schwanenflugel et al., 1992). If Ecological concepts score high in abstractness, visualizing their referents and acting responsibly towards them might require additional efforts. For instance, if people consider the concept of *environmental pollution* as abstract, this might prevent the mental visualization of related environmental damages and consequently bring less emotional engagement and motivation to adopt responsible behaviors. On a more practical level, it might be harder to relate the concept to everyday experiences, for instance, not throwing cooking oil down the sink. As for Technological concepts, their higher abstractness might explain how far we are from fully understanding the origins, potential, and functioning of the interfaces we use in daily life. In line with this, studying these recently emerged classes of concepts under the light of concreteness~abstractness might help to understand the aspects underlying the tip of the iceberg of visible behaviors and to explain the incongruence between the awareness of the best ways to act and actual behaviors.

1.1. The Present Study

Here, we sought to understand, for the first time, whether these categories of concepts of recent emergence might constitute "hybrid" conceptual domains, lying at the edge between Abstract and Concrete concepts. To do so, we used a rating task (e.g., Mazzuca et al., 2022) in which we asked participants to evaluate target words on several semantic dimensions with 7-points Likert scales. Our linguistic stimuli consist of Ecological (e.g., *climate change, ozone hole, biodiversity*) and Technological concepts (e.g., *Internet, connection, wi-fi*), along with Natural (e.g., *water, bee, tree*) and Geographical/Geopolitical concepts (e.g., *mountain, ocean, desert, city, state, hamlet*—from now, "Geo" concepts). These last categories (i.e., Natural and Geo concepts) included words referring to some consequences or contributors to climate change (e.g., atmospheric events, natural elements), as well as natural entities (e.g., animals, plants) and locations (natural and urbanized environments) typically affected by climate changes. All the set of words was evaluated on 39 semantic dimensions. We decided to include numerous dimensions with the aim to characterize more in-depth these new conceptual domains. Our approach is in line with recent proposals on conceptual organization (Multiple Representations Views - e.g., Borghi et al., 2017, 2018b; Crutch et al., 2013; Dove, 2009, 2014, 2022; Zdrazilova et al., 2018). More traditional views imply a sharp dichotomy between Abstract and Concrete concepts. For instance, differently from Concrete concepts, Abstract concepts are generally acquired later (Gilhooly & Logie, 1980) and processed more slowly (Paivio, 1990). In addition, since they usually refer to well-defined objects, sensorimotor components would be more relevant for their processing; Abstract concepts might instead rely more on linguistic, internal, and social components (Borghi et al., 2019a, 2019b). By contrast, Multiple Representations Views propose to study the semantic characterization of concepts regardless of their distinction into the macro-categories of Abstract and Concrete concepts, suggesting concreteness~abstractness is just one among the multifarious semantic properties concepts might encode. Under these accounts, concepts are represented in a multidimensional space encompassing sensorimotor, internal, linguistic, and social components. In keeping with this characterization, one should focus on specific aspects that mostly contribute to the representation of specific conceptual domains. For instance, numerical concepts were found to be consistently linked with sensorimotor states (e.g., finger counting) despite being generally understood as abstract (Fischer & Shaki, 2018).

In our study, we embraced these new research insights by treating Ecological and Technological concepts as two distinct categories of concepts, and we confronted them with typical Abstract and Concrete concepts to better explore their nature. Specifically, we first compared Ecological and Technological concepts' Concreteness~Abstractness scores with those of Abstract and Concrete concepts broadly distinguished, and with those of specific sub-kinds of Abstract and Concrete concepts. Then, we assessed how they scored on semantic dimensions typically considered relevant for the characterization of Abstract and Concrete concepts (e.g., Age and Modality of Acquisition, Imageability, Context Availability). With the aim of achieving an overarching characterization of the domains, we then identified the most important dimensions for Ecological and Technological concepts together with Natural and Geo concepts using a dimension reduction technique (i.e., Principal Component Analysis - PCA) and inspecting the categories distribution in the related semantic space. This was then complemented by a Hierarchical Cluster Analysis. Finally, we compared our four *a-priori* categories (Ecological, Technological, Geo, Natural) on the most important dimensions resulting from the PCA, to detect specific properties of Ecological and Technological concepts.

2. Data Availability

All the materials, data, scripts, and analyses of the study, along with the TECo Database, are available at the OSF repository: https://doi.org/10.17605/OSF.IO/M6PH9.

3. Methods

3.1. Participants

A sample of 340 Italian participants took part in the study in a window of time between February 21st 2022, and January 18th 2023. We implemented the surveys on the online platform of Qualtrics. Participants were contacted via an anonymous link either by posting the questionnaires on social networks (Facebook, Instagram, Twitter) or by spreading the surveys through the research team's extended network of acquaintances. Participants were eligible for the study if they were Italian native speakers aged more than 18 years. Originally, we contacted 533 participants, but 193 of them (36.21% of the total sample) were excluded for various reasons. First, in line with Brysbaert et al.'s (2014) procedure, we eliminated 165 participants because they did not complete the questionnaires, likely because of their length. Second, to identify outliers we used Della Rosa et al.' s (2010) criterion, eliminating participants who used the same response option (e.g., "7") for more than 85% of the total responses of the surveys—hence excluding data with consistent lack of variability. In line with this, we removed 28 further participants. As an additional outliers' exclusion criterion, we added some attentional checks in the surveys (see section 3.3 for details), but no participant failed to respond to them more than once. The final sample is therefore composed of 340 participants (225 females: *M age* = 32.58; *SD age* = 13.48; 113 males: *M age* = 38.67; *SD age* = 17.07; 2 intersex: *M age* = 38.50; *SD age* = 19.09), all Italian native speakers. All the other socio-demographic information collected can be found in Table S1, Supplementary Materials (from now "SM").

3.2. Materials

Words. The stimuli pool was composed of 200 Italian target words. These pertained to four categories: Ecological concepts (*n* = 50), Natural concepts (*n* = 50), Geo concepts (*n* = 50), and Technological concepts (*n* = 50). Ecological concepts included words referring to ecology-related phenomena (e.g., *climate change, global warming, ozone hole*) or indicating causes of the ecological crisis (e.g., *fumes, industrial drain, pesticides*). Natural concepts contained words related to natural and environmental entities that are relevant for debates on ecological topics, representing both consequences or contributors to climate change and entities typically affected by it. Specifically, four sub-categories were included: animals (*n* = 13, e.g., *bee, whale, turtle*), natural elements (*n* = 12, e.g., *water, oxygen, amianthus*), atmospheric events (*n* = 12, e.g., *flood, blaze, wind*), and plants (*n* = 13, e.g., *tree, flower, oak tree*). Geo concepts included words referred to both Geographical (*n* = 25, e.g., *sea, mountain, river*) and Geopolitical (*n* = 25, e.g., *state, nation, meridian*) entities, i.e., natural and urbanized locations in which climate change phenomena usually occur. Finally, Technological concepts encompassed words not related to the *green* domain as Ecological, Natural and Geo concepts, and referred to informatics and technological fields—i.e., devices and software mostly useful to communicate and interact with others (e.g., *account, display, Facebook*). The whole set of words can be found in Table S2, SM.

The selection of the 200 target words was carried out through a manual search for glossaries on the Internet, taking care to select only concepts coming from websites pertinent to each topic. Target words were selected among those that most often occurred across glossaries. For instance, Ecological words were extracted among the most frequent in glossaries created by Italian institutions or associations involved in natural protection and awareness initiatives coping with climate change consequences (e.g., https://www.isprambiente.gov.it/it/attivita/biodiversita/glossario). The same criterion was followed for all the remaining categories, except for Natural concepts for which some words (i.e., animals and plants) were taken from Della Rosa et al.' s (2010) database. We selected principally basic level nouns. The basic level is the intermediate level of categorization; basic-level terms (e.g., *cat*) are typically more distinctive than subordinate concepts (e.g., *Siamese cat*) and more informative than superordinate ones (e.g., *animal*). They are generally learned earlier and used more frequently than subordinate and superordinate concepts and represent the most prototypical word categories (Rosch, 1978; Rosch et al., 1976).

Since we were mostly interested in Ecological and Technological concepts, and to the best of our knowledge, this is the first study targeting these categories, we made sure the exemplars we selected were representative of each domain. Specifically, we asked an independent sample of 20 young adult participants (16 females, *M age* = 36.69; *SD age* = 10.28; 4 males, *M age* = 36.50; *SD age* = 12.92) to rate how representative Ecological and Technological concepts were for their related domain using a 7-point Likert scale (from 1 = "very few" to 7 = "very much"). In the survey, dimensions (i.e., "Ecological Representativeness" and "Technological Representativeness") were randomly presented within participants, and Target Words were randomly presented within each dimension. We found that both Ecological and Technological words were overall highly representative of the related domain (Ecological: *Mdn* = 5; *M* = 5.07; *SD* = 1.80; *SE* = 0.06; Technological: *Mdn* = 5.00; *M* = 4.95; *SD* = 1.72; *SE* = 0.05), but encompassed a broad range of representativeness scores (*Range:* Ecological = 3.70 – 6.65; Technological = 2.55 – 6.25) with some concepts being less representative for the target category, despite receiving average representativeness scores (Ecological: e.g., *petroleum* = 3.70; *sewer* = 3.75; *industry* = 3.80. Technological: e.g., *fax* = 2.55; *slide* = 2.95; *compact disk* = 3.30), and others being instead very representative (Ecological: e.g., *environment* = 6.65; *recycling* = 6.55; *zero impact* = 6.30. Technological: *computer* = 6.25; *Internet* = 6.15; *web* = 6.15). Finally, a t-test showed no differences between Ecological and Technological concepts in terms of domain representativeness, $t(98) = 0.709$, $p = .480$, suggesting that they were similarly representative of the category they belong to.

To compare Ecological and Technological concepts with Abstract and Concrete concepts on different semantic properties (see section 4.1 and 4.1.1), we further randomly selected 50 Abstract concepts from the Italian database by Villani et al. (2019) and 50 Concrete concepts that overlapped between the Italian databases by Della Rosa and colleagues (2010) and Repetto and colleagues (2022). For Concrete concepts, ratings of Concreteness~Abstractness, Age of Acquisition, Modality of Acquisition, Imageability, and Context Availability were taken from Della Rosa et al.'s (2010), while ratings of Interoception, Perceptual Strength, Mouth and Hand action effectors were extracted from Repetto et al.'s (2022), as Della Rosa et al.'s (2010) database did not feature these dimensions.

Finally, to compare Ecological and Technological concepts with different sub-kinds of Abstract and Concrete concepts on Concreteness~Abstractness (see section 4.1) we randomly selected 50 words from each of the four subclusters of Abstract concepts identified in Villani et al. (2019)—i.e., Philosophical/Spiritual, Emotional/Inner, Self/Sociality, and Physical/Spatio-temporal/Quantitative—and 50 randomly selected Concrete words referring to Tools—including both manipulable and non-manipulable objects—from Della Rosa et al.'s (2010). Concreteness~Abstractness scores were taken from the related databases.

Semantic Dimensions. The complete list of words was rated by participants on 39 semantic dimensions. Some dimensions referred to traditionally investigated conceptual properties in literature; others were instead dimensions of recent interest in the field, or completely new ones. Among the more traditional dimensions, we first targeted those typically used to identify abstract concepts: Concreteness~Abstractness, referring to the amount of abstractness of a concept (Paivio, 1990; Paivio et al., 1988; Villani et al., 2019); Imageability (Paivio, 1990; Paivio et al., 1988; Villani et al., 2019) and Context Availability (Schwanenflugel et al., 1992; Villani et al., 2019), relating to the easiness by which a concept evokes respectively mental images and different contexts or situations; Familiarity, referred to the level of personal knowledge of a concept (Barca et al., 2002); and Frequency, indicating the estimated frequency of use of a word in written and spoken language (Laudanna & Burani, 1995). In our database (the "TECo database", see section 3.4), we also included an objective measure of word frequency (see the OSF repository: https://doi.org/10.17605/OSF.IO/M6PH9; for further details on its relationship with the Frequency measure we collected, see Appendix A, SM).

Second, in line with suggestions of Multiple Representation Views (e.g., Words As social Tools – WAT view - Borghi et al., 2018b; Borghi, 2023; Borghi & Binkofski, 2014), we included semantic dimensions testing to what extent concepts are grounded in different kinds of experiences. Specifically, we targeted sensorimotor experience with Body-Object-Interaction, measuring the extent by which it is easy interact with the object to which a concept refers through the body (Bennett et al., 2011; Siakaluk et al., 2008; Tillotson et al., 2008; Villani et al., 2019); Perceptual Strength, indicating to what extent a concept can be experienced through the five sensory modalities (i.e., through vision, touch, hearing, taste, and smell - Connell & Lynott, 2012, 2014; Lynott & Connell, 2013; Villani et al., 2019); and Action Effectors, indicating how much a concept activates specific bodily parts (specifically, feet/legs, hands/arms, mouth/throat, and torso - Lynott et al., 2019). Two dimensions referred to inner experiences, i.e., Interoception, indicating how much a word evokes internal body states (Connell et al., 2018; Villani et al., 2019, 2021); and Metacognition, indicating how much a word evokes mental and cognitive processes (Villani et al., 2019). Two dimensions addressed conceptual components related to social experience: Social Metacognition, referring to the extent by which we feel the need to rely on others to understand the meaning of a concept (Borghi et al., 2018b, 2018a, 2019a, 2019b; Villani et al., 2019); and Social Valence, indicating how much a concept evokes social situations (Diveica et al., 2023; Pexman et al., 2023; Villani et al., 2019). For this last dimension, we decided to base on the operationalization of the construct provided in the Italian database by Villani et al. (2019), despite being aware of the work of other authors on the topic (for the construct of "Socialness", see Diveica et al., 2023; Pexman et al., 2023). This indeed allowed us to perform comparisons on this dimension between our categories of concepts and those included in the database by Villani et al. (2019) (see section 4.1.1 for more details). Four dimensions we took into consideration were related to emotional experience. They were: Emotionality, indicating the amount of emotional load of a concept (Ponari et al., 2018; Vigliocco et al., 2014; Villani et al., 2019); Valence, Dominance, and Arousal, referring respectively to the emotional valence of the concept (negative~positive), to the degree of perceived control on the object to which the concept refers, and to the degree of inner activation generated by the word (Montefinese et al., 2014). We also included two dimensions related to word acquisition, i.e., Age of Acquisition (Gilhooly & Logie, 1980) and Modality of Acquisition (Wauters et al., 2003, 2006), which respectively refer to the age and modality (sensorimotor~linguistic experiences) through which a concept/word has been acquired.

Among novel semantic dimensions, five referred to metacognitive processes. Word Confidence and Confidence in Experts (Mazzuca et al., 2022), indicate how confidently people think they or field experts master the meaning of a word, respectively; Easiness of Providing a Definition of the word; one dimension concerns the perceived scientific character of the word (Scientificity); and a last dimension related to how much participants feel the need to rely on experts to understand the meaning of a concept (Expert Social Metacognition). This dimension is similar to that of Social Metacognition (Borghi et al., 2018b, 2018a, 2019a, 2019b; Villani et al., 2019), with the difference that in this case it is specified that individuals to rely on are those participants considered as experts of the domain to which concepts belong. To ideate this dimension, we also took inspiration from the more classical construct of Epistemic Trust (e.g., see McCraw, 2015).

Another set of these dimensions rely on pragmatic aspects, such as the easiness to start a conversation with a specific concept (Easiness to Start a Conversation - Fini et al., 2023); and the openness to negotiate the meaning of a concept with others (Openness to Negotiation - Fini et al., 2023). Six dimensions referred to the impact of concepts in our life, such as Political Relevance, indicating the extent by which a concept can generate public and social debates (taking insights from Mazzuca & Santarelli, 2022); Perceived Distance from the concept (Mazzuca et al., 2022); Perceived Impact of the concept in our past, present, and future; and perceived Personal Experience with it. Finally, we added a dimension named Naturalness~Artificiality to investigate how concepts are categorized into the macro-categories of natural *vs* artifactual entities (taking inspiration from Forde & Humphreys, 2005). The operationalization of the dimensions along with the Italian and English versions of the instructions can be found in the OSF repository (https://doi.org/10.17605/OSF.IO/M6PH9).

3.3. Procedure

The experiment was approved by the Ethics Committee of the Department of Dynamic and Clinical Psychology, and Health Studies, Sapienza University of Rome (Prot. n. 000147 - 04/02/2022) and was carried out in accordance with the ethical standards of the 1964 Declaration of Helsinki. Participants took part in an online survey implemented on Qualtrics. Before compiling the survey, participants were informed of the general purpose of the study and provided informed consent for the participation in the study and the publication of the related results. Once agreed to take part in the experiment, participants were presented with the rating task. They were asked to evaluate target words on the targeted semantic dimensions using a 7-point Likert scale and encouraged to respond as carefully and quickly as possible without spending too much time thinking about every single word. Each item was delivered individually in a short piece of framing text followed by the relevant rating scale. In the last section of the survey, participants provided socio-demographic information. They were asked to report their age, birth sex, level of education, occupational state, socio-economic status, city and region of provenience, native language, and other linguistic competencies. We also asked them to indicate whether their place of provenance and residence was rural or urban, and to rate their perceived level of expertise in ecological and natural environmental topics on a 7-point Likert scale (see Table S1, SM). Participants were allowed to pause the experiment at any time and restart it at their own pace, as long as they handed in the survey within 72 hours from the start.

We implemented a total of 17 surveys, each of which was compiled by an independent sample of 20 participants. Sample size for each dimension was calculated in line with similar works (Villani et al., 2019). In line with this, we gained 20 ratings per word per dimension. Each participant completed only one survey. Following Villani et al. (2019), participants evaluated the entire set of words on two or more dimensions. Surveys (n = 3) included more than two semantic properties when these represent sub-categories of the same dimension (e.g., vision, touch, hearing, taste, and smell sensory modalities for the "Perceptual Strength" dimension). In the surveys, dimensions were randomly presented within participants, and Target Words were randomly presented within each dimension. The structure of surveys is reported in the OSF repository (Table 1 - https://doi.org/10.17605/OSF.IO/M6PH9). In each survey, four attentional checks per dimension were inserted and randomly delivered, to ensure participants' attention. Specifically, participants were presented with geometric figures and their names and asked to indicate the figure corresponding to the name.

3.4. Data Analysis

Before analyzing the data, participants' responses were inspected to identify incomplete responses and outliers. In keeping with exclusion criteria (see section 3.1), we discarded 36.21% of data. The final dataset was therefore composed of 156.000 data points with 20 ratings per word per dimension. We then estimated the interrater reliability (i.e., Cronbach's alpha - Cronbach, 1951), a measure of the internal consistency of the ratings provided by each pool of 20 participants per dimension. The Cronbach's alphas resulted to be excellent for all dimensions, ranging from .90 to 1.00 (see Table S3, SM). As a second step, we calculated summary statistics (median, mean, standard deviation, standard error, range value, words obtained the highest and lowest scores) per dimension (see Table S4, SM), and finally we extracted the mean scores and standard deviations for all the words and for each dimension. This allowed us to create a database containing information related to all the semantic properties we targeted for our four categories of concepts (Ecological, Geo, Natural, and Technological). The database (TECo Database - i.e., Technological and Ecological Concepts), is available at the OSF repository (https://doi.org/10.17605/OSF.IO/M6PH9), together with raw data, analyses scripts, and materials.

Data were pre-processed and analyzed through R (R Core Team, 2019) and RStudio (version 4.2.2). "Tidyverse" R's package (Wickham & et al., 2019) was used to prepare dataset(s) for analyses.

To perform comparisons across categories of concepts (Abstract, Concrete, Ecological, Technological), we fitted separate ANOVAs for each semantic dimension (i.e., Concreteness~Abstractness, Age of Acquisition, Modality of Acquisition, Imageability, Interoception, Context Availability, Perceptual Strength, Mouth and Hand action effectors, Social Metacognition, Social Valence, Emotionality and Metacognition - see sections 4.1 and 4.1.1). All the models featured averaged rating scores as dependent variable and Category of Word (Abstract, Concrete, Ecological, Technological) as independent variable. Unfortunately, for some dimensions (i.e., Social Metacognition, Social Valence, Emotionality and Metacognition), a comparison also with Concrete concepts was not possible due to the lack of availability of Italian databases investigating such semantic properties for this category of words. Hence, we fitted the same statistical models but only included Abstract, Ecological and Technological concepts. For models on Interoception, Perceptual Strength, Mouth, and Hand action effectors scores, ratings of Concrete concepts were converted on a 7-point Likert scale, as they were given on 6-point Likert scales in Repetto et al. (2022), while both Abstract concepts in Villani et al. (2019) and Ecological and Technological concepts in TECo database use 7-point Likert scales (for more details on the transformation, see scripts in the OSF repository: https://doi.org/10.17605/OSF.IO/M6PH9). In addition, rating scores for Perceptual Strength dimension were calculated by averaging evaluations participants provided on the five sensory modalities (i.e., hearing, smell, taste, touch, and vision) for each Target Word.

We also compared Ecological and Technological concepts with different sub-kinds of both Abstract and Concrete concepts along with Natural and Geo concepts on Concreteness~Abstractness (see section 4.1). Models were identical to those comparing Abstract, Concrete, Ecological and Technological concepts, but with Subclusters (Philosophical/Spiritual, Emotional/Inner, Self/Sociality, Physical/Spatio-temporal/Quantitative, Ecological, Geo, Natural, Technological, and Tools) as independent variable.

Pairwise comparisons for all models in the paper were fitted using "emmeans" R's package (Lenth, 2023), with adjusted *p*-values using Tukey's corrections.

A Principal Component Analysis (PCA - Jolliffe, 2010) was performed using "tidymodels" R's package (Kuhn & Wickham, 2020) to investigate which dimensions weighted the most in explaining the variability of data and how they were grouped together (see section 4.2). PCA is a dimensionality reduction method that allows reducing the dimensionality of large data sets by transforming a large set of variables into a smaller one (i.e., the most salient) that still contains most of the information in the large set. Before applying PCA, all the variables (i.e., average ratings per word per dimension) were centered and standardized. In the PCA, we entered the Category of Word (Ecological, Geo, Natural, and Technological) and the Target Word (i.e., our 200 concepts) as outcome variables and the 39 dimensions as numerical predictors. We then extracted PCA components explaining the majority of variance, and for each component we identified dimensions whose weight was higher than |.2|—which can be interpreted as a small effect size (see Cohen, 1988). Data visualization of the resulting semantic space was carried out through "ggplot2" (Wickham, 2016) and "plotly" (Sievert, 2020) R's packages. To assess the relative weight of categories of concepts for each dimension of the PCA, we performed separate Ordinal Regression Models (i.e., Cumulative Link Mixed Models), using "ordinal" R's package (Christensen, 2022), on dimensions weighing more than |.3| (i.e., indicating a medium effect size - Cohen, 1988) (see section 4.3). The models featured rating scores as dependent variable, Category of Word (Ecological, Geo, Natural, Technological) as fixed factor, and Target Words and Participants as random intercepts. Significant main effects of the model were identified with Type II ANOVAs using "RVAideMemoire" R's package (Hervé, 2022).

To further explore our data, we assessed whether and how the complete set of words clustered in the semantic space composed by our 39 dimensions of interest, by performing a Hierarchical Clustering Analysis (HCA) on Spearman correlation-based distances using "FactoMineR" (Lê et al., 2008), and "factoextra" (Kassambara & Mundt, 2020) R's packages (see section 4.2 and Appendix B, SM). HCA is an algorithm that groups similar objects into groups called clusters, so that objects within a group are similar to each other and different from objects in other groups. This allowed us to address whether and how our *a-priori* categorization aligned with underlying properties of the data, as reflected by ratings. Before applying any clustering algorithm, we made sure the data were clusterable using Hopkins' clusterability test (*H* - Lawson & Jurs, 1990). To estimate the best number of clusters we used "NbClust" (Charrad et al., 2014), a R's package containing a function that simultaneously computes several available indices (until 30) in a single function call, returning the optimal number of clusters by relying on that indicated by most of the indexes. To validate our clusters, we used "clValid" R's package (Brock et al., 2008). Specifically, we performed internal and stability validations. We used Euclidean distances across Spearman's correlations among ratings for each dimension as input for the cluster analysis, and Ward's clustering algorithm (see Harpaintner et al., 2018; Mazzuca et al., 2020, 2022 for similar methods), i.e., an agglomerative clustering algorithm that minimizes the total within clusters variance. We then estimated the number of concepts from each category of words (Ecological, Geo, Natural, Technological) which fell in each cluster.

Finally, to explore semantic differences across clusters, we implemented a Linear Mixed Effects Model with "lme4" R's package (Bates et al., 2015), that featured rating scores as dependent variable, Cluster (Cluster 1 vs Cluster 2), Dimension ($N = 39$), and their interaction as fixed factors, and Target Words as random intercepts. Significant interaction of the model was identified with a Type III ANOVA.

4. Results

Results are divided into three main sections. In the first section, we will assess the nature of Ecological and Technological concepts, to understand whether they can be considered as "hybrids" in terms of their semantic properties. To do so, we will first investigate their positioning in the concreteness~abstractness continuum, by contrasting them with both Abstract and Concrete concepts broadly distinguished and with specific sub-kinds of Abstract and Concrete concepts (section 4.1). Then, we will turn to a more in-depth exploration of their semantic properties, comparing them with Abstract and Concrete concepts broadly distinguished on dimensions typically relevant for the characterization of these two "traditional" categories of concepts (section 4.1.1). In the second section (section 4.2), we will only focus on our dataset. Specifically, we will seek to understand what are the most important dimensions that explain our data and how our categories of concepts are organized in the related semantic space, using a Principal Component Analysis and visually inspecting word distribution in the multidimensional semantic space. Then, we will explore how our set of words clusterizes in the semantic space composed by all the target dimensions, using a Hierarchical Cluster Analysis. Finally, in the last section (section 4.3) we will further characterize specific properties of Ecological and Technological concepts by comparing them with Geo and Natural concepts on the most important dimensions extracted from the PCA.

4.1. Comparing Ecological and Technological with Abstract and Concrete Concepts and Related Subclusters on Concreteness~Abstractness Scores

With the aim of testing whether Ecological and Technological concepts might represent "hybrid" categories in terms of their semantic properties, we first assessed their scoring on Concreteness~Abstractness compared to other categories of concepts. We started by contrasting them against Abstract and Concrete concepts, broadly distinguished. In this first comparison, for theoretical reasons we decided to focus specifically on Ecological and Technological concepts, thus excluding Geo and Natural concepts.

We found a main effect of Category of Word, $F(3, 196) = 54.520$, $p < .01$. Pairwise comparisons showed that Concrete concepts were the least abstract category of words, Concrete vs Abstract, $t(196) = -11.046$, $p < .0001$; Concrete vs Ecological, $t(196) = -10.244$, $p < .0001$; Concrete vs Technological, $t(196) = -9.904$, $p < .0001$, while no other significant difference across the other categories of concepts emerged, Abstract vs Ecological, $t(196) = 0.802$, $p = .853$; Abstract vs Technological, $t(196) = 1.142$, $p = .664$; Ecological vs Technological, $t(196) = 0.340$, $p = .986$. This suggests that Abstract ($M = 3.97$; $SD = 1.00$), Ecological ($M = 3.79$; $SD = 1.26$), and Technological concepts ($M = 3.72$; $SD = 1.42$) are comparable in their abstractness scores, and overall, more abstract than Concrete concepts ($M = 1.50$; $SD = 0.62$) (see Panel A, Figure 1).

To further address the concreteness~abstractness of Ecological and Technological concepts, we additionally contrasted them with different sub-kinds of Abstract and Concrete concepts. Specifically, we compared them with four kinds of Abstract concepts—i.e., Philosophical/Spiritual, Emotional/Inner, Self/Sociality, and Physical/Spatio-temporal/Quantitative concepts—and with two kinds of Concrete concepts, i.e., Tools and Natural concepts from our set of words (which can be considered as a particular kind of Concrete concepts - see Berlin, 2014; Keil, 1989). We also included Geo concepts among the Subclusters. We found a main effect of Subclusters, $F(8, 441) = 60.310$, $p < .01$. Pairwise comparisons showed that Ecological and Technological concepts were similarly abstract, $t(441) = 0.389$, $p = 1.000$, and as abstract as both Self-Sociality, Ecological vs Self/Sociality, $t(441) = 0.237$, $p = 1.000$; Technological vs Self/Sociality, $t(441) = -0.153$, $p = 1.000$, and Inner/Emotional concepts, Ecological vs Inner/Emotional, $t(441) = -2.081$, $p = .488$; Technological vs Inner/Emotional, $t(441) = -2.470$, $p = .250$. For comparisons with Philosophical/Spiritual and Geo concepts, the pattern of Ecological and Technological concepts diverged. Indeed, while Ecological concepts were rated as abstract as Philosophical/Spiritual concepts, $t(441) = -3.113$, $p = .051$) and more abstract than Geo concepts, $t(441) = 3.481$, $p = .016$, Technological concepts were rated as less abstract than Philosophical/Spiritual concepts, $t(441) = -3.502$, $p = .015$) and as abstract as Geo concepts, $t(441) = -3.092$, $p = .054$. Finally, both Ecological and Technological concepts were significantly more abstract than Physical/Spatio-temporal/Quantitative concepts, Ecological vs Physical/Spatio-temporal/Quantitative, $t(441) = 5.417$, $p < .0001$; Technological vs Physical/Spatio-temporal/Quantitative, $t(441) = 5.028$, $p < .0001$, Natural, Ecological vs Natural, $t(441) = 9.189$, $p < .0001$; Technological vs Natural, $t(441) = 8.800$, $p < .0001$, and Tools concepts, Ecological vs Tools, $t(441) = 13.499$, $p < .0001$; Technological vs Tools, $t(441) = 13.110$, $p < .0001$ (for a complete overview of all pairwise comparisons, see Table S5, SM).

So, overall our results indicate that Ecological and Technological concepts lean more towards the most abstract end of the concreteness~abstractness continuum, with abstractness scores comparable with those of the abstract subclusters (i.e., Philosophical/Spiritual: $M = 4.40$; $SD = 0.76$; Inner/Emotional: $M = 4.20$; $SD = 0.70$; Self/Sociality: $M = 3.75$; $SD = 0.81$)—apart from Technological concepts which resulted to be less abstract than Philosophical/Spiritual concepts—, and higher than those of more concrete categories of both Abstract and Concrete concepts (i.e., Physical/Spatiotemporal/Quantitative: $M = 2.73$; $SD = 0.59$; Natural: $M = 2.00$; $SD = 1.18$; Tools: $M = 1.16$; $SD = 0.20$) (see Panel B, Figure 1).

Interestingly, by looking at the distribution of data points in Figure 1, we can see that Ecological and Technological concepts cover a broad range of concreteness~abstractness values, with a pretty substantial share of words showing ratings more similar to Concrete (and to Subclusters of Concrete) concepts than Abstract ones (Ecological: e.g., *fertiliser* = 1.30; 1.70; *plastic* = 1.40; *waste* = 1.50. Technological: e.g., *cellphone* = 1.30; *monitor* = 1.25; *mouse* = 1.15). To better understand this evidence, we investigated the relationship between words' Concreteness~Abstractness and their scores on the representativeness of the domain to which they belong (i.e., Ecological or Technological, see section 3.2). We found a weak but significant positive Spearman correlation among the dimensions, $r_s(98) = .42$, $p = .009$, suggesting that the more concepts were rated as abstract, the more they were representative of their specific domain.

4.1.1. Comparing Ecological and Technological with Abstract and Concrete Concepts on Other Semantic Properties besides Concreteness~Abstractness

Since the study of Ecological and Technological concepts represents a novelty in the literature on conceptual representation, we aimed at characterizing these categories of concepts as precisely as possible. In the previous analyses (section 4.1) we found that, when looking at Concreteness~Abstractness scores, these new categories are on average more similar to Abstract than to Concrete concepts—both when compared with the broader categori-

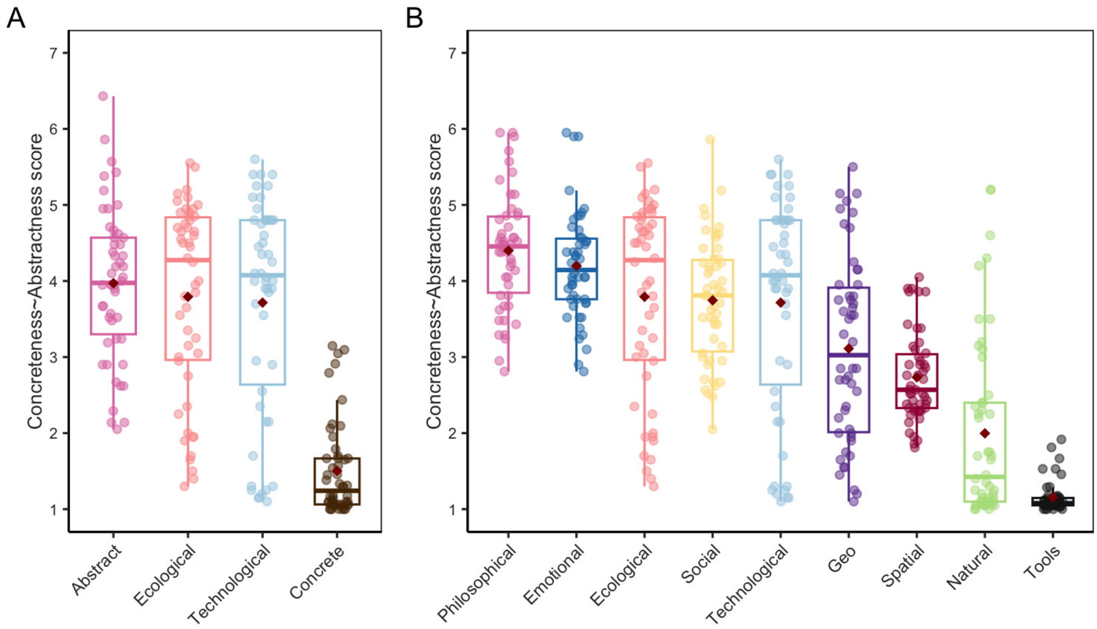

Figure 1. Panel A) Boxplots of Concreteness~Abstractness rating scores of Abstract, Concrete, Ecological, and Technological concepts, ordered according to their descending mean value. Panel B) Boxplots of Concreteness~Abstractness rating scores of Philosophical/Spiritual, Emotional, Ecological, Self/Sociality, Technological, Geo, Physical/Spatio-temporal/Quantitative, Natural, and Tools concepts, ordered according to their descending mean value. In the boxplots, red rhombuses indicate mean values, bold horizontal lines the median, and vertical extremes of the boxplots represent the minimum and maximum value in the data. The boxes' length shows the interquartile range, with the upper side representing the 75th percentile and the bottom side the 25th percentile. Colored dots represent raw data points (i.e., Target Words).

cal distinction of Abstract *vs* Concrete concepts, and when accounting for more subtle differences within these domains—, despite encompassing also more Concrete-like exemplars.

To broaden our investigation, we now explore how Ecological and Technological concepts score on semantic dimensions typically used for the characterization of the two categories of Abstract and Concrete concepts. Specifically, we first compared Ecological and Technological concepts with Abstract and Concrete concepts on dimensions that are typically understood as discriminating between Abstract and Concrete concepts, i.e., Age of Acquisition, Modality of Acquisition, Imageability, Interoception, Context Availability, Perceptual Strength, and Mouth and Hand action effectors. In fact, Abstract concepts are usually acquired later (Bergelson & Swingley, 2013; see also Bellagamba et al., 2022 and Della Rosa et al., 2010 for Italian data), through linguistic information rather than perception (Wauters et al., 2003; see also Della Rosa et al., 2010 and Villani et al., 2019 for Italian data), are less imageable (Paivio, 1986, 1990; see also Della Rosa et al., 2010 for Italian data), more related to interoceptive processes (Banks & Connell, 2023; Connell et al., 2018; see also Villani et al., 2019, 2021 for Italian data), have less contextual availability (Schwanenflugel & Shoben, 1983; see also Della Rosa et al., 2010 for Italian data), lower perceptual strength (Connell & Lynott, 2012; for Italian data see Morucci et al., 2019; Repetto et al., 2023; Vergallito et al., 2020), and some studies suggest they are more associated to the mouth compared to the hand effector (Moseley et al., 2012; for Italian data see ; Borghi et al., 2017; Ghio et al., 2013; Mazzuca et al., 2018; Villani et al., 2019, 2021).

Then, we further compared Ecological and Technological concepts with Abstract concepts on Social Metacognition, Social Valence, Metacognition, and Emotionality—i.e., other semantic dimensions whose higher scores have been identified as characterizing Abstract concepts (e.g., Diveica et al., 2023; Pexman et al., 2023; for Italian data see Ponari et al., 2018; Villani et al., 2019). Since ratings for these dimensions are available in Italian only for Abstract words, we could only compare our dataset with other databases of Abstract words (see section 3.4). Below we report the results of each model.

Age of Acquisition. We found a main effect of Category of Word, $F(3, 196) = 173$, $p < .01$. Pairwise comparisons showed that there was no difference in the age of acquisition of Ecological and Technological concepts, $t(196) = 1.357$, $p = .528$. However, both categories of concepts were acquired later than both Abstract, Ecological vs Abstract, $t(196) = 10.488$, $p < .0001$; Technological vs Abstract, $t(196) = 9.130$, $p < .0001$, and Concrete concepts, Ecological vs Concrete, $t(196) = 20.047$, $p < .0001$; Technological vs Concrete, $t(196) = 18.690$, $p < .0001$. Finally—and in line with previous studies—Abstract concepts were acquired later than Concrete concepts, $t(196) = 9.560$, $p < .0001$.

Modality of Acquisition. We found a main effect of Category of Word, $F(3, 196) = 93.52$, $p < .01$. Pairwise comparisons showed that, compared to all the other categories, Ecological concepts were most acquired through linguistic exchanges, Ecological vs Technological, $t(196) = 2.654$, $p = .042$; Ecological vs Abstract, $t(196) = 6.677$, $p < .0001$; Ecological vs Concrete, $t(196) = 15.636$, $p < .0001$. In a decreasing order, they were followed by Technological concepts, Technological vs Abstract, $t(196) = 4.023$, $p = .0005$; Technological vs Concrete, $t(196) = 12.982$, $p < .0001$, by Abstract concepts, Abstract vs Concrete, $t(196) = 8.959$, $p < .0001$, and finally by Concrete concepts, that were mostly acquired through sensorimotor experiences.

Imageability. We found a main effect of Category of Word, $F(3, 196) = 115.6$, $p < .01$. Pairwise comparisons showed that both Ecological and Technological concepts were similarly imageable, $t(196) = -0.924$, $p = .792$, and less imageable than both Abstract, Ecological vs Abstract, $t(196) = -6.784$, $p < .0001$; Technological vs Abstract, $t(196) = -5.860$, $p < .0001$, and Concrete concepts, Ecological vs Concrete, $t(196) = -16.536$, $p < .0001$; Technological vs Concrete, $t(196) = -15.612$, $p < .0001$. Finally—and in line with previous studies—we found that Concrete concepts were more imageable than Abstract concepts, $t(196) = 9.752$, $p < .0001$.

Interoception. We found a main effect of Category of Word, $F(3, 196) = 36.13$, $p < .01$. Pairwise comparisons showed that Ecological, Technological, and Abstract concepts evoked similarly inner processes, Ecological vs Technological, $t(196) = 2.389$; $p = .083$; Ecological vs Abstract, $t(196) = 2.389$; $p = .083$, Technological vs Abstract, $t(196) = 0.000$, $p = 1.000$, and more than Concrete concepts, Ecological vs Concrete, $t(196) = 9.790$, $p < .0001$; Technological vs Concrete, $t(196) = 7.401$, $p < .0001$; Abstract vs Concrete, $t(196) = 7.401$, $p < .0001$.

Context Availability. We found a main effect of Category of Word, $F(3, 196) = 167.6$, $p < .01$. Pairwise comparisons showed that Ecological concepts evoked less contexts than Technological concepts, $t(196) = -2.663$, $p = .041$, and that Ecological and Technological concepts evoked less contexts than both Abstract, Ecological vs Abstract, $t(196) = -14.514$, $p < .0001$; Technological vs Abstract, $t(196) = -11.851$, $p < .0001$, and Concrete concepts, Ecological vs Concrete, $t(196) = -18.996$, $p < .0001$; Technological vs Concrete, $t(196) = -16.332$, $p < .0001$. Finally—and in line with previous studies—Concrete concepts evoked more contexts than Abstract concepts, $t(196) = 4.481$, $p = .0001$, ranking highest across all the other categories on this dimension.

Perceptual Strength. We found a main effect of Category of Word, $F(3, 196) = 29.32$, $p = .003$. Pairwise comparisons showed that Ecological and Technological concepts evoked sensory modalities similarly to Abstract concepts, Ecological vs Abstract, $t(196) = 0.948$, $p = .779$; Technological vs Abstract, $t(196) = -1.769$, $p = .291$, and less than Concrete concepts, Ecological vs Concrete, $t(196) = -6.097$, $p < .0001$; Technological vs Concrete, $t(196) = -8.815$, $p < .0001$. Moreover, Ecological concepts evoked sensory modalities more than Technological concepts, $t(196) = 2.718$, $p = .036$. Finally—and in line with previous studies—Concrete concepts activated perceptual senses more than Abstract ones, $t(196) = 7.046$, $p < .0001$ (for an overview of Abstract, Concrete, Ecological and Technological concepts' scores as a function of subdimensions of Perceptual Strength, see Figure S1, SM).

Mouth Action Effector. We found a main effect of Category of Word, $F(3, 196) = 32.24$, $p < .01$. Pairwise comparisons showed that Ecological and Abstract concepts similarly activated the mouth effector, $t(196) = 1.132$, $p = .670$, and significantly more than Technological, Ecological vs Technological, $t(196) = 7.986$, $p < .0001$; Abstract vs Technological, $t(196) = 6.854$, p $< .0001$, and Concrete concepts, Ecological vs Concrete, $t(196) = 6.871$, $p < .0001$; Abstract vs Concrete, $t(196) = 5.739$, $p < .0001$. There was instead no difference between Technological and Concrete concepts, $t(196) = -1.115$, $p = .681$, that activated the mouth effector less than all the other categories.

Hand Action Effector. We found no main effect of Category of Word, $F(3, 196) = 0.743$, $p = .528$.

Social Metacognition. We found a main effect of Category of Word, $F(2, 147) = 108.3$, $p < .01$. Pairwise comparisons showed that, across all categories, participants judged Ecological concepts as concepts for which they felt the most the need to rely on others to understand them, Ecological vs Technological, $t(147) = 6.035$, $p < .0001$; Ecological vs Abstract, $t(147) = 14.639$, $p < .0001$. Participants also felt the need to rely on others more with Technological concepts than with Abstract concepts, $t(147) = 8.604$, $p < .0001$.

Social Valence. We found no main effect of Category of Word, $F(2, 147) = 26.00$, $p = .065$.

Metacognition. We found a main effect of Category of Word, $F(2, 147) = 7.952$, $p = .0005$. Pairwise comparisons showed that Technological concepts elicited less mental processes than both Ecological and Abstract concepts, Technological vs Ecological, $t(147) = -3.383$, $p = .003$; Technological vs Abstract, $t(147) = -3.520$, $p = .002$. Instead, no differences between Ecological and Abstract concepts emerged, $t(147) = -0.137$, $p = .990$, thus indicating that they represented the categories which elicited the most mental processes.

Emotionality. We found a main effect of Category of Word, $F(2, 147) = 222.300$, $p < .01$. Pairwise comparisons showed that Ecological concepts were more emotionally charged than Technological concepts, $t(147) = 18.359$, $p < .0001$, but there was no difference between Ecological and Abstract concepts, $t(147) = 0.195$, $p = .979$. Technological concepts were also less emotionally charged than Abstract concepts, $t(147) = -18.164$, $p < .0001$.

Table 1 summarizes similarities and differences between Ecological and Technological concepts with Abstract and Concrete concepts, and across categories for the targeted semantic dimensions.

According to recent insights from Multiple Representation Views (e.g., Borghi et al., 2017, 2018b; Crutch et al., 2013; Dove, 2009, 2014, 2022; Zdrazilova et al., 2018), the best way to tackle Ecological and Technological concepts is to understand them in a multidimensional seman-

Table 1. Similarities and differences between Ecological and Technological concepts with Abstract and Concrete concepts and across categories on targeted semantic dimensions.

Dimension	Target Category of Word	Contrasted Category of Word		
		Abstract	Concrete	Ecological
Concreteness~Abstractness	Ecological	=	-	//
	Technological	=	-	=
Age of Acquisition	Ecological	+	+	//
	Technological	+	+	=
Modality of Acquisition	Ecological	+	+	//
	Technological	+	+	-
Imageability	Ecological	-	-	//
	Technological	-	-	=
Interoception	Ecological	=	+	//
	Technological	=	+	=
Context Availability	Ecological	-	-	//
	Technological	-	-	+
Perceptual Strength	Ecological	=	-	//
	Technological	=	-	-
Mouth action effector	Ecological	=	+	//
	Technological	-	=	-
Hand action effector	Ecological	=	=	//
	Technological	=	=	=
Social Metacognition	Ecological	+	//	//
	Technological	+	//	-
Social Valence	Ecological	=	//	//
	Technological	=	//	=
Emotionality	Ecological	=	//	//
	Technological	-	//	-
Metacognition	Ecological	=	//	//
	Technological	-	//	-

Dimensions are reported according to the order they appeared in the main text. For comparisons between Ecological and Technological concepts, we used "Ecological" concepts as the contrast category. In the table, the minus sign ("-") indicates that the target Category of Word (Ecological/Technological) scored significantly lower than the contrasted Category of Word (Abstract/Concrete/Ecological). The plus sign ("+") indicates that the target Category of Word (Ecological/Technological) scored significantly higher than the contrasted Category of Word (Abstract/Concrete/Ecological). The equal sign ("=") indicates that the scores to the target Category of Word (Ecological/Technological) did not significantly differ from those to the contrasted Category of Word (Abstract/Concrete/Ecological). Finally, the "//" sign indicates that there was no available comparison between the target Category of Word (Ecological/Technological) and the contrasted Category of Word (Abstract/Concrete/Ecological).

tic space encompassing different dimensions (e.g., Crutch et al., 2013), and to individuate those that are most salient for their characterization beyond abstractness and concreteness. So, in the next section, we explore how our set of words is organized in the multidimensional space composed by our dimensions of interest.

4.2. Exploring the Distribution of Ecological, Geo, Natural, and Technological Concepts in the Overall Semantic Space

We performed a Principal Component Analysis (PCA - Jolliffe, 2010) to investigate which semantic dimensions explained most variance in our set of words and how they were grouped together (Components). We found that, among the 39 components extracted by the PCA, Component 1 (PC1) explained the majority of variance (33%); this was followed by Component 2 (PC2), and Component 3 (PC3), which explained respectively the 18% and 14% of variance. Together, the three components explained the 65% of the variance of the dataset. We decided to focus only on the first three components since all the others explained less than 5% of the dataset's variance, each.

We then identified the dimensions that contribute the most to each component, i.e., those whose weight was higher than |.2| (small effect size - Cohen, 1988). This resulted in six dimensions for Component 1 (PC1), nine dimensions for Component 2 (PC2), and eight dimensions for Component 3 (PC3). Figure 2 presents the contribution of dimensions to PC1, PC2, and PC3, along with their negative and positive values (for a complete overview of the contribution of all the dimensions to the components, see Table S6, SM).

Looking at the contribution of the dimensions to each component, we found that the first component (PC1) seemed to reflect the more general distinction between Ab-

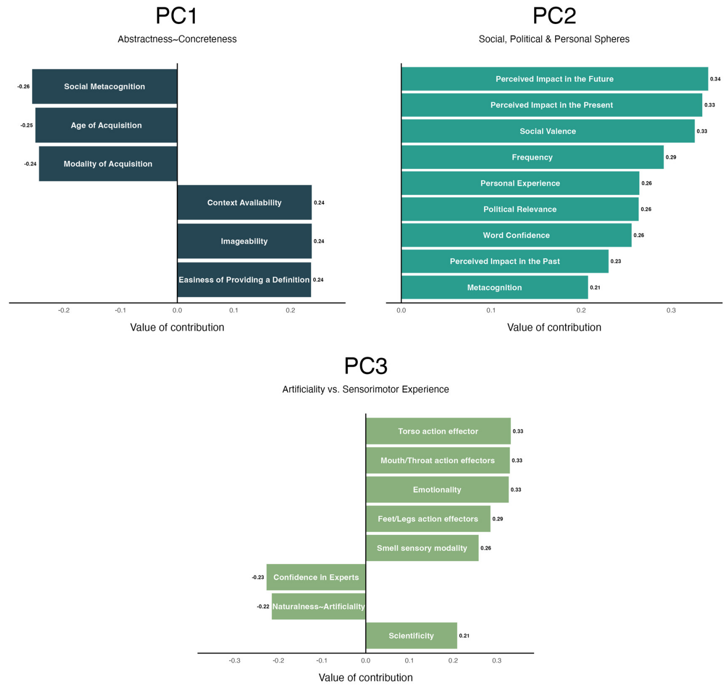

Figure 2. Contribution of dimensions weighting more than |.2| on PC1, PC2, and PC3, along with their positive and negative values.

stract and Concrete concepts. In our case, positive loadings pointed to more Concrete words, i.e., concepts for which is easier to think about a context (Context Availability), that are highly imaginable (Imageability), and easier to define (Easiness of Providing a Definition). Negative loadings pointed instead to more Abstract words, i.e., concepts for the understanding of which we need more others (Social Metacognition), and that are acquired later (Age of Acquisition) and principally through language (Modality of Acquisition).

The second component (PC2) was instead characterized by dimensions with a positive contribution (in our case) and referring to social, political, and personal aspects. In particular, it mainly encompassed words indicating things perceived as having a high impact in our future (Perceived Impact in the Future), present (Perceived Impact in the Present), and past life (Perceived Impact in the Past), socially relevant (Social Valence), that generate political discussions (Political Relevance), which are personally experienced (Personal Experience), frequently heard in daily written and spoken language (Frequency), the meaning of which is well mastered (Word Confidence), and activating mental processes (Metacognition).

Finally, the third component (PC3) was mainly characterized by an opposition between words referring to entities that are perceived as artifactual (Naturalness~Artificiality) and well mastered by field experts (Confidence in Experts), against concepts conceived as scientific (Scientificity), emotionally charged (Emotionality), and indicating things experienced through torso (Torso action effector), mouth/throat (Mouth/Throat action effectors), feet/legs (Feet/Legs action effectors), and olfaction (Smell sensory modality).

Once identified the most salient components of the PCA, we then assessed how our *a-priori* distinction into Ecological, Geo, Natural, and Technological concepts fitted in the multidimensional space extracted by the PCA. An interactive 3D plot of word distribution in the tridimensional space resulting from PC1, PC2, and PC3 interception can be downloaded from the OSF repository (https://doi.org/10.17605/OSF.IO/M6PH9). For reasons of clarity, here we report two graphic representations of words' distribution in a bidimensional space, respectively obtained by plotting PC2on PC1 (Figure 3, Panel A) and PC3 on PC1 (Figure 3, Panel B).

In Panel A, the leftmost part of the plot is mostly composed of Ecological (e.g., *Ocean Acidification, Ozone Hole, Compost*) and Technological concepts (e.g., *Processor, Optic Fiber, Formatting*) with few Geo concepts (in particular, Geopolitical, e.g., *Meridian, Settlement, District*). These words are opposed mainly to Natural (e.g., *Water, Cat, Grass*) and Geo concepts (in particular, Geographical, e.g., *Sea, Beach, Mountain*). This is in line with the characterization of our PC1, that contrasts more Abstract concepts (left) to more Concrete ones (right).

In the uppermost part of the plot (i.e., where the positive loadings of our PC2 fall) we instead find primarily Ecological (e.g., *Pollution, Environment, Climate Change*) and Technological concepts (e.g., *Internet, Connection, Chat*), along with some Natural (e.g., *Water, Air, Oxygen*) and Geo concepts (e.g., *Sea, City, Beach*) mainly referred to ecological themes. In keeping with the characterization of PC2, these are all concepts that are perceived as personally, socially, and politically relevant, as well as frequently encountered.

In Panel B, the leftmost part of the plot is mainly composed of Technological concepts (e.g., *Account, Keyboard,*

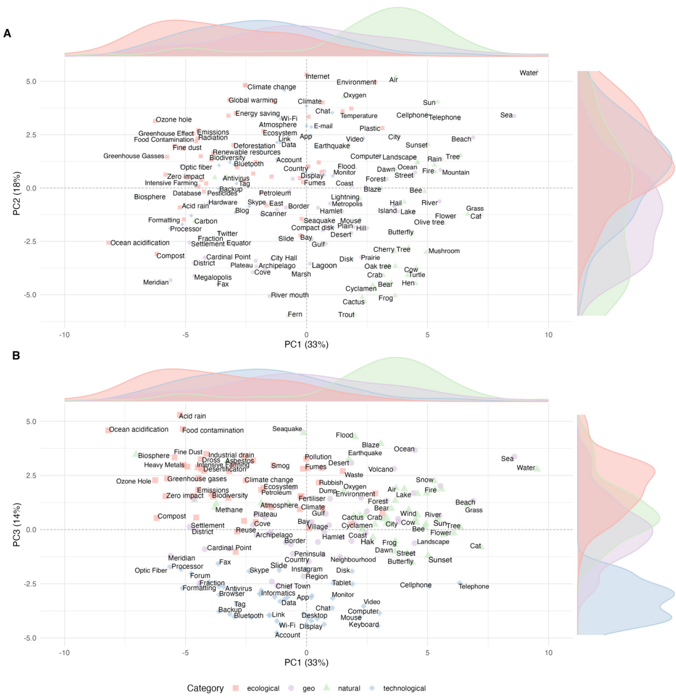

Figure 3. Panel A) Distribution of Target Words in the bidimensional space resulting from the interception of PC1 and PC2, along with their distinction into categories (Ecological, Geo, Natural, and Technological). Panel B) Distribution of Target Words in the bidimensional space resulting from the interception of PC1 and PC3, along with their distinction into categories (Ecological, Geo, Natural, and Technological).

Wi-Fi). These words are opposed in the uppermost part principally to Ecological concepts (e.g., *Acid Rain, Food Contamination, Ocean Acidification*) and to some Natural (e.g., *Seaquake, Flood, Blaze*) and Geo concepts (in particular, Geographical, e.g., *Ocean, Sea, Desert*). This is in line with the characterization of our PC3, that contrasts concepts perceived as artificial entities, well known by field experts (i.e., Technological ones) to concepts that are scientific, emotionally charged, and experienced through sensorimotor modalities (principally Ecological concepts). It is interesting to note that Ecological and Natural concepts—to a minor extent—included in this area all relate to breathing, smelling, and eating (e.g., Ecological: *Pollution, Fine Dust, Food Contamination;* Natural: *Blaze, Air, Water*), thus justifying the importance of olfaction and smell as well as the relevance of mouth/throat and torso for this component. In fact, here we find concepts relating to actions we can perform with specific body parts and sensory modalities, or that elicit them. The relevance of feet/legs effectors might instead be specifically related to the Natural and Geo concepts found in this area. Indeed, these mostly include concepts requiring movements, representing both consequences of climate change (Natural concepts, e.g., *Blaze, Earthquake, Flood*), and locations affected by it (Geo concepts, e.g., *Ocean, Sea, Desert*).

A cluster analysis performed on our set of words suggested data were clusterable (H = .68) and that *two* was the best number of clusters for most of the indexes (N = 6 indexes, i.e., *Silhouette* = 0.20; *KL* = 2.45; *CH* = 60.76; *Duda* = 0.93; *PseudoT2* = 8.60; *McClain* = 0.78). Internal and Stability validation measures indicated a good validation for the two-clusters solution (clustering internal validation: *Connectivity* = 54.66; *Silhouette* = 0.20; clustering stability validation: *APN* = 0.02; *ADM* = 0.18).

Cluster 1 contained 110 words and mostly encompassed Ecological and Technological concepts with most of the Geopolitical concepts included in the Geo category (specifically, n = 43 Ecological, n = 21 Geo, n = 6 Natural, n = 40 Technological); Cluster 2 instead contained 90 words, which included mostly Natural and Geographical concepts from the Geo category (specifically, n = 7 Ecological, n = 29 Geo, n = 44 Natural, n = 10 Technological). Interestingly, the clustering seemed to reflect the opposition we found in the first component of the PCA. Indeed, we found a significant two-way interaction between Clusters and Dimension, $F(38, 7524) = 79.827$, $p < .01$, showing that words in Cluster 1 had a typical Abstract-like characterization (e.g., more abstract, acquired later and more through language, more politically and socially relevant, requiring more the others' help to be understood); instead, words in Cluster 2 were more similar to Concrete concepts (e.g., more consistently activating bodily parts and sensory modalities, more imaginable, evoking more contexts and body-objects interactions). For a complete overview of these analyses, see Appendix B, SM.

4.3. Exploring Differences across Categories of Words on The Most Important Semantic Dimensions of the PCA

Once identified the most salient dimensions in the semantic space resulting from the PCA, as a final step we probed differences across our *a-priori* categories (i.e., Ecological, Geo, Natural, and Technological concepts) on said dimensions. In doing so, we sought to identify the relative weight of each category of concepts for specific components of the PCA, and to gain a more fine-grained characterization of Ecological and Technological concepts.

We first focused on dimensions weighting more than |.3| on the PCA (which represents a medium effect size - Cohen, 1988). Below, we report results of models along with the specific dimension's contribution to each component (see Figure 2; see also Table S6, SM).

Perceived Impact in the Future (0.34, PC2). We found a main effect of Category of Word, $\chi^2(3)$ = 32.248, p =.004. Pairwise comparisons showed that Ecological concepts were perceived as more life-impacting in the future than both Geo, z = 5.708, SE = .167, p < .0001, and Natural concepts, z = 3.867, SE = .167, p = .0006. There was instead no difference between the perceived impact in the future of Ecological and Technological concepts, z = 2.459, SE = .167, p = .066. Technological concepts were perceived as more life-impacting than Geo concepts, z = 3.259, SE = .167, p = .006, but there was no difference between the perceived future impact of Technological and Natural concepts, z = 1.413, SE = .167, p = .491. Finally, Natural and Geo concepts were judged as equally impactful, z = -1.847, SE = .166, p = .251.

Perceived Impact in the Present (0.33, PC2). We found a main effect of Category of Word, $\chi^2(3)$ = 23.762, p = .018. Pairwise comparisons showed that Technological concepts were perceived as more life-impacting in the present than both Geo, z = 4.525, SE = .162, p < .0001, and Natural concepts, z = 2.709, SE = .162, p = .034. There was instead no difference between the perceived impact in the present of Technological and Ecological concepts, z = 0.704, SE = .161, p = .896. Ecological concepts were perceived as more life-impacting than Geo concepts, z = 3.832, SE = .161, p = .0007, but there was no difference between the perceived present impact of Ecological and Natural concepts, z = 2.012, SE = .161, p = .183. Finally, Natural and Geo concepts were judged as equally impactful, z = 1.816, SE = .161, p = .266.

Social Valence (0.33, PC2). We found a main effect of Category of Word, $\chi^2(3)$ = 58.191, p =.021. Pairwise comparisons showed that Ecological concepts evoked more social situations than both Geo, z = 5.413, SE = .195, p < .0001, and Natural concepts, z = 7.549, SE = .195, p < .0001. Likewise, Technological concepts evoked more social situations than both Geo, z = 3.162, SE = .194, p = .009, and Natural concepts, z = 5.314, SE = .195, p < .0001. There was instead no difference between Ecological and Technological concepts, z = 2.257, SE = .195, p = .108, nor between Geo and Natural concepts, z = 2.168, SE = .194, p = .132.

Mouth/Throat (0.33, PC3). We found a main effect of Category of Word, $\chi^2(3)$ = 128.3, p =.002. Pairwise comparisons revealed that Ecological and Natural concepts activated the mouth/throat effectors the most, Ecological vs Technological, z = 12.010, SE = .163, p < .0001; Ecological vs Geo, z = 5.624, SE = .159, p < .0001; Natural vs Technological, z = 10.510, SE = .163, p < .0001; Natural vs Geo, z = 4.048, SE = .159, p = .0003, with a comparable degree of activation, z = 1.577, SE = .158, p = .392. Finally, Technological concepts activated these bodily parts the least, differing also from Geo concepts, z = -6.632, SE = .162, p < .0001.

Torso (0.33, PC3). We found a main effect of Category of Word, $\chi^2(3)$ = 122.22, p = .002. Pairwise comparisons showed once again that Natural and Ecological concepts activated this effector more than the other categories, Natural vs Technological, z = 11.053, SE = .142, p < .0001; Natural vs Geo, z = 2.766, SE = .138, p = .029; Ecological vs Technological, z = 10.912, SE = .142, p < .0001; Ecological vs Geo, z = 2.618, SE = .137, p = .044, with a comparable degree of activation, z = 0.148, SE = .138, p = .999. Technological concepts activated this effector the least, differing also from Geo concepts, z = -8.434, SE = .141, p = .029.

Emotionality (0.33, PC3). We found a main effect of Category of Word, $\chi^2(3)$ = 187.86, p =.002. Pairwise comparisons showed that Ecological and Natural concepts evoked more emotions than the other categories, Ecological vs Technological, z = 14.523, SE = .206, p < .0001; Ecological vs Geo, z = 5.493, SE = .199, p < .0001; Natural vs Technological, z = 15.125, SE = .206, p < .0001; Natural vs Geo, z = 6.124, SE = .199, p < .0001, with comparable emotionality scores, z = 0.631, SE = .197, p = .922. Technological concepts evoked emotions less than the other categories, differing also from Geo concepts, z = -9.311, SE = .204, p < .0001.

To summarize, we found that Ecological and Technological concepts predominantly determined the importance of Perceived Impact in the Future, Perceived Impact in the Present, and Social Valence for Component 2 of the PCA. Indeed, compared to the other categories, they were judged as the most socially relevant concepts, and with the highest impact on our present and future life. On the other hand, Ecological and Natural concepts mostly contributed to Component 3, with higher rating scores on Torso and Mouth/Throat activation, and Emotionality. Overall, these results are in line with what emerged from the visual inspection of word distribution in the semantic space (see section 4.2 and Figure 3).

Finally, with the aim of capturing all possible nuances of the semantic space constituted by our categories and dimensions, we inspected the less salient dimensions of the PCA, i.e., those weighting more than |.2| (indicating a small effect size - Cohen, 1988; see Figure 2; see also Table S6, SM). We provide a graphic representation (see Figure 4) along with descriptive statistics in relation to our four categories of concepts (see Table 2).

For Component 1 of the PCA, Ecological and Technological concepts seemed to be perceived as the most difficult words to define.

For Component 2, Ecological and Technological concepts seemed to be slightly more frequently heard and used in everyday life than Geo and Natural concepts. Moreover, Ecological concepts seemed the most politicized ones, while Technological concepts appeared as the most mastered, the ones with the highest impact in our past life, and the most personally experienced.

Finally, for Component 3 Technological concepts seemed the ones participants perceived as the most mastered by field experts and the most artifactual. Ecological concepts

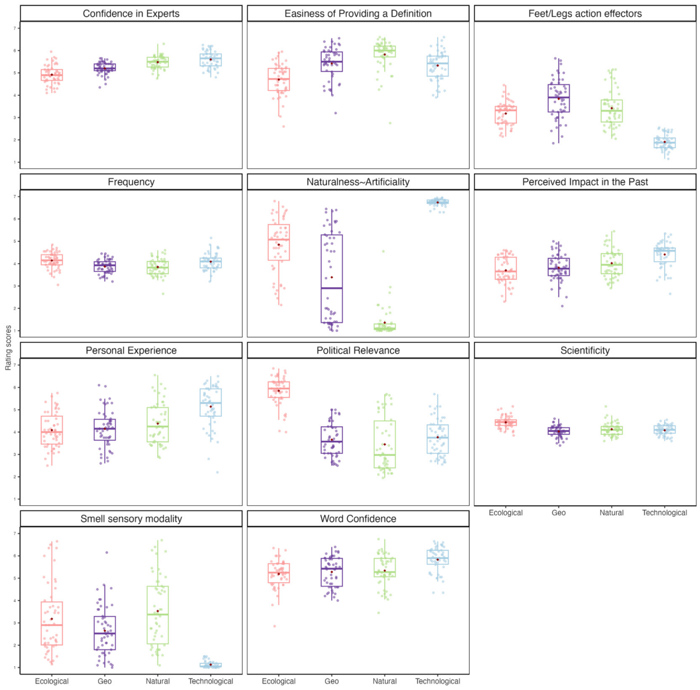

Figure 4. Boxplots of rating scores of Ecological, Geo, Natural, and Technological concepts on Confidence in Experts (0.23, PC3), Easiness of Providing a Definition (0.24, PC1), Feet/Legs action effectors (0.29, PC3), Frequency (0.29, PC2), Naturalness~Artificiality (0.22, PC3), Perceived Impact in the Past (0.23, PC2), Personal Experience (0.26, PC2), Political Relevance (0.26, PC2), Scientificity (0.21, PC3), Smell (0.26, PC3), and Word Confidence (0.26, PC2). In the boxplots, red rhombuses indicate mean values, bold horizontal lines the median, and vertical extremes of the boxplots represent the minimum and maximum value in the data. The boxes' length shows the interquartile range, with the upper side representing the 75th percentile and the bottom side the 25th percentile. Colored dots represent raw data points (i.e., Target Words).

resulted as the most scientific words, and along with Natural concepts the most experienced through smell sensory modality; finally, Geo concepts and Natural concepts—even though to a minor extent—seemed to activate the most feet/legs bodily parts.

5. Discussion

Ecology and *Technology* are two domains recently emerged and increasingly impacting in the modern era we live in. A considerable amount of literature has investigated the distinction between natural kinds and artifacts or living and nonliving entities (Forde & Humphreys, 2005; Warrington & Shallice, 1984). More recently, studies have focused on food, a concept at the border between natural kinds and artifacts, depending on whether food is natural or transformed (e.g., Vignando et al., 2018). In our study, we focused on Ecological and Technological concepts because they are novel, emerging concepts that lie at the intersection between artifacts and natural kinds. Ecological concepts refer to natural elements transformed by humans, while Technological concepts refer to complex artifacts—for example, *computers*—which have inner parts that influence how they work (Keil, 1989). Ecological and Technological concepts are thus "special" because they concern a specific domain and convey contents that do not fully overlap with that of natural kinds or artifacts. Intriguingly, natural kinds and artifacts are Concrete concepts, while most Ecological and Technological might not be completely so. Specifically, with our work, we investigated whether they might be considered "hybrid", lying at the interface between more Abstract and more Concrete concepts. Indeed, although both Ecological and Technological concepts usually refer to well-defined entities (e.g., *blaze, flooding, computer, mouse*) as Concrete concepts typically do, at the same time, their high personal, social, and political value might make them similar also to more Abstract concepts. We probed this by asking an Italian sample of 340 mostly young adult participants to rate concepts pertaining to Ecological and Technological along with Natural and Geo domains on 39 semantic dimensions. Most of them consisted in dimensions that are typically employed for characterizing Abstract and Concrete concepts (e.g., Context Availability, Imageability, Social Metacognition); others were instead completely new (e.g., Confidence in Experts, Political Relevance, Scientificity).

We started by exploring their abstractness when compared with Abstract and Concrete concepts broadly distinguished, and with specific sub-kinds of Abstract (e.g., Philosophical/Spiritual, Inner/Emotional, Self/Sociality concepts) and Concrete concepts (e.g., Tools, Natural concepts). We found that, in both cases, they were more similar to Abstract than to Concrete concepts, despite Ecological concepts might be considered slightly more abstract than

Table 2. Means (*M*) and Standard Deviations (*SD*) for Ecological, Geo, Natural, and Technological concepts on dimensions weighted more than |.20| on the PCA (i.e., Confidence in Experts (0.23, PC3), Easiness of Providing a Definition (0.24, PC1), Feet/Legs action effectors (0.29, PC3), Frequency (0.29, PC2), Naturalness~Artificiality (0.22, PC3), Perceived Impact in the Past (0.23, PC2), Personal Experience (0.26, PC2), Political Relevance (0.26, PC2), Scientificity (0.21, PC3), Smell (0.26, PC3), and Word Confidence (0.26, PC2)).

Dimension	Category of Word	*M*	*SD*
Confidence in Expert	Ecological	4.92	1.69
	Geo	5.20	1.62
	Natural	5.48	1.65
	Technological	5.60	1.67
Easiness of Providing a Definition	Ecological	4.70	1.84
	Geo	5.42	1.66
	Natural	5.82	1.55
	Technological	5.33	1.84
Feet/Legs action effectors	Ecological	3.18	2.14
	Geo	3.84	2.11
	Natural	3.42	2,16
	Technological	1.91	1.58
Frequency	Ecological	4.14	1.30
	Geo	3.87	1.42
	Natural	3.85	1.50
	Technological	4.09	1.33
Naturalness~Artificiality	Ecological	4.85	1.91
	Geo	3.39	2.40
	Natural	1.36	1.03
	Technological	6.74	0.77
Perceived Impact in the Past	Ecological	3.70	1.87
	Geo	3.82	2.05
	Natural	4.02	2.07
	Technological	4.41	1.95
Personal Experience	Ecological	4.09	2.12
	Geo	4.15	2.16
	Natural	4.38	2.13
	Technological	5.14	1.88
Political Relevance	Ecological	5.85	1.39
	Geo	3.66	1.95
	Natural	3.45	2.11
	Technological	3.77	2.09
Smell	Ecological	3.18	2.34
	Geo	2.65	2.10
	Natural	3.53	2.34
	Technological	1.13	0.54
Scientificity	Ecological	4.44	1.23
	Geo	4.03	1.51
	Natural	4.13	1.51
	Technological	4.08	1.50
Word Confidence	Ecological	5.19	1.62
	Geo	5.28	1.78
	Natural	5.34	1.81
	Technological	5.83	1.37

Technological ones, with abstractness scores similar to Philosophical/Spiritual concepts—i.e., the most abstract subcluster of Abstract concepts. Interestingly, Ecological and Technological concepts also displayed a broad range of concreteness~abstractness values, with a remarkable share of exemplars receiving more Concrete-like scores. So, despite being, on average, more similar to Abstract than Concrete concepts, Ecological and Technological concepts encompassed both Abstract-like and Concrete-like exemplars, hence providing evidence of their "hybrid" character. Interestingly, though, we found that more concrete Ecological and Technological words were also rated as less representative of their respective categories than those with higher abstractness scores.

We then compared Ecological and Technological concepts with Abstract and Concrete concepts on dimensions that are typically relevant for the distinction of concepts into the broader *concrete-abstract* categories. In line with results from previous literature, we found that compared to Concrete concepts Abstract concepts were rated as being acquired later and more through language (e.g., Bergelson & Swingley, 2013; Wauters et al., 2003), less imaginable (e.g., Paivio, 1986, 1990), evoking less contexts (e.g., Schwanenflugel & Shoben, 1983), more interoceptive aspects (e.g., Banks & Connell, 2023; Connell et al., 2018), less sensory modalities (e.g., Connell & Lynott, 2012), and more activating the mouth effector (e.g., Mazzuca et al., 2018; Moseley et al., 2012). Instead, we found no differences in the activation of the hand action effector across Abstract and Concrete concepts along with Ecological and Technological ones. This might be due to the kind of stimuli we selected for each category of concepts, which might activate in a similar extent this bodily part, even if for different goals (e.g., Abstract: *defensive, prayer*; Concrete; *knife, glass*; Ecological: *plastic; deforestation*; Technological: *computer, cellphone*).

As for the characterization of Ecological and Technological concepts in relation to the traditional categories, we found that they occasionally overcame Abstract and Concrete concepts in their "abstract" pattern. To illustrate, Ecological and Technological concepts were rated as being acquired later and more through language, as being less imageable and evoking less contexts than both Concrete and—more importantly—Abstract concepts. Likewise, they evoked the need for others' help to be understood more than Abstract concepts. At the same time, for other aspects Ecological and Technological concepts' characterization was more strictly similar to that of Abstract than Concrete concepts. To illustrate, as Abstract concepts they were rated as evoking more interoceptive aspects and less sensory modalities than Concrete concepts. Likewise, Ecological and Technological concepts evoked social situations similarly to Abstract concepts.

As for the remaining dimensions, despite not differing for some aspects (e.g., in their late age of acquisition, in their low level of imaginability, and in their high activation of interoceptive aspects and social situations), the characterization of Ecological and Technological concepts in the semantic space appeared quite different. Specifically, Ecological concepts' characterization was mostly similar to Abstract concepts (e.g., in their emotional loading, their activation of mental processes and of the mouth effector), and more abstract than Technological concepts. In fact, compared to Technological concepts, Ecological concepts evoked less contexts, were more linguistically acquired, more emotionally charged, elicited more the need of others' help to be understood, and activated more mental processes. Conversely, Technological concepts, despite displaying "abstract" features, also showed a more "concrete" pattern (i.e., they were less emotionally charged and elicited fewer mental processes than both Ecological and Abstract concepts, as well as they activated the mouth effector lower than them and similarly to Concrete concepts). Interestingly, Ecological concepts displayed a more "concrete" features than Technological ones in Perceptual Strength dimension: indeed, despite seeming more abstractly characterized than Technological concepts, they evoked more sensory modalities than them.

To summarize, for a consistent set of dimensions we found that both Ecological and Technological concepts overcome traditional categories in abstractness or were more strictly similar to Abstract concepts. For the remaining dimensions, Ecological and Technological concepts' characterization diverged. Indeed, while Ecological concepts were more similar to Abstract concepts and more abstractly characterized than Technological ones, Technological concepts showed a more "concrete" pattern.

So, our results partially support our initial hypothesis about the "hybrid" character of Ecological and Technological concepts. What we found is that these classes are "hybrid" not in the sense that they are at the edge between Abstract and Concrete concepts, but given their multivariate nature, being more abstractly or concretely characterized depending on the property under scrutiny.

From a theoretical perspective, our findings also indicate Ecological and Technological concepts might be considered separate from Abstract and Concrete concepts. This is also motivated by theoretical reasons. Differently from most Abstract concepts, Ecological and Technological concepts can also have a physical referent that can be experienced through the five senses (e.g., *acid rain*, *pesticides*, *keyboard*, *processor*), so they inherently question typical definitions of abstractness according to which something is abstract if it cannot be experienced through the five senses (e.g., see Brysbaert et al., 2014). Similarly, our results question distinctions based on the fact that, while Concrete concepts have an object as referent, Abstract concepts refer to situations, events, and complex interactions among objects (e.g., Barsalou, 2003). Ecological and Technological concepts, in fact, might refer to single objects and entities. And yet, when taken together as a category, these concepts are considered as abstract as traditional Abstract concepts. This might be explained in the framework of Multiple Representation Theories (e.g., Barsalou et al., 2018; Borghi et al., 2018b; Reilly et al., 2023), suggesting that multiple dimensions contribute to defining abstractness and that there is more to abstractness than simply concreteness~abstractness. Indeed, when taking into account different semantic components, Ecological and Technological concepts display specific patterns. People evaluate Ecological concepts more often as linguistically acquired than Technological and Abstract concepts, and Technological concepts as less emotionally charged than Ecological and Abstract concepts. Finally, both Ecological and Technological score higher than Abstract concepts in Social Metacognition (need of the other's help to understand the conceptual meaning), even if they are both similar to Abstract concepts in their abstractness level and other aspects like social relevance. This aligns with studies differentiating groups of Abstract concepts based on their different weight on multiple semantic components (e.g., Italian: Villani et al., 2019; German: Harpaintner et al., 2018). Another important fact is worth highlighting. Concepts differ in semantic dimensions, such as Valence and Concreteness~Abstractness, but they can also vary because of their content. It is the case of the distinction, within Concrete concepts, between natural kinds and artifacts, and "hybrid" concepts such as food (Vignando et al., 2018), and it is also the case—as our results revealed—of Ecological and Technological concepts.

Results from the PCA complemented these insights. We found three main components that explained the majority of variance. Component 1 was characterized by an opposition between words possessing typical Abstract (e.g., high scores in Social Metacognition, late and prevalently linguistic acquisition) *vs* Concrete (e.g., high scores in Contextual Availability, highly imaginable, activating vision) properties; Component 2 was mostly characterized by words relevant for personal, political, and social spheres (e.g., highly impacting in our past, present, and future life, politically and socially relevant, mainly personally experienced); finally, Component 3 was defined by an opposition between artificial words along with words well-mastered by experts against scientific concepts highly emotionally charged and activating bodily parts and sensory modalities (specifically, words with high scores in torso and mouth/throat bodily effectors, high involvement of olfaction).

A visual inspection of words distribution in the tridimensional space obtained by intersecting the three components, along with subsequent analyses exploring differences across categories (Ecological, Geo, Natural, and Technological) on the most salient dimensions, helped us to better frame these results and to further characterize specific properties of Ecological and Technological concepts. In Component 1, Ecological and Technological concepts weighted more on the abstract extreme, while Geo (in particular, Geographical) and Natural concepts weighted more toward the opposite concrete extreme. In line with this, for instance, Ecological and Technological concepts were rated as the most difficult words to define. The concreteness~abstractness dichotomy of Component 1 was also confirmed by a Hierarchical Cluster Analysis performed on our dataset, which revealed the presence of two main clusters differing between each other for their more Abstract-like (e.g., later and more linguistic acquisition, more political and social relevance, more eliciting the need of others to be understood) *vs* Concrete-like (e.g., higher activation of bodily parts and sensory modalities, higher imaginability, evoking more contexts and body-objects interactions) characterization. Again, Ecological and Technological concepts grouped—along with Geopolitical concepts—mostly in the more Abstract cluster, while Natural and Geographical concepts mostly in the more Concrete one.

Ecological and Technological concepts were particularly relevant also for Component 2 of the PCA, constituting the greatest share of words with high weight on dimensions relevant for social, political, and personal spheres. To illustrate, when compared with Geo and Natural concepts, Ecological and Technological concepts were judged as more socially relevant, more frequently encountered, and having the highest impact on our present and future life. Moreover, Ecological concepts appeared as the most politicized category of words. Technological concepts, on the other hand, represented the category that was better mastered by participants, the most personally experienced, and the most impactful on participants' past life.

Finally, Component 3 was mainly characterized by Ecological and Natural concepts, with a high emotional load and activating torso, mouth/throat effectors, and olfaction. This might be related to breathing, smelling, and eating actions these words refer to (e.g., *pollution, food contamination, water*). Moreover, Natural and Geo concepts had a consistent weight on feet/legs activation, probably since they refer to both consequences of climate change and locations affected by it, all requiring lower limb movements (e.g., *earthquake, ocean*). All these concepts opposed Technological ones, which represented the most artifactual and well-mastered concepts by field experts.

5.1. Future Studies and Limitations

While our study represents a novelty in the literature on concepts, it has some limitations that are worth mentioning. First, although rating tasks are among the preferred methodologies to investigate semantic aspects related to the representation of concepts (see e.g., Barca et al., 2002; Bennett et al., 2011; Brysbaert et al., 2014; Della Rosa et al., 2010; Diveica et al., 2023; Lynott et al., 2019; Lynott & Connell, 2013; Montefinese et al., 2014; Repetto et al., 2022; Tillotson et al., 2008), other behavioral tasks employing more implicit measures (e.g., reaction times, kinematics indexes, associations and feature production tasks), neurophysiological measures (e.g., EEG indexes like Event-Related Potentials or frequency bands) and a combination of both methodologies might be useful to elucidate further (e.g., conceptual processing) and deeper (e.g., electrophysiological markers) cognitive aspects related to the conceptualization of Ecological and Technological concepts. In this sense, the TECo database represents a useful instrument for selecting words to use in future research according to specific semantic properties.

On a different note, our results might not generalize to the entire population, as our data were collected from a sample of Italian participants and mostly from young adults. Indeed, there might be specific differences related to varying experiences with Ecological and Technological concepts across contexts, languages and cultures, and generational cohorts, since conceptual representations are shown to vary in relation to these factors (contexts/languages/cultures: e.g., Borghi & Mazzuca, 2023; Lewis et al., 2023; lifespan: e.g., Borghi & Setti, 2017; Wulff, De Deyne, et al., 2022; Wulff et al., 2016; Wulff, Hills, et al., 2022). Finally, the question of whether our results hold across participants with differing levels of expertise in specific domains such as ecology and technology remains open (Blasi et al., 2022; Buchanan et al., 2021; Croijmans et al., 2020; Purves et al., 2023; Villani et al., 2021). Despite these limitations driven by the novelty of the research purview, we believe our work represents a starting point for the study of Ecological and Technological domains from a conceptual perspective.

6. Conclusion

Our results show that Ecological and Technological concepts, despite being more similar to Abstract than to Concrete concepts in abstractness, have a multifarious semantic characterization. This prevents us from considering them as either completely Abstract or completely Concrete entities—thus underscoring their "hybrid" semantic nature. They also challenge the traditional idea according to which Concrete concepts refer to single objects or entities, while Abstract concepts refer to events and situations. Indeed, while Ecological and Technological concepts' referents are often well-defined single entities, their semantic characterization in most cases is similar—or even overcome—that of Abstract concepts. So, our data contribute to questioning traditional theories of concepts, showing that not all conceptual categories can be confined into the strict *concrete-abstract* dichotomy, and suggest tackling their semantic characterization by studying other semantic properties besides Concreteness~Abstractness. In line with this, our study represents the first work investigating underlying semantic components of these two recently emerged and timely domains. From a practical perspective, which extends beyond semantics, our study is the first attempt to build a cognitive map of concepts featuring human progress and environment transformation. Understanding how the Western population represents semantic categories related to ecology and technology, which are evolving rapidly, might impact the design and implementation of pedagogical, political, and social practices. For instance, knowing that people struggle to mentally visualize Ecological concepts, stakeholders might invest more in efficient strategies to better visualize concepts like the *ozone hole*, the *greenhouse effect*, and *deforestation*. Indeed, visualizing helps reduce the psychological distance from events (see Trope & Liberman, 2010), which in turn might lead to adopting positive concrete behaviors. Moreover, although Technological concepts are represented as less abstract than Ecological ones, they also show Abstract-like features, indicating how difficult it can be to fully understand the origin and the functioning of cognitive tools mediating our lives. For this reason, digital education could be integrated into school curricula to foster a deeper understanding of the cognitive processes underpinning our technological landscape. The effectiveness of social and experimental practices aimed at promoting familiarization with Ecological and Technological concepts might be assessed by testing whether specific semantic dimensions are affected by interventions. For instance, we might expect that the abstractness of Ecological concepts might decrease after a session of landscape visualization while their emotionality and political relevance might increase. In this regard, the current database offers validated measures to assess how the representation of relevant concepts in our contemporary Western society might evolve under the influence of contextual and social factors. In conclusion, from a social point of view, comprehending how people represent ecological issues is undoubtedly useful for the implementation of more efficient awareness campaigns to cope with climate change consequences; likewise, understanding the conceptual representations underlying the use of technology might be of help for a more conscious use of these devices by the general population.

Contributions

Contributed to conception and design: IF, CF, CM, AMB.
Contributed to acquisition of data: IF.
Contributed to analysis of data: IF, CM.
Contributed to interpretation of data: IF, CF, CM, AMB.
Drafted the article: IF.
Revised the article: AMB, CF, CM.
Approved the submitted version for publication: IF, CF, CM, AMB.

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Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Data Accessibility Statement

All data, scripts, and analyses of the study, along with the TECo Database, are available at the OSF repository: https://doi.org/10.17605/OSF.IO/M6PH9.

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