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To cite this article: Radim Belohlavek & Tomas Mikula (27 Mar 2024): Are human categories formal concepts? A case study using Dutch data, International Journal of General Systems, DOI: [10.1080/03081079.2024.2311917](https://doi.org/10.1080/03081079.2024.2311917)

To link to this article: <https://doi.org/10.1080/03081079.2024.2311917>



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Published online: 27 Mar 2024.



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Are human categories formal concepts? A case study using Dutch data

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ABSTRACT

While the notion of a formal concept, as used in formal concept analysis, is inspired by the traditional view of human concepts, the psychological relevance of formal concepts has not been examined in the past. In this paper, we provide an experimental exploration of the psychological plausibility of formal concepts as human categories. For this purpose, we use the currently most extensive available psychological data regarding human categories. The data involve several human categories, over 400 exemplars of these categories, several hundreds of binary attributes that describe these exemplars and several binary matrices representing which exemplars have which attributes. Our primary question is: Are human categories formal concepts? That is, do the involved human categories represent formal concepts in the respective exemplar-attribute binary matrices? In most of the examined instances, the answer to this question turns out affirmative. This supports the hypothesis that formal concepts provide a psychologically plausible model of human categories. In addition, we discuss several related questions, provide observations on the psychological data used and present topics for future exploration.

ARTICLE HISTORY

Received 26 August 2023
Accepted 24 January 2024

KEYWORDS

Category; concept; formal concept; psychology; data analysis

1. Human concepts versus formal models of concepts and our aim

Concepts, or categories, are central to human reasoning (Machery 2007; Murphy 2002; Smith and Medin 1981). Various attempts have been made to provide formal models of concepts and concept formation and include numerous approaches in logic, machine learning, data mining and artificial intelligence. These have been studied mainly from the mathematical and computational viewpoints, and the viewpoint of possible applications in various domains.

A viewpoint central to our paper is that of a psychological relevance of formal models of concepts. Clearly, this viewpoint is of great importance not only from the psychological perspective but also from the viewpoint of the overall value of the particular model of concepts. Yet, studies of the psychological relevance of formal models of concepts are

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virtually non-existent. The rare comments on the psychological relevance are restricted to intuitive considerations, unsubstantiated by experiments with solid psychological data. While the general reason for this unsatisfactory situation is, for the most part, the ignorance of the question of psychological relevance in the respective fields mentioned above, a particular obstacle in a possible pursuit of this question is a lack of proper psychological data that would make the pursuit realizable.

The main aim of our paper is to explore experimentally the psychological plausibility of the notion of a formal concept – a well-known simple mathematical model of human concepts employed in formal concept analysis (Carpineto and Romano 2004; Ganter and Wille 1999). The notion of a formal concept is based on a long-standing, traditional understanding of human concepts, worked out in particular in the Port-Royal logic (Arnauld and Nicole 1962), as an entity consisting of its extent, i.e. a collection of objects to which the concept applies, and its intent, i.e. a group of attributes characteristic of the concept. From the viewpoint of the psychology of concepts, formal concept analysis may be regarded as a simple formalization of an old tradition, known as the classical view of concepts (Murphy 2002; Smith and Medin 1981), according to which a human concept (category) is determined by a collection of its defining attributes (characteristics): An object is a member of the category if and only if it has each of the defining attributes.

Formal concepts proved useful in various domains; see, e.g. the books by Carpineto and Romano (2004), Ganter et al. (2016) and Ganter, Stumme, and Wille (2005). The corresponding mathematical and computational foundations are well developed and are still subject of current research (Ganter et al. 2016; Ganter and Wille 1999).¹ Still the basic question of whether the notion of a formal concept is psychologically plausible has not been studied in the past. The above-described situation applies also in a broader sense in that with some exceptions, the psychological relevance of the notions and results in formal concept analysis is ignored.²

We approach the question of psychological plausibility of formal concepts experimentally using the now available Dutch data (De Deyne et al. 2008; Ruts et al. 2004); see also Belohlavek and Mikula (2023). The Dutch data represents high-quality psychological data concerning human categories, which was gathered from several hundred respondents (De Deyne et al. 2008; Ruts et al. 2004). The data is particularly suited for our purpose as it involves a variety of human categories with a broad coverage, hundreds of exemplars of these categories and hundreds of attributes, i.e. features, pertaining to these categories and exemplars, along with a number of binary matrices representing which exemplars have which features. Our most significant finding is that in most instances, the human categories of the Dutch data indeed do form formal concepts in the respective binary matrices. In addition, we provide various related observations regarding formal concepts as well as the Dutch data itself.

Our paper is organized as follows. In Section 2, we provide preliminaries on formal concept analysis and, in particular, present the notion of a formal concept, provide relevant information from the psychology of concepts and describe the Dutch data. In Section 3, we present our experimental evaluation, observations and a discussion of the experimental results. Concluding remarks and topics for future exploration are the content of Section 4.

Table 1. Binary matrix representing five objects (rows), four attributes (columns), and a relation I between objects and attributes.

I	y_1	y_2	y_3	y_4
x_1	0	1	1	0
x_2	0	1	1	0
x_3	0	1	1	1
x_4	1	1	1	1
x_5	1	0	0	0

2. Formal concepts and the Dutch data

2.1. Formal concepts

The notion of a formal concept is the central notion of formal concept analysis (Carpineto and Romano 2004; Ganter and Wille 1999). Consider non-empty sets X and Y of objects and attributes, respectively, and a binary relation I (incidence relation) between X and Y . That is to say, an object $x \in X$ being in the relation I to an attribute $y \in Y$, which is denoted by $\langle x, y \rangle \in I$, indicates that x has y . The triplet $\langle X, Y, I \rangle$, called a formal context in terms of formal concept analysis, may be represented by a binary matrix such as the one in Table 1, in which the 1s (0s) represent that x_i has y_j (x_i does not have y_j).³

A formal concept in a given formal context $\langle X, Y, I \rangle$ is a pair $\langle A, B \rangle$ consisting of a set $A \subseteq X$ of objects (the so-called extent) and a set $B \subseteq Y$ of attributes (the so-called intent) satisfying

$$A^\uparrow = B \quad \text{and} \quad B^\downarrow = A, \quad (1)$$

where

$$\begin{aligned} A^\uparrow &= \{y \in Y \mid \text{for each } x \in A : \langle x, y \rangle \in I\} \text{ and} \\ B^\downarrow &= \{x \in X \mid \text{for each } y \in B : \langle x, y \rangle \in I\}. \end{aligned}$$

Condition (1) means that B is just the set of the attributes shared by all objects in A and A consists of the objects sharing all the attributes in B .

In Table 1, the pair consisting of $A = \{x_3, x_4\}$ and $B = \{y_2, y_3, y_4\}$ represents a formal concept. It may be understood as a category defined by a simultaneous presence of the binary features y_2 , y_3 and y_4 , or, put differently, a satisfaction of the three yes/no conditions represented by y_2 , y_3 and y_4 . Such a category includes the objects x_3 and x_4 , but not, e.g. x_1 because x_1 does not possess y_4 . Likewise, the pairs consisting of $A = \{x_1, x_2, x_3, x_4\}$ and $B = \{y_2, y_3\}$, and of $A = \{x_4\}$ and $B = \{y_1, y_2, y_3, y_4\}$, represent formal concepts. On the other hand, $A = \{x_4, x_5\}$ and $B = \{y_1, y_2\}$ do not form a concept because x_5 does not have y_2 .

The set of all formal concepts in a given formal context $\langle X, Y, I \rangle$ is denoted by $\mathcal{B}(X, Y, I)$, i.e.

$$\mathcal{B}(X, Y, I) = \{\langle A, B \rangle \mid A^\uparrow = B \text{ and } B^\downarrow = A\},$$

and is called the concept lattice of $\langle X, Y, I \rangle$.

When equipped with a natural subconcept–superconcept hierarchy \leq , defined by

$$\langle A, B \rangle \leq \langle C, D \rangle \quad \text{if and only if} \quad A \subseteq C,$$

or, equivalently, if and only if $B \supseteq D$, the set $\mathcal{B}(X, Y, I)$ indeed becomes a partially ordered set, which in fact turns out to be a complete lattice, the structure of which is described by the so-called basic theorem of concept lattices (Ganter and Wille 1999).

2.2. Dutch data

The Dutch data (De Deyne et al. 2008) is a unique, rather extensive data which has been gathered by psychologists within a carefully designed study, in which hundreds of human respondents participated. The main theme of Dutch data is common language categories (concepts) and accompanying data which includes binary attributes (features) relevant to these categories, objects (exemplars) in these categories, and various psychologically relevant characteristics pertaining to these objects, attributes and categories.

For our purpose, we restrict to the part of the Dutch data concerning selected categories, the objects in these categories and relevant attributes. The data includes 16 linguistic categories, which consist of 10 natural-kind categories, 6 of which belong to the animal domain. In addition, it includes 6 categories of the artifact domain. Each category is represented by a set of objects (exemplars), such as a robin for the category “bird”. The exemplars were collected in an exemplar-listing process involving 527 participants in a previous study (Ruts et al. 2004). For each category, a number of exemplars, aimed at 30 per category, were selected from the listed exemplars, including typical and atypical ones, with the restriction that they are familiar to the vast majority of participants (Ruts et al. 2004).

We do not utilize the four non-animal natural kind categories as these are not part of the larger object-attribute data needed to conduct the intended experiments. The natural-kind categories we utilize are the 6 animal categories “amphibians” (includes 5 exemplars),⁴ “birds” (30), “fish” (23), “insects” (26), “mammals” (30) and “reptiles” (22).⁵ The 6 artifact categories are: “clothing” (29), “kitchen utensils” (33), “musical instruments” (27), “tools” (30), “vehicles” (30) and “weapons” (20).⁶ For convenience, the exemplars of all the involved categories are described in Table A1 in Appendix 1.

The animal and the artifact categories comprise 129 and 166 exemplars, respectively, which are representative of these categories.⁷ Coverage by the animal, as well as the artifact categories, is considerable (for instance, the animal categories cover a rather large part of the known animal domain).

The attributes (features) which describe the objects of the particular categories were obtained from 1003 respondents in two ways (we refer to De Deyne et al. (2008) for details): First, the respondents were required to list relevant attributes for a given category (these are called the category attributes). Second, they were asked to list relevant attributes for each object involved in the categories (exemplar attributes).

The numbers of objects in the two domains mentioned above and the numbers of attributes of the two kinds are displayed in Table 2. These numbers represent the four types of binary matrices used in our experiments, i.e. the 129×225 matrix of the animal domain with category attributes, 129×764 matrix of the animal domain with exemplar attributes, and the 166×301 and 166×1295 matrices of the artifact domain with category and exemplar attributes, respectively.

Table 2. Four types of binary matrices used in our experiments: objects in the animal/artifact domain with the respective category/exemplar attributes.

Domain	Objects	Category attributes	Exemplar attributes
Animal	129	225	764
Artifact	166	301	1295

The actual binary matrices corresponding to these four types are called the exemplar-by-feature applicability matrices by the authors of the Dutch data. They describe which objects have which attributes and represent a crucial component of the data for the questions we explore. Each of these matrices was completed separately by four respondents. Hence, there are four 129×225 binary matrices, corresponding to four respondents, and the same for the other three types of matrices.

In fact, the four respondents filling the 129×225 matrix with category attributes also filled the 166×301 matrix with category attributes, while the respondents filling the two matrices with exemplar attributes were eight distinct people (four per matrix). Note also that the matrices with the exemplar attributes were filled first and that the filled values for the exemplar attributes that were also among the category attributes⁸ were copied to the 129×225 and 166×301 matrices with category attributes; the four respondents were then asked to complete the missing values in the two matrices with category attributes.⁹

The Dutch data also contains the corresponding four aggregated matrices, in which the values 0, 1, 2, 3 and 4 provide the number of respondents who agreed on that the respective object has the respective attribute. These matrices thus represent the strength of consensus among respondents as regards the presence of the attributes on the exemplars. There is hence one 129×225 consensus matrix with values equal to 0, 1, 2, 3 or 4, and the same for the remaining three types of matrices.

To obtain binary matrices from the consensus matrices, one naturally thresholds the matrix entries. For instance, from the 129×225 matrix with values in $\{0, 1, 2, 3, 4\}$ a binary matrix corresponding to the threshold “ ≥ 2 ” is obtained which contains 1 at row x and column y iff at least two respondents agreed that the object x has the attribute y (i.e. iff the value at row x and column y in the consensus matrix is ≥ 2). To illustrate, the matrix on the left (a made-up consensus matrix) gets transformed to the one on the right (corresponding binary matrix):

$$\begin{pmatrix} 0 & 2 & 3 & 1 \\ 1 & 4 & 4 & 0 \\ 0 & 3 & 4 & 3 \\ 2 & 2 & 2 & 4 \\ 2 & 1 & 0 & 1 \end{pmatrix} \xrightarrow{\text{“}\geq 2\text{”}} \begin{pmatrix} 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

This way, one obtains four thresholded binary matrices corresponding to the thresholds “ ≥ 1 ”, “ ≥ 2 ”, “ ≥ 3 ” and “ $= 4$ ”, for each of the four consensus matrices with dimensions described in Table 2, i.e. 16 binary matrices of considerable dimensions in total.

The original data contains some minor semantic and technical issues as regards a possible machine processing of the data. We hence modified the Dutch data, which is now available, along with a convenient Python wrapper, on GitHub (Belohlavek and Mikula 2023).

3. Experiments

3.1. The logic of our experiments

As described in Section 2.2, the Dutch data contains several binary matrices I each of which describes a set X of all exemplars of a given collection of categories using a set Y of binary attributes. As further explained above, these matrices are of four dimensions, namely 129×225 (animal domain with category attributes), 129×764 (animal domain with exemplar attributes), 166×301 (artifact domain with category attributes) and 166×1295 (artifact domain with exemplar attributes). For each of these dimensions, there are four binary matrices corresponding to four respondents who filled the matrices, and four thresholded binary matrices corresponding to the thresholds “ ≥ 1 ”, “ ≥ 2 ”, “ ≥ 3 ” and “ $= 4$ ”, which result from the consensus matrices. In total, we hence have 16 binary matrices describing the animal domain and 16 ones for the artifact domain: For each domain, $16 = 2$ (category or exemplar attributes) $\times 8$ (4 respondents’ matrices plus 4 thresholded matrices).¹⁰

We may hence compute the corresponding 16 concept lattices $\mathcal{B}(X, Y, I)$ for the animal domain and the 16 concept lattices for the artifact domain. For each such concept lattice $\mathcal{B}(X, Y, I)$ and each given Dutch data category of the respective domain, which is represented by a subset C of the set X of all exemplars of the domain, we may then ask whether the category actually represents a formal concept in $\mathcal{B}(X, Y, I)$, i.e. whether

$$C = A \text{ for some formal concept } \langle A, B \rangle \in \mathcal{B}(X, Y, I). \quad (2)$$

Due to a basic property of the concept-forming operators (Ganter and Wille 1999), (2) holds true if and only if

$$C = (C^\uparrow)^\downarrow \quad (3)$$

with \uparrow and \downarrow being the operators associated with the matrix I ; see Section 2.1.

Since the categories, the exemplars, the binary features, as well as the binary exemplar-feature matrices have been obtained from a large number of human respondents via a carefully designed process, this kind of experiment may indicate whether the mathematical notion of a formal concept indeed represents a psychologically plausible model of human concepts. This is the principal question we address in our experiments. In addition, we also explore various related topics which naturally appear when exploring the principal question.

3.2. Closer look at relevant aspects of Dutch data

Before turning to the exploration outlined in the previous section, we examine additional characteristics and aspects of the data relevant to our principal question. These characteristics are not part of the Dutch data and may be of interest for other studies involving the data as well.

The first concerns the overlap between the collections of category and exemplar attributes for each domain. According to Section 2.2, the overlap affects the resulting binary matrices. As Table 3 shows, the overlap is considerable: More than 50 % of the category attributes appear among the exemplar attributes in both domains. This implies that because of the way the matrices have been gathered, more than half of the matrices with category

Table 3. Overlap of category and exemplar attributes for the animal and the artifact domain.

Domain	Objects	Category attributes	Exemplar attributes	Attribute overlap
Animal	129	225	764	129
Artifact	166	301	1295	176

Table 4. Density of matrices of individual respondents.

Domain	Attribute type	Dimensions	Respondent			
			1	2	3	4
Animal	Category	129 × 225	0.30	0.27	0.26	0.33
Artifact	Category	166 × 301	0.21	0.19	0.21	0.20
Animal	Exemplar	129 × 764	0.12	0.11	0.09	0.17
Artifact	Exemplar	166 × 1295	0.09	0.07	0.10	0.07

Table 5. Density of the thresholded matrices.

Domain	Attribute type	Dimensions	≥ 1	≥ 2	≥ 3	$= 4$
Animal	Category	129 × 225	0.43	0.32	0.25	0.17
Artifact	Category	166 × 301	0.34	0.23	0.15	0.09
Animal	Exemplar	129 × 764	0.23	0.13	0.08	0.04
Artifact	Exemplar	166 × 1295	0.16	0.09	0.05	0.02

attributes were copied from the corresponding matrices with exemplar attributes. As a consequence, the corresponding matrices with category and exemplar attributes are consistent regarding the presence or absence of the overlap attributes on the exemplars.

Another characteristic of possible interest is the density of the involved binary matrices, i.e. the proportion of the entries containing 1 among all entries in a given matrix. The densities of all the matrices are provided by Tables 4 and 5. While Table 5 only reflects the logical rule of decreasing densities as the threshold for consensus increases, Table 4 reveals a notable fact: For all matrices except for those for the animal domain with exemplar attributes, the densities corresponding to individual respondents are comparable, which indicates a reasonable consistency of respondents. For the matrix for animal domain and exemplar attributes, the density corresponding to respondent 4 is almost twice as high as the densities corresponding to the first three respondents. We hypothesize that this may be a result of a careless filling by the fourth respondent or of an excessively long contemplation of the respondent, which – as a rule – results in filling more 1s.

An interesting point with regard to the main question we explore is consistency among respondents as regards their judgment of whether a given attribute applies or does not apply to a given object. This information is provided by Tables 6, 7 and 8, which represent agreement among all the 6 pairs, all the 4 triples and of the whole quadruple of respondents, respectively. As an example, the column labelled “1, 2” in Table 6 represents the agreement of respondents 1 and 2: The values a , b , c and d are the numbers of entries defined as follows:

a : respondent 1 entered 1, respondent 2 entered 1,

b : respondent 1 entered 1, respondent 2 entered 0,

c : respondent 1 entered 0, respondent 2 entered 1,

d : respondent 1 entered 0, respondent 2 entered 0.

Table 6. Agreement of pairs of respondents.

		1, 2	1, 3	1, 4	2, 3	2, 4	3, 4	mean
Animal Category	<i>a</i>	6343	5949	7272	5875	6666	6337	
	<i>b</i>	2411	2805	1482	2045	1254	1150	
	<i>c</i>	1577	1538	2387	1612	2993	3322	
	<i>d</i>	18694	18733	17884	19493	18112	18216	
129 × 225	SMC	0.86	0.85	0.87	0.87	0.85	0.85	0.86
Artifact Category	<i>a</i>	6754	6935	6787	6512	6533	6440	
	<i>b</i>	3900	3719	3867	2754	2733	4217	
	<i>c</i>	2512	3722	3101	4145	3355	3448	
	<i>d</i>	36800	35590	36211	36555	37345	35861	
166 × 301	SMC	0.87	0.85	0.86	0.86	0.88	0.85	0.86
Animal Exemplar	<i>a</i>	6604	5750	8368	6075	8081	6970	
	<i>b</i>	4989	5843	3225	4519	2513	2159	
	<i>c</i>	3990	3379	8402	3054	8688	9799	
	<i>d</i>	82974	83585	78562	84908	79274	79628	
129 × 764	SMC	0.91	0.91	0.88	0.92	0.89	0.88	0.9
Artifact Exemplar	<i>a</i>	9893	10842	9184	9875	8462	8643	
	<i>b</i>	9052	8103	9762	5440	6853	12140	
	<i>c</i>	5422	9941	4905	10908	5627	5446	
	<i>d</i>	190603	186084	191120	188747	194029	188742	
166 × 1295	SMC	0.93	0.92	0.93	0.92	0.94	0.92	0.93

Table 7. Agreement of triples of respondents.

		1, 2, 3	1, 2, 4	1, 3, 4	2, 3, 4	mean
Animal Category	<i>a</i>	5201	5808	5501	5426	
	<i>d</i>	17830	17165	17182	17411	
129 × 225	SMC	0.79	0.79	0.78	0.79	0.79
Artifact Category	<i>a</i>	5220	5360	5231	5085	
	<i>d</i>	34370	34872	33698	34555	
166 × 301	SMC	0.79	0.81	0.78	0.79	0.79
Animal Exemplar	<i>a</i>	4588	5842	5122	5326	
	<i>d</i>	81082	76812	77032	77864	
129 × 764	SMC	0.87	0.84	0.83	0.84	0.85
Artifact Exemplar	<i>a</i>	7061	6558	6504	6089	
	<i>d</i>	183476	187603	183319	185675	
166 × 1295	SMC	0.89	0.9	0.88	0.89	0.89

The table also contains degrees of agreement of the pairs of respondents expressed by the simple matching coefficient (SMC), which is defined as $\frac{a+d}{a+b+c+d}$, i.e. as the proportion of entries in which both respondents agree (Sokal and Michener 1958), as well as the mean value of SMC over all the 6 pairs of respondents. Tables 7 and 8 represent analogous information for the triples and the quadruple of respondents. In this case, we use a natural generalization of the SMC defined as $\frac{a+d}{n}$, where the values *a* and *d* denote the number of entries for which all the respondents of the triple or the quadruple entered 1 and 0, respectively, and *n* denotes the number of all entries of the binary matrix.

As one may observe, the agreement of the pairs, as well as the triples and the quadruple of respondents, is considerably high. This also justifies our consideration of the matrices

Table 8. Agreement of the quadruple of respondents.

		1, 2, 3, 4
Animal Category	<i>a</i>	4919
	<i>d</i>	16630
129×225	SMC	0.74
Artifact Category	<i>a</i>	4394
	<i>d</i>	32960
166×301	SMC	0.75
Animal Exemplar	<i>a</i>	4318
	<i>d</i>	75760
129×764	SMC	0.81
Artifact Exemplar	<i>a</i>	4925
	<i>d</i>	181451
166×1295	SMC	0.87

obtained from the consensus matrices by thresholds “ $\geq i$ ” for $i = 1, 2, 3, 4$. In addition, notice that the somewhat abnormal density of the animal domain matrix with exemplar attributes of respondent 4 is apparent in Table 6: In all the columns “1, 4”, “2, 4” and “3, 4”, the values *b* are significantly smaller than the corresponding values *c*, indicating that respondent 4 entered considerably more 1s compared to respondents 1, 2 and 3.

3.3. Answers to main questions

We now present basic results regarding the question of whether the 11 human categories of the Dutch data turn out to be formal concepts in each of the available binary matrices, i.e. the thresholded consensus matrices and the individual respondent’s matrices. The results are provided in Table 9 (thresholded consensus matrices) and Table 10 (individual respondents’ matrices).

3.3.1. Main observations

3.3.1.1. Thresholded consensus matrices. We first turn to Table 9, where the corresponding binary matrices are derived from consensus among respondents and may hence be considered as representing a common view regarding the presence or absence of attributes. The table rows correspond to the inspected categories of the animal and the artifact domain (the first five and the next six categories, respectively). The columns represent the binary matrices for these two domains derived from the $\{0, 1, 2, 3, 4\}$ -valued consensus matrices with the category attributes via the thresholds “ ≥ 1 ”, “ ≥ 2 ”, “ ≥ 3 ” and “ $= 4$ ”. The entry at a row corresponding to a category *C* and a column corresponding to a binary matrix *I* contains “yes” if *C* represents a formal concept in the corresponding concept lattice $\mathcal{B}(X, Y, I)$, i.e. if (3) holds, and “no” otherwise. Each table hence represents 44 tests (11 categories \times 4 matrices). In total, Table 9 represents 88 tests of whether a category is a formal concept in a reasonably elaborated description of exemplars by binary attributes, of which 40 are for the animal and 48 for the artifact domain.

Table 9. Are human categories formal concepts? Thresholded consensus matrices.

Attribute type	Domain	Category	≥ 1	≥ 2	≥ 3	$= 4$
Category	Animal	Bird	yes	yes	yes	yes
		Fish	yes	yes	yes	yes
		Insect	yes	yes	yes	yes
		Mammal	yes	yes	yes	no
		Reptile	yes	yes	yes	no
	Artifact	Clothing	yes	yes	yes	no
		Kitchen utensil	yes	yes	yes	no
		Musical instrument	yes	yes	yes	yes
		Tool	yes	yes	no	no
		Vehicle	no	no	no	no
		Weapon	no	no	no	no
Exemplar	Animal	Bird	yes	yes	yes	yes
		Fish	yes	yes	yes	yes
		Insect	yes	yes	yes	yes
		Mammal	yes	yes	yes	yes
		Reptile	yes	yes	yes	no
	Artifact	Clothing	yes	yes	yes	yes
		Kitchen utensil	yes	yes	yes	no
		Musical instrument	yes	yes	yes	yes
		Tool	yes	yes	no	no
		Vehicle	yes	no	no	no
		Weapon	no	no	no	no

A summary of the results of our tests is provided in the following table:

	Animal domain	Artifact domain	All
no. yes/no. tests	37/40	26/48	63/88

Let us mention a considerable sensitivity of the notion of formal concept to the description of objects by binary attributes, which is relevant in the assessment of these results. The absence of a single attribute on a given object may result in excluding the object from the extent of a given formal concept. Due to the large number of attributes and due to possible mistakes and flaws in the judgment of the respondents, both “false negatives” and “false positives” are likely to occur in the binary matrices involved in the Dutch data. In this perspective, the overall number of tests in which a category indeed turned out to represent a formal concept may be regarded as considerably high.

Intuitively, the matrices corresponding to thresholds “ ≥ 2 ” and “ ≥ 3 ” seem most natural since they represent a reasonable consensus of the respondents as regards the presence of attributes on exemplars. The matrix corresponding to “ $= 4$ ” represents the maximal possible consensus, which arguably is not natural to be considered a common human view of the domain. Likewise, the matrix corresponding to “ ≥ 1 ” may be considered somewhat extreme since it displays a presence of an attribute whenever any of the respondents claims this presence (the matrix hence equals the union of the individual respondents’ matrices).

For the sake of completeness and a possible further exploration, we include the list of all the formal concepts corresponding to all the entries of Table 9 in Tables A2 (category attributes) and A3 (exemplar attributes) in Appendices 2 and 3, respectively.¹¹ In particular, for each category represented by a set C of exemplars and each threshold “ $\geq i$ ” of the

Table 10. Are human categories formal concepts? Individual respondents' matrices.

Attribute type	Domain	Category	Respondent			
			1	2	3	4
Category	Animal	Bird	yes	yes	yes	yes
		Fish	yes	yes	yes	yes
		Insect	yes	yes	yes	yes
		Mammal	yes	yes	yes	yes
		Reptile	yes	yes	yes	yes
	Artifact	Clothing	yes	yes	yes	no
		Kitchen utensil	no	yes	no	no
		Musical instrument	yes	yes	yes	yes
		Tool	no	yes	yes	no
		Vehicle	no	no	yes	no
		Weapon	no	no	no	no
	Exemplar	Bird	yes	yes	yes	yes
		Fish	yes	yes	yes	yes
		Insect	yes	no	yes	yes
		Mammal	yes	yes	yes	yes
		Reptile	yes	yes	yes	yes
	Artifact	Clothing	yes	yes	yes	no
		Kitchen utensil	yes	yes	yes	no
		Musical instrument	yes	yes	yes	no
		Tool	yes	yes	yes	no
		Vehicle	yes	yes	yes	no
		Weapon	no	no	no	no

respective domain matrix, we list the formal concept $\langle C^{\uparrow\downarrow}, C^{\uparrow} \rangle$ generated by C by listing the objects of its extent and the attributes of its intent. We also include “yes” if the category forms a formal concept, i.e. $C = C^{\uparrow\downarrow}$, and “no” otherwise. If the category does not form a formal concept, then $C \subset C^{\uparrow\downarrow}$, in which case we include the names of additional objects in $C^{\uparrow\downarrow} - C$ in *italics*.

Notice that for any given category C , the corresponding intent $C^{\uparrow i}$ of the $\geq i$ -thresholded matrix I gets larger as the threshold value i gets smaller. This is due to the following immediate consequence of the definition of the operator \uparrow_i induced by the $\geq i$ -thresholded matrix I :

$$\text{If } i \leq j, \text{ then } C^{\uparrow i} \supseteq C^{\uparrow j} \text{ for any } C \subseteq X.$$

3.3.1.2. Animal domain and artifact domain. The numbers of positive and negative tests are apparently different for the animal and the artifact domain. In the animal domain, all tests except for three have positive results. The three negative results, however, occur in the matrix corresponding to the maximal possible respondents' consensus “= 4”, which may be regarded as somewhat unnatural. The animal domain clearly supports the hypothesis that the notion of a formal concept provides a plausible model of human categories.

An important factor, which appears to contribute to the results, is the fact that all the categories in this domain are of the so-called natural kind.¹² Namely, the natural-kind categories tend to be more salient compared to artificial ones (Barsalou 1985), and “categorically distinct” in that “there cannot be a smooth transition from one kind to another”

(Bird and Tobin 2023). We thus contend that the natural-kind categories are better definable in terms of attributes generated by humans, as indicated by the animal-domain parts of Table 9.

In the artifact domain, the situation is different. Even when one disregards the matrix corresponding to the maximal consensus, i.e. the threshold “= 4”, there remain categories, namely “tool”, “vehicle” and “weapon”, which do not form formal concepts. Consider “tool” first, which does not form a formal concept for thresholds “ ≥ 3 ” and “= 4” for either kind of attributes. For the threshold “ ≥ 3 ”, the extent $C^{\uparrow\downarrow}$ includes (see Appendix 2) the set C of “tool” exemplars and, in addition, also some exemplars of “kitchen utensil” (10 for the category attributes and 19 for the exemplar attributes), such as a sieve, nutcracker, can opener and scissors. Clearly, the exemplars of “kitchen utensil” may rightly be regarded as exemplars of “tool” as well. Thus the reason for “tool” not being a formal concept in the “ ≥ 3 ”-thresholded consensus matrix is the natural overlap of “tool” and “kitchen utensil” that is not reflected in how these two categories are represented by exemplars in the Dutch data. A similar reason explains the situation with threshold “= 4”, in which case the sets $C^{\uparrow\downarrow}$ contain 57 and 42 additional exemplars for the category and exemplar attributes, respectively.

The categories “vehicle” and “weapon”, which fail to form formal concepts in 7 out of the 8 cases are somewhat more complicated. The presence of additional exemplars in $C^{\uparrow\downarrow}$ for the two sets C representing “vehicle” and “weapon” may partly be explained in a way similar to that for “tool”. Intuitively, however, these categories, and the category “tool” as well, exemplify categories that are not as clearly separable as the natural-kind categories. A natural explanation of this intuition, which results in a failure to form a formal concept in most cases, is offered by Barsalou’s research on goal-derived categories (Barsalou 1985). The goal-derived categories, of which “vehicle” and “weapon” are good examples, are formed with respect to the achievement of a certain goal. Such categories often include exemplars of several natural-kind categories, but not all exemplars of any such category. As a consequence, the exemplars of goal-oriented categories may be more difficult to define by binary features listed as exemplar or category attributes by respondents exposed to the exemplar and category names. Indeed, except for “vehicle” and the “ ≥ 1 ” threshold, the sets of binary attributes shared by the exemplars of the two categories, “vehicle” and “weapon”, do not include attributes that convincingly represent the goals of the respective categories; cf. description of these categories in Appendix 2.

3.3.1.3. Individual respondents’ matrices. In addition to the tests with the thresholded consensus matrices described above, we also provide in Table 10 results of the tests with the binary matrices filled by the individual respondents. These experiments test whether a category forms a formal concept with respect to individual person’s knowledge rather than consensus knowledge. A summary of the results is the following:

	Animal domain	Artifact domain	All
No. yes/no. tests	40/40	26/48	66/88

In the animal domain, all tested categories turn out to form formal concepts irrespective of whether category attributes or exemplars attributes were used for the description of

Table 11. Number of formal concepts in the thresholded consensus matrices $I_{\geq i}$.

Domain	Attribute type	≥ 1	≥ 2	≥ 3	$= 4$
Animal	Category	11 097 215	1 669 900	156 632	28 212
Animal	Exemplar	671 126 463	13 258 687	236 387	21 148
Artifact	Category	12 853 601	3 243 995	725 063	54 292
Artifact	Exemplar	1 379 165 960	15 146 201	1 051 635	25 242

the objects. Note that this also is true for respondent 4 for the animal domain with exemplar attributes whose matrix contains considerably more 1s than those of the other three respondents; see Section 3.2. A possible explanation of this remarkable fact is that in spite of the higher density, respondent's 4 matrix contains a consistent view of the exemplars and features in which all the categories still are definable by the features.

The ratio of 26/48 in the artifact domain deserves a deeper look. First, we see a notable number of negative results for the category “weapon” and also for “vehicle”, similarly as in the case of the threshold consensus matrices above. The reason for this is arguably similar to the one in the consensus case, namely the somewhat peculiar nature of these two categories (see above).

Notice also the results for respondents 4 in Table 10 containing “no” almost everywhere. Recall that these respondents are two different persons, which we now denote r4c and r4e, because they filled the matrices with category and exemplar attributes, respectively; due to how the matrices we filled, almost half of the matrix of r4c (the part corresponding to the overlap attributes) was copied from the matrix of r4e. We hypothesize that while the matrix of r4e, for whatever conceivable reason, simply does not render the artifact categories as formal concepts, the main reason for the “no” answers for the matrix of r4c is the copying of the values of overlapping attributes from the matrix of r4e. Namely, we observed that when these values were copied from the matrices of respondents 1, 2 and 3, the majority of the answers are positive.

3.3.2. Further observations

Let us now present additional observations on matters related to the main question explored in the previous section. The first concerns the following pattern present in Table 9. In both tables, it holds true that all the entries right to any “no”-entry also contain “no”. That is, if a category fails to be a formal concept in a consensus matrix for threshold “ $\geq i$ ”, then it also fails to be a formal concept for all higher thresholds, i.e. for “ $\geq j$ ” with $j > i$ (equivalently, if a category forms a formal concept for “ $\geq i$ ”, then it forms a formal concept for all lower thresholds). This pattern, however, is but a result of coincidence in the Dutch data, as one can easily construct data with matrices $I_{\geq i} > I_{\geq j}$ for $i < j$ and find a set C of objects which is an extent w.r.t. $I_{\geq j}$, but not w.r.t. $I_{\geq i}$.

Another observation concerns the size of the concept lattices $\mathcal{B}(I_{\geq i})$ of the thresholded consensus matrices I_{\geq} . Namely, it turns out that for both the animal and the artifact domain and for both category and exemplar attributes, the number of formal concepts gets smaller as the consensus threshold increases. That is,

$$i < j \text{ implies } |\mathcal{B}(I_{\geq i})| > |\mathcal{B}(I_{\geq j})|,$$

as is apparent from Table 11.

Table 12. No. cases in which a category form a formal concept for the thresholded consensus matrices in Table 9.

	<i>cat</i> = yes <i>exe</i> = yes	<i>cat</i> = yes <i>exe</i> = no	<i>cat</i> = no <i>exe</i> = yes	<i>cat</i> = no <i>exe</i> = no
Animal	18	0	1	1
Artifact	12	0	2	10
Both	30	0	3	11

Table 13. No. cases in which a category forms a formal concept for the individual respondents' matrices in Table 10.

	<i>cat</i> = yes <i>exe</i> = yes	<i>cat</i> = yes <i>exe</i> = no	<i>cat</i> = no <i>exe</i> = yes	<i>cat</i> = no <i>exe</i> = no
Animal	20	0	0	0
Artifact	10	1	5	8
Both	30	1	5	8

One might hence be tempted to conclude that, e.g. the formal concepts of $\mathcal{B}(I_{\geq 3})$ are included in $\mathcal{B}(I_{\geq 2})$. Such a conclusion would be false. In fact, it appears that even though $|\mathcal{B}(I_{\geq i})| > |\mathcal{B}(I_{\geq j})|$, only a very small fraction of the extents of formal concepts in $\mathcal{B}(I_{\geq j})$ actually are also extents of formal concepts in $\mathcal{B}(I_{\geq i})$.

Note also that one needs to be careful in drawing seemingly intuitive but, in fact, wrong conclusions about the relationships between the tables regarding the thresholded consensus matrices and the matrices corresponding to the individual responses. For example, it is not true that if a category forms a formal concept with regard to all four matrices of the individual respondents, then it forms a formal concept in the matrix corresponding to the maximum consensus, i.e. to the “= 4”-thresholded matrix, nor vice versa: The categories “reptile” and “clothing” in the matrices with category attributes serve as counterexamples.

Our next observation concerns the relationship between category and exemplar attributes, as regards their capability to define a category. In particular, we consider the confidence of the rules¹³

$cat \rightarrow exe$: if a category is a formal concept for *category* attributes,
it also is formal concept for *exemplar* attributes,

and

$exe \rightarrow cat$: if a category is a formal concept for *exemplar* attributes,
it also is formal concept for *category* attributes.

The relevant numbers of cases in which the inspected categories form formal concepts are provided by Table 12 (thresholded consensus matrices) and Table 13 (individual respondents' matrices).

For instance, the numbers 18 and 0 in the “animal” line of Table 12 indicate that in 18 of the 20 entries of the animal-domain part of Table 9, the value is “yes” for the table with category attributes and “yes” for the table with exemplar attributes; and, moreover, that in 0 of

Table 14. Confidence of rules $cat \rightarrow exe$ and $exe \rightarrow cat$ for data in Table 12 (left) and Table 13 (right).

	Animal	Artifact	Both		Animal	Artifact	Both
$cat \rightarrow exe$	1	1	1	$cat \rightarrow exe$	1	0.91	0.97
$exe \rightarrow cat$	0.95	0.86	0.91	$exe \rightarrow cat$	1	0.67	0.86

these 20 entries the respective values are “yes” for category attributes and “no” for exemplar attributes. The confidence values of both rules, $cat \rightarrow exe$ and $exe \rightarrow cat$, are provided in Table 14; the values on the left and on the right correspond to the thresholded consensus matrices and the individual respondents’ matrices, respectively. The confidence values of $cat \rightarrow exe$ may be interpreted as confirming the intuition that the exemplar attributes have a better distinctive ability compared to the category ones: With only a few exceptions, if a category is definable using the category attributes, it also is definable using the exemplar attributes.

4. Conclusions and future research

4.1. Basic findings

Our primary goal is to explore the psychological plausibility of the notion of a formal concept using the now available but little-exploited high-quality psychological data referred to as the Dutch data. In a broader sense, we intend to bring attention to the psychological relevance of the formal notions utilized in data mining, machine learning, and artificial intelligence inspired by the human mind.

We assess our primary question by asking whether the human categories involved in the Dutch data form formal concepts in the several binary matrices provided in the data. In brief, the matrices represent binary data gathered from individual respondents and data representing a consensus among the respondents. The matrices concern two large domains, namely the animal domain and the artifact domain. They are available with two large collections of attributes: Category attributes and exemplar attributes.

It turns out that our main question of whether a given human category forms a formal concept has an affirmative answer for most of the available human categories and binary matrices. This supports the view that the notion of a formal concept indeed provides a psychologically plausible model of human categories. In addition to the main question, we examine various aspects of the Dutch data, such as the overlap of the category and exemplar attributes, the densities of the binary exemplar-feature matrices, and the consistency of data provided by the individual respondents, which provides a relevant context for our explorations and themselves are of psychological interest.

4.2. Future research topics

Our explorations shall lead to further research and a renewed interest in the classical view of concepts, both from the viewpoint of the psychology of concepts and from the perspective of utilizing formal models of concepts in applications. The classical view has been the prevailing approach since Aristotle. It dominated the psychological approaches to concepts before the 1970s when it came to be questioned, given the psychological studies by Eleanor

Rosch (Rosch 1978; Rosch and Mervis 1975; Rosch et al. 1976); see Murphy (2002) for a thorough exposition.

Recall that according to the classical view, a concept is determined by a collection of binary attributes with a defining role: The concept applies to an object if and only if the object has all these defining attributes. Rosch's findings brought to attention what is nowadays referred to as the graded structure of concepts, which has since been regarded as empirical evidence against the classical view. In brief, Rosch's experiments revealed that various phenomena, such as membership in a human concept (category), are a matter of degree rather than bivalent (yes–no), as the classical view assumes. In addition to empirical evidence, which is considered the main argument against the classical view, there is also the following in-principle argument against it, which is attributed to Wittgenstein (1953). Even though a majority of concepts seems to be defined by a collection of binary attributes, i.e. the necessary and sufficient conditions, for most concepts it appears to be impossible actually to specify the defining attributes. Whenever one suggests a collection of attributes as a definition of a given concept, there seems to pop up an object subsumed by the concept that does not satisfy the definition or, vice versa, an object meeting the definition is not subsumed by the concept. The above arguments led to dismissing the classical view as a viable approach within the psychology of concepts.

In our view, an overall dismissal of the classical view is inappropriate. On the one hand, the classical view is currently justly regarded as not accounting properly for several phenomena considered within the psychological research. In the end, the realm of human concepts is highly complex, and one may hardly hope that any given formal model of concepts copes with all the peculiarities involved to complete satisfaction. On the other hand, however, the classical view provides a rather appealing model of human concepts of considerable pragmatic value:

- Numerous publications in the psychology of concepts that appeared even a long time after the 1970s dismissal of the classical view still employ models in which human categories are represented by classical sets of exemplars further described by binary attributes.
- Binary attributes may naturally explain several graded phenomena accompanying human concepts. A case in point is the phenomenon of typicality of exemplars in human categories; see the above works of Rosch, the references in Murphy (2002) and our recent study (Belohlavek and Mikula 2022).
- The classical view provides at least a reasonable approximation of human concepts. It is useful in data management applications, particularly in analyzing data. Moreover, it may provide a useful, albeit simplified, formal model for psychological explorations, amenable to quantitative considerations which may help understand various psychological phenomena. With appropriate further developments, e.g. extensions and modifications, such as including graded (fuzzy) attributes instead of relying on only binary attributes, it may obtain a better psychological plausibility; see, e.g. Belohlavek and Klir (2011).

We, therefore, believe that further explorations in the classical view of concepts are needed that include an interaction of the psychological viewpoint and the formal (i.e.

logico-mathematical) viewpoint. Below we describe some particular problems in which we started to take the first steps.

A question that naturally offers itself is: If a human category forms a formal concept $\langle A, B \rangle$ with respect to a given exemplar-feature matrix, does the set of attributes B provide a natural definition of the category? Note first that the scenario of our experiments differs from the one commonly employed when reasoning about the classical view: The set of binary attributes defining a given category is not supplied by a human; instead, the defining attributes are sought in the exemplar-feature matrix.

An inspection of Appendix 2 reveals that the answer is affirmative for some categories and binary matrices with relatively small sets B , such as “bird” or “fish” in the matrices with the category as well as exemplar attributes corresponding to “ ≥ 3 ” or “ $= 4$ ” or “clothing” for “ ≥ 3 ”. For most categories, however, the corresponding set B of attributes may not be regarded as a natural definition of the category, the primary reason being the excessive number of attributes in B ; see, e.g. “bird” for both types of matrices corresponding to “ ≥ 1 ”. In our view, this is generally caused by the fact that some of the attributes in B are naturally considered more critical than others, and hence play a more important role for defining a category in a natural way.

One aspect in these considerations relates to the logical entailment of attributes. The possibly large set B may contain a smaller subset $B^* \subseteq B$ that entails every attribute in B in that every exemplar with all the attributes in the smaller B^* also has every attribute in B . Arguably, the attributes in B^* may be considered more essential for the given category than the entailed attributes in B that do not belong to B^* . For instance, for the category “bird” and the matrix with the category attributes corresponding to “ ≥ 2 ”, the set B of the corresponding formal concept $\langle A, B \rangle$ consists of 33 attributes but includes a three-attribute set B^* , namely,

$$B^* = \{\text{has a bill, has feathers, has two paws}\},$$

that entails all the remaining 30 attributes in B . Arguably, B^* may be regarded as a reasonable definition of the category “bird”. As one may see, the same set may work as a definition of “bird” with respect to the exemplar attributes.

It is a matter of an immediate observation that B^* entails B if and only if B^* generates B in that $(B^*)^{\downarrow\uparrow} = B$. When looking for natural definitions, one hence seems compelled to look for small generators B^* . We observed that it might not be best to look for generators with the smallest possible size or for generators that are minimal with respect to set inclusion. Namely, each of the three singleton subsets of the above three-attribute set B^* itself, i.e.

$$\{\text{has a bill}\}, \{\text{has feathers}\} \text{ and } \{\text{has two paws}\},$$

is a generator. But while B^* may be regarded as a reasonable definition of “bird”, none of the singletons can. The principles according to which some attributes may be dropped require further study.

The preceding question of which attributes may be removed from an intent of a formal concept connects to a more general question of what makes a set B of attributes a good definition of a given category. In exploring this question, it seems that one shall proceed unconfined by the basic imperative of the classical view, namely, that an exemplar is a member of the category if and only if it satisfies all the attributes in B . Such a view allows no exceptions. Instead, one might consider more relaxed conditions which allow

missing attributes for certain objects, such as “can fly” for a penguin in the category “bird”. These considerations go beyond the classical view of concepts and may be regarded as its extension worth further exploration.

Note

1. See also the numerous foundational contributions and applications described in the papers of the three dedicated conferences, the ICFA (Int. Conf. Formal Concept Analysis), the CLA (Concept Lattices and Their Applications), and ICCS (Int. Conf. Formal Concept Analysis).
2. Two exceptions we are aware of are the recent studies by Belohlavek and Trnecka (2020a, 2020b) and by Belohlavek and Mikula (2022).
3. For convenience and by a slight abuse of notation, we also say “binary matrix I ” instead of “relation I ”.
4. As the category “amphibians” only contains 5 exemplars, which are all included in the category “reptiles”, we omit it in most of our considerations below; see De Deyne et al. (2008) for reasons to include the exemplars of “amphibians” in “reptiles”.
5. The binary matrices, which we describe below and use in our experiments, contain only 20 exemplars of the category “reptiles” because the respondents who were to fill in these matrices turned out not to be familiar with two exemplars, komodo and iguanodon (De Deyne et al. 2008).
6. Here, we use the plural in category names, as the authors do (De Deyne et al. 2008); below, we use singular, i.e. “bird” rather than “birds” to be consistent with our previous writings.
7. In addition to the 5 amphibians included in reptiles and two omitted exemplars of reptiles as mentioned above, three exemplars of the artifact categories are included in two distinct categories. There are no other overlaps of the categories.
8. Namely, the exemplar and category attributes overlap; see below.
9. The data also contains much smaller matrices corresponding to the individual categories. For every category, there are two matrices describing all exemplars of the category using binary attributes, one using the category attributes and the other using the exemplar attributes associated with the given category. These matrices are not interesting for the problem we examine since each such matrix describes just one category.
10. Recall that there were 12 respondents in total filling in all the 32 matrices: Four respondents, each filling a matrix describing the animal domain by category attributes, the same four respondents for the matrices describing the artifact domain by category attributes, additional four respondents for the matrices describing the animal domain by exemplar attributes, and yet other four respondents for the matrices describing the artifact domain by exemplar attributes. In what follows, we refer to the four respondents corresponding to each given matrix type as respondents 1, 2, 3, and 4, respectively.
11. We include the list, particularly for a possible exploration by the psychologists.
12. The term “natural kind” in relation to categories appears in psychology and philosophy. The adjective “natural” does not refer to the naturalness of the entities being grouped by a given category. Rather it refers to the naturalness of the grouping represented by the category in that it “that reflects the structure of the natural world rather than the interests and actions of human beings” (Bird and Tobin 2023). The notion of a natural kind is not clear cut, though, and the terminology is even ambiguous in the psychology of concepts. According to Murphy (2002, n. 4, p. 500), for instance,

[t]he term *natural categories* refers to categories that people naturally and normally use in everyday life – not to categories of nature. They are to be contrasted with *artificial categories*, which are made up by experimenters to test their theories. So, furniture and guns would be considered natural categories, because these are categories people use in everyday life. Unfortunately, there is another term called *natural kinds*, which does refer in part to categories of nature.”

13. A confidence of a rule $\varphi \rightarrow \psi$ is the defined as $\frac{m}{n}$, where m is the number of cases in which both φ and ψ are true, and n is the number of cases in which φ is true.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Supported by grants IGA_PrF_2022_018, IGA_PrF_2023_026, and partly by the 2024 IGA grant of the Palacký University Olomouc.

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Appendices

Appendix 1. Categories and their exemplars

Table A1. The categories involved in the Dutch data.

Category	Count	Exemplars
Bird	30	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker
Fish	23	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale
Insect	26	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flea, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm
Mammal	30	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra
Reptile	20	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper
Clothing	29	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit
Kitchen utensil	33	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok
Musical instrument	27	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin
Tool	30	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench
Vehicle	30	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin
Weapon	20	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip

Appendix 2. Formal concepts of the exemplar-by-feature binary matrices

Table A2. Categories and formal concepts of the animal and artifact domains with category attributes.

Category	Threshold	Is formal concept?	Extent	Intent
Bird	≥ 1	Yes	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker	belongs to nature, breathes, breathes through lungs, builds nests, can become ill, can walk, carries over diseases, comes in different sizes, contains proteins, descends from reptiles, dies, does not smell well, doesn't resemble a human being, eats, eats insects, eats small animals, eats worms, exists for ages, flies or crawls, has a beak, has a bill, has a central nervous system, has a leathery skin, has a mouth, has a tail, has air sacs, has an aerodynamic body, has brains, has eyes, has feathers, has legs (poten), has lungs, has no eyelids, has no hairs, has sharp claws (nagels), has skin, has two eyes, has two paws, has two wings, has wings, is a bird, is a carnivore, is a collective noun, is a living being, is a vertebrate, is able to reproduce, is an animal, is eaten by other animals, is fascinating, is not a mammal, is not dangerous, is not yet independent at birth, is soft, is useful, is warm-blooded, its vascular system is less developed than that of mammals, lays eggs, lives in the wild, lives on land, makes a lot of noise, makes a sound, sometimes smells, there are lots of these, there are many kinds of it
Bird	≥ 2	Yes	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker	belongs to nature, breathes, breathes through lungs, builds nests, can become ill, can walk, comes in different sizes, contains proteins, descends from reptiles, dies, doesn't resemble a human being, eats, has a beak, has a bill, has a central nervous system, has a mouth, has air sacs, has brains, has eyes, has feathers, has legs (poten), has lungs, has no hairs, has skin, has two eyes, has two paws, has two wings, has wings, is a bird, is a living being, is a vertebrate, is able to reproduce, is an animal, is eaten by other animals, is not a mammal, is not yet independent at birth, is useful, is warm-blooded, lays eggs, lives on land, makes a lot of noise, makes a sound, sometimes smells, there are lots of these
Bird	≥ 3	Yes	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker,	belongs to nature, breathes, breathes through lungs, can become ill, contains proteins, descends from reptiles, dies, doesn't resemble a human being, eats, has a beak, has a bill, has a central nervous system, has brains, has eyes, has legs (poten), has lungs, has no hairs, has skin, has two eyes, has two paws, has wings, is a bird, is a living being, is a vertebrate, is able to reproduce, is an animal, is not a mammal, is not yet independent at birth, is useful, is warm-blooded, lays eggs, makes a sound
Bird	≥ 4	Yes	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker	breathes, can become ill, contains proteins, dies, doesn't resemble a human being, eats, has a bill, has a central nervous system, has brains, has eyes, has legs (poten), has lungs, has skin, has two eyes, has two paws, has wings, is a bird, is a living being, is a vertebrate, is able to reproduce, is an animal, is not a mammal

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Fish	≥ 1	Yes	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale	belongs to nature, breathes, breathes under water, can become ill, can swim, can't fly, comes in different sizes, contains proteins, dies, doesn't have wings, doesn't live on land, doesn't resemble a human being, eats, eats small animals, eats worms, exists for ages, has a central nervous system, has a mouth, has a tail, has an aerodynamic body, has brains, has eyes, has fins, has gills, has no eyelids, has no hairs, has no paws, has short paws, has teeth, has two eyes, herds, is a carnivore, is a collective noun, is a living being, is a vertebrate, is able to reproduce, is an animal, is cold-blooded, is eaten by other animals, is fascinating, is fast, is slippery, is smooth, is sometimes eaten by man, is useful, lives in Africa, lives in the sea, lives in the wild, lives in warm countries, lives in water, lives nearby the water, makes a lot of noise, shines, sometimes smells, there are lots of these, there are many kinds of it
Fish	≥ 2	Yes	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale	belongs to nature, breathes, breathes under water, can become ill, can swim, can't fly, comes in different sizes, contains proteins, dies, doesn't have wings, doesn't live on land, doesn't resemble a human being, eats, eats small animals, has a central nervous system, has a mouth, has an aerodynamic body, has brains, has eyes, has fins, has gills, has no hairs, has no paws, has teeth, has two eyes, is a living being, is able to reproduce, is an animal, is eaten by other animals, is slippery, is smooth, is useful, lives in the sea, lives in the wild, lives in warm countries, lives in water, sometimes smells
Fish	≥ 3	Yes	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale	belongs to nature, breathes, can become ill, can swim, can't fly, contains proteins, dies, doesn't have wings, doesn't live on land, doesn't resemble a human being, eats, has a central nervous system, has brains, has eyes, has gills, has no hairs, has no paws, has two eyes, is a living being, is able to reproduce, is an animal, is slippery, is smooth, is useful, lives in the wild, lives in water
Fish	≥ 4	Yes	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale	can become ill, can swim, can't fly, dies, doesn't have wings, doesn't resemble a human being, eats, has a central nervous system, has eyes, has no hairs, has two eyes, is a living being, is able to reproduce, is an animal, is slippery, is smooth, lives in water

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Insect	≥ 1	Yes	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flea, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm	Belongs to nature, breathes, builds nests, can become ill, comes in different sizes, contains proteins, dies, does not taste well, doesn't have a central nervous system, doesn't resemble a human being, eats, exists for ages, has a central nervous system, has a mouth, has an exoskeleton, has brains, has eyes, has feelers, has no eyelids, has no hairs, has short paws, has teeth, has two eyes, herds, invertebrate, is a collective noun, is a living being, is able to reproduce, is an animal, is athrodopal, is eaten by an insectivore, is eaten by birds, is eaten by other animals, is exterminated, is fascinating, is found in the garden, is killed by man, is more often encountered during summer, is not a mammal, is not very popular among man, is small (klein), is smaller than a meter, is useful, its vascular system is less developed than that of mammals, lays eggs, lives in Africa, lives in the wild, lives in warm countries, lives on land, sometimes smells, there are lots of these, there are many kinds of it, uses the sun to keep body temperature stable
Insect	≥ 2	Yes	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flea, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm	belongs to nature, breathes, can become ill, comes in different sizes, contains proteins, dies, does not taste well, doesn't have a central nervous system, doesn't resemble a human being, eats, has a mouth, has brains, has eyes, has feelers, has no eyelids, has no hairs, has short paws, has two eyes, invertebrate, is a living being, is able to reproduce, is an animal, is eaten by other animals, is found in the garden, is not a mammal, is small (klein), is smaller than a meter, is useful, its vascular system is less developed than that of mammals, lays eggs, lives in Africa, lives in the wild, lives in warm countries, lives on land, there are lots of these, uses the sun to keep body temperature stable
Insect	≥ 3	Yes	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flea, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm	belongs to nature, breathes, can become ill, contains proteins, dies, does not taste well, doesn't have a central nervous system, doesn't resemble a human being, eats, has brains, has no eyelids, has no hairs, invertebrate, is a living being, is able to reproduce, is an animal, is not a mammal, is small (klein), is smaller than a meter, is useful, its vascular system is less developed than that of mammals, lays eggs, lives in the wild, lives on land, uses the sun to keep body temperature stable
Insect	≥ 4	Yes	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flea, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm	breathes, dies, doesn't resemble a human being, has no eyelids, invertebrate, is a living being, is an animal, is not a mammal, is small (klein), is smaller than a meter, its vascular system is less developed than that of mammals, lives on land

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Mammal	≥ 1	Yes	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra	belongs to nature, breastfeeds its babies, breathes, breathes through lungs, can become ill, can bite, can walk, comes in different sizes, contains proteins, descends from reptiles, dies, does not lay eggs, does not smell well, eats, exists for ages, has a central nervous system, has a fur (vacht), has a leathery skin, has a mouth, has a tail, has brains, has eyes, has four paws, has legs (poten), has lungs, has nipples, has skin, has teeth, has two eyes, is a carnivore, is a collective noun, is a living being, is a vertebrate, is able to reproduce, is an animal, is eaten by other animals, is fascinating, is hairy, is not yet independent at birth, is useful, is warm-blooded, its babies are born alive, lives in Africa, lives on land, makes a lot of noise, makes a sound, mammal, sometimes smells, there are lots of these, there are many kinds of it, thick skin
Mammal	≥ 2	Yes	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra	belongs to nature, breastfeeds its babies, breathes, breathes through lungs, can become ill, comes in different sizes, contains proteins, dies, does not lay eggs, eats, has a central nervous system, has a mouth, has a tail, has brains, has eyes, has legs (poten), has lungs, has nipples, has skin, has teeth, has two eyes, is a living being, is a vertebrate, is able to reproduce, is an animal, is eaten by other animals, is not yet independent at birth, is useful, is warm-blooded, its babies are born alive, lives on land, makes a sound, mammal, sometimes smells
Mammal	≥ 3	Yes	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra	belongs to nature, breastfeeds its babies, breathes, breathes through lungs, can become ill, contains proteins, dies, does not lay eggs, eats, has a central nervous system, has a mouth, has brains, has eyes, has legs (poten), has lungs, has nipples, has skin, has teeth, has two eyes, is a living being, is a vertebrate, is able to reproduce, is an animal, is not yet independent at birth, is useful, is warm-blooded, its babies are born alive, lives on land, mammal
Mammal	≥ 4	No	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra, <i>dolphin, whale, orca</i>	breathes, breathes through lungs, can become ill, contains proteins, dies, eats, has a central nervous system, has brains, has eyes, has lungs, has skin, has two eyes, is a living being, is a vertebrate, is able to reproduce, is an animal, mammal

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Reptile	≥ 1	Yes	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper	belongs to nature, breathes, breathes through lungs, builds nests, can become ill, can swim, can't fly, comes in different sizes, contains proteins, dark colour, descends from reptiles, dies, does not taste well, doesn't have wings, doesn't resemble a human being, eats, eats insects, eats plants, eats small animals, eats worms, exists for ages, has a central nervous system, has a mouth, has a tail, has brains, has eyes, has lungs, has no eyelids, has no hairs, has scales, has short paws, has skin, has teeth, has two eyes, is a carnivore, is a collective noun, is a hunter, is a living being, is a vertebrate, is able to reproduce, is an animal, is cold-blooded, is eaten by other animals, is fascinating, is not a mammal, is smaller than a meter, is ugly, is useful, its vascular system is less developed than that of mammals, lays eggs, lives in Africa, lives in the wild, lives in the zoo, lives in warm countries, lives nearby the water, lives on land, makes a lot of noise, sometimes smells, there are lots of these, there are many kinds of it, uses the sun to keep body temperature stable
Reptile	≥ 2	Yes	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper	belongs to nature, breathes, breathes through lungs, can become ill, can't fly, comes in different sizes, contains proteins, dies, does not taste well, doesn't have wings, doesn't resemble a human being, eats, eats insects, eats small animals, has a central nervous system, has a mouth, has brains, has eyes, has lungs, has no eyelids, has no hairs, has two eyes, is a living being, is a vertebrate, is able to reproduce, is an animal, is cold-blooded, is not a mammal, is useful, its vascular system is less developed than that of mammals, lays eggs, lives in Africa, lives in the wild, lives in warm countries, sometimes smells, uses the sun to keep body temperature stable
Reptile	≥ 3	Yes	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper	breathes, can become ill, can't fly, contains proteins, dies, does not taste well, doesn't have wings, doesn't resemble a human being, eats, has a central nervous system, has brains, has eyes, has no hairs, has two eyes, is a living being, is able to reproduce, is an animal, is not a mammal, is useful, its vascular system is less developed than that of mammals, lays eggs, lives in the wild, lives in warm countries, uses the sun to keep body temperature stable
Reptile	≥ 4	No	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper, <i>salmon, cod, pike, plaice, goldfish, piranha, anchovy, ray, eel, trout, sole, sardine, stickleback, squid, shark, herring, carp</i>	breathes, can become ill, can't fly, dies, doesn't resemble a human being, eats, has a central nervous system, has eyes, has no hairs, has two eyes, is able to reproduce, is an animal, is not a mammal

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Clothing	≥ 1	Yes	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit	bought in a store, can also be used out of the kitchen, can be carried, can be recycled, can be seen on television, can be used inside and outside the house, can become dirty, can rip, can stand heat, can wear off, comes in different fabrics, comes in different materials, comes in different styles, comes in different weights, comes in very handy, comes into fashion/goes out of fashion, different types are available, differs from one culture to the other, doesn't have a specific odour, easily gets dirty, exists in different brands, exists in different colors, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, expresses your personality, has esthetic purposes, has no taste, implement/tool, is a collective noun, is a good invention, is available for each price range, is beautiful, is black, is bought in a specialist shop, is brown, is colourful, is dependent upon the occasion, is different for men and women, is flammable, is found in a cupboard, is functional, is light, is made by designers, is made by hand, is made in a factory, is made under bad circumstances, is meant to wear, is only used by humans, is pliable, is replaceable, is sewn, is shown on the catwalk, is sometimes given as a present for christmas, is used a lot, is used to cover yourself, needs good care, ready-to-wear clothes, sold in clothes shops
Clothing	≥ 2	Yes	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit	bought in a store, can also be used out of the kitchen, can be carried, can be seen on television, can be used inside and outside the house, can become dirty, can rip, can stand heat, can wear off, comes in different fabrics, comes in different materials, comes in different styles, comes into fashion/goes out of fashion, different types are available, doesn't have a specific odour, exists in different brands, exists in different colors, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, has esthetic purposes, is a good invention, is available for each price range, is dependent upon the occasion, is flammable, is found in a cupboard, is made by designers, is made in a factory, is made under bad circumstances, is meant to wear, is only used by humans, is replaceable, is sewn, is shown on the catwalk, ready-to-wear clothes
Clothing	≥ 3	Yes	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit	bought in a store, can also be used out of the kitchen, can become dirty, can stand heat, can wear off, different types are available, doesn't have a specific odour, exists in different brands, exists in different colors, exists in different kinds, exists in different types, is a good invention, is flammable, is found in a cupboard, is made by designers, is made in a factory, is only used by humans, is replaceable, is sewn, ready-to-wear clothes

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Clothing	≥ 4	No	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit, <i>plate, towel, mixer, toaster</i>	can become dirty, can wear off, different types are available, exists in different brands, exists in different colors, exists in different types, is a good invention, is only used by humans, is replaceable
Kitchen utensil	≥ 1	Yes	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok	bought in a store, can be dishwashed, can be recycled, can be seen on television, can become dirty, can stand heat, can wear off, comes in different materials, comes in different styles, comes in different weights, comes in very handy, different types are available, doesn't have a specific odour, easily gets dirty, exists in different brands, exists in different colors, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different types, feels cold to the skin, has no taste, implement/tool, is a collective noun, is a good invention, is an aid, is available for each price range, is bought in a specialist shop, is easy to work with, is functional, is made by designers, is made in a factory, is only used by humans, is practical, is replaceable, is shared, is sometimes given as a present for christmas, is sometimes given to newly-weds as a present, is stainless, is the same for men and women, is used a lot, is used all over the world, is used to prepare food, is useful, makes work easier, makes work in the kitchen easier, used by cooks, used by everybody, used in the kitchen
Kitchen utensil	≥ 2	Yes	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok	bought in a store, can become dirty, can stand heat, can wear off, comes in different styles, comes in very handy, different types are available, doesn't have a specific odour, easily gets dirty, exists in different brands, exists in different forms, exists in different kinds, exists in different types, has no taste, implement/tool, is a good invention, is easy to work with, is functional, is made in a factory, is only used by humans, is practical, is replaceable, is shared, is useful, used in the kitchen
Kitchen utensil	≥ 3	Yes	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok	bought in a store, can become dirty, can stand heat, different types are available, exists in different brands, exists in different forms, is a good invention, is made in a factory, is only used by humans, is practical, is replaceable, is useful, used in the kitchen

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Kitchen utensil	≥ 4	No	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok, <i>harmonica, cymbals, file, rope, bagpipe, top, pullover, shorts, clamp, grinding disc, clarinet, oil can, bathing suit, nail, tongs, lawn mower, hammer, piano, adjustable spanner, blouse, sweater, flute, wire brush, skirt, dungarees, vacuum cleaner, chisel, cap, skateboard, double bass, bass guitar, level, tambourine, trumpet, saxophone, accordion, bra, synthesizer, paint brush, banjo, bassoon, wheelbarrow, jeans, shovel, drill, belt, harp, dress, beanie, trombone, mittens, hat, recorder, cello, kick scooter, t-shirt, pan flute, guitar, wrench, shirt, axe, motorbike (moto), tracksuit, drum, bicycle, suit, tie, pickaxe, saw, coat, sled, plane, violin, screwdriver, pants, filling knife, drum set, anvil, crowbar (breekijzer), scarf, bow</i>	bought in a store, different types are available, is a good invention, is only used by humans
Musical instrument	≥ 1	Yes	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin	bought in a store, can also be used out of the kitchen, can be dishwashed, can be played on, can be recycled, can be seen on television, can be used inside and outside the house, can be used to make music with, can become dirty, can move, can stand heat, can wear off, comes in different materials, comes in different styles, different types are available, doesn't have a specific odour, easily gets dirty, exists in different brands, exists in different colors, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different types, feels cold to the skin, for sale in a music shop, has no taste, implement/tool, is a collective noun, is a good invention, is available for each price range, is bought in a specialist shop, is firm, is found on a stage, is fun, is functional, is hard, is made by designers, is made by hand, is made in a factory, is meant to make music with, is only used by humans, is replaceable, is sometimes given as a present for christmas, is the same for men and women, is used all over the world, is used in orchestras, is used to communicate, is used to make something with, its vibrations produce sounds, makes a special noise, needs good care, one has to learn how to play, played by a musician, produces noise, produces sound, provides entertainment, provides you with freedom, sounds beautiful, you can earn money with it, you have to learn how to use it

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Musical instrument	≥ 2	Yes	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin	bought in a store, can also be used out of the kitchen, can be played on, can be seen on television, can be used inside and outside the house, can be used to make music with, can become dirty, can stand heat, can wear off, different types are available, doesn't have a specific odour, exists in different brands, exists in different colors, exists in different kinds, for sale in a music shop, is a good invention, is available for each price range, is bought in a specialist shop, is found on a stage, is made by hand, is meant to make music with, is only used by humans, is used in orchestras, its vibrations produce sounds, makes a special noise, needs good care, one has to learn how to play, played by a musician, produces noise, produces sound, provides entertainment, you can earn money with it, you have to learn how to use it
Musical instrument	≥ 3	Yes	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin	bought in a store, can also be used out of the kitchen, can be played on, can be used to make music with, can become dirty, different types are available, doesn't have a specific odour, exists in different brands, for sale in a music shop, is a good invention, is found on a stage, is meant to make music with, is only used by humans, one has to learn how to play, played by a musician, produces noise, produces sound
Musical instrument	≥ 4	Yes	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin	can be played on, exists in different brands, is a good invention, played by a musician, produces sound
Tool	≥ 1	Yes	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench	bought in a store, can also be used out of the kitchen, can be dishwashed, can be recycled, can be seen on television, can become dirty, can stand heat, can wear off, comes in different materials, comes in different styles, comes in different weights, comes in very handy, different types are available, doesn't have a specific odour, easily gets dirty, exists in different brands, exists in different colors, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, has no taste, implement/tool, is a collective noun, is a good invention, is a handtool, is a tool, is an aid, is available for each price range, is bought in a specialist shop, is easy to work with, is efficient, is functional, is made by designers, is made in a factory, is not for children, is only used by humans, is practical, is replaceable, is shared, is sometimes given as a present for christmas, is the same for men and women, is used all over the world, is used by a professional, is used to work with, is useful, makes work easier, used to work with

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Tool	≥ 2	Yes	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench	bought in a store, can also be used out of the kitchen, can be seen on television, can become dirty, can stand heat, can wear off, comes in different weights, comes in very handy, different types are available, doesn't have a specific odour, exists in different brands, exists in different colors, exists in different sizes (groottes), has no taste, implement/tool, is a good invention, is an aid, is bought in a specialist shop, is functional, is made in a factory, is only used by humans, is replaceable, is shared, is the same for men and women, is used to work with, is useful, makes work easier, used to work with
Tool	≥ 3	No	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench, <i>stove, sieve, colander, nutcracker, can opener, scissors, mixer, spatula, grater, whisk</i>	bought in a store, can become dirty, can stand heat, different types are available, implement/tool, is a good invention, is an aid, is made in a factory, is only used by humans, is replaceable, is the same for men and women, is useful, makes work easier
Tool	≥ 4	No	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench, <i>stove, tram, microwave oven, colander, bottle, kettle, fork, helicopter, shield, bowl, wok, plate, motorbike (brommer), scooter, blouse, carriage, car, go-cart, bus, nutcracker, skateboard, hovercraft, fridge, train, truck (camion), towel, bra, teaspoon, van, mug, spoon, percolator, jeep, sieve, can opener, tractor, airplane, scissors, scales, pan, mixer, bow, electric kettle, oven, apron, toaster, kick scooter, truck (vrachtwagen), place mat, taxi, zeppelin, motorbike (moto), cart, tie, bicycle, subway train, sled, pants, trailer, spatula, grater, pot, whisk</i>	is a good invention, is made in a factory, is only used by humans

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Vehicle	≥ 1	No	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin, <i>lawn mower</i>	bought in a store, can also be used out of the kitchen, can be dangerous, can be recycled, can be seen on television, can be used to get from one place to the other, can become dirty, can cause accidents, can move, can stand heat, can wear off, comes in different materials, comes in different styles, comes in different weights, consists of different parts, different types are available, doesn't have a specific odour, easily gets dirty, exists in different brands, exists in different colors, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, feels cold to the skin, has no taste, implement/tool, is a collective noun, is a faster form of transport than going by foot, is a good invention, is an aid, is available for each price range, is bought in a specialist shop, is firm, is functional, is grey, is hard, is made by designers, is made in a factory, is only used by humans, is replaceable, is shared, is subject to rules, is the same for men and women, its vibrations produce sounds, needs good care, you have to learn how to use it
Vehicle	≥ 2	No	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin, <i>drill, tank</i>	can also be used out of the kitchen, can be seen on television, can become dirty, can cause accidents, can move, can stand heat, can wear off, comes in different styles, different types are available, doesn't have a specific odour, exists in different brands, exists in different colors, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different types, implement/tool, is made in a factory, is only used by humans, is replaceable
Vehicle	≥ 3	No	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin, <i>stove, microwave oven, colander, bottle, kettle, top, pullover, shorts, fork, shield, bowl, plate, bathing suit, lawn mower, blouse, sweater, glass, skirt, dungarees, nutcracker, sword, vacuum cleaner, cap, socks, fridge, towel, bra, teaspoon, mug, spoon, shoes, percolator, jeans, sieve, drill, belt, can opener, spear, dress, scissors, beanie, scales, pan, pistol, mixer, electric kettle, slingshot, hat, oven, apron, toaster, t-shirt, place mat, pyjamas, rifle, shirt, tracksuit, suit, panties, boots, tie, coat, pants, spatula, grater, pot, scarf, whisk</i>	can become dirty, can stand heat, different types are available, exists in different colors, exists in different forms, exists in different kinds, exists in different types, is made in a factory, is only used by humans

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Vehicle	≥ 4	No	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin, stove, microwave oven, colander, kettle, top, pullover, shorts, fork, grinding disc, bowl, wok, plate, bathing suit, lawn mower, blouse, sweater, glass, skirt, dungarees, cap, socks, fridge, towel, bra, teaspoon, mug, spoon, paint brush, shoes, jeans, shovel, belt, plough, dress, beanie, pan, mittens, mixer, hat, toaster, t-shirt, pyjamas, shirt, tracksuit, suit, panties, boots, tie, coat, pants, spatula, pot, scarf, whisk	can become dirty, different types are available, is only used by humans
Weapon	≥ 1	No	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip, wheelbarrow, crowbar (koevoet), shovel, drill, clamp, grinding disc, plough, knife, oil can, nail, tongs, lawn mower, chisel, wrench, saw, pickaxe, plane, screwdriver, filling knife, crowbar (breekijzer), hammer	can also be used out of the kitchen, can be dishwashed, can be recycled, can be seen on television, can become dirty, can stand heat, can wear off, comes in different materials, comes in different styles, comes in different weights, different types are available, doesn't have a specific odour, easily gets dirty, exists in different brands, exists in different colors, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, has no taste, implement/tool, is a collective noun, is an aid, is available for each price range, is dangerous for children, is efficient, is firm, is functional, is made in a factory, is not for children, is primarily used by men, is replaceable, is the same for men and women, is used all over the world, is useful
Weapon	≥ 2	No	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip, file, jeep, submarine, crowbar (koevoet), shovel, wheelbarrow, drill, clamp, grinding disc, helicopter, airplane, plough, knife, oil can, motorbike (brommer), scooter, nail, tongs, lawn mower, hammer, adjustable spanner, boat, wire brush, car, truck (vrachtwagen), taxi, zeppelin, vacuum cleaner, chisel, wrench, motorbike (moto), cart, level, hovercraft, saw, pickaxe, subway train, plane, screwdriver, filling knife, rocket, anvil, crowbar (breekijzer), paint brush	can also be used out of the kitchen, can be seen on television, can become dirty, can stand heat, can wear off, different types are available, doesn't have a specific odour, exists in different brands, exists in different sizes (groottes), has no taste, implement/tool, is functional, is made in a factory, is replaceable, is the same for men and women

(continued)

Table A2. Continued

Category	Threshold	Is formal concept?	Extent	Intent
Weapon	≥ 3	No	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip, <i>harmonica</i> , cymbals, stove, file, crowbar (koevoet), tram, microwave oven, colander, bottle, kettle, fork, clamp, grinding disc, helicopter, bowl, knife, wok, plate, oil can, motorbike (brommer), scooter, nail, tongs, lawn mower, hammer, adjustable spanner, wire brush, car, glass, go-cart, bus, nutcracker, vacuum cleaner, chisel, skateboard, level, hovercraft, tambourine, fridge, train, towel, rocket, teaspoon, van, mug, spoon, synthesizer, paint brush, percolator, jeep, sieve, submarine, wheelbarrow, shovel, drill, can opener, tractor, airplane, plough, scissors, triangle, scales, pan, mixer, electric kettle, oven, boat, recorder, toaster, kick scooter, truck (vrachtwagen), place mat, taxi, zeppelin, wrench, motorbike (moto), cart, drum, saw, pickaxe, sled, subway train, plane, screwdriver, filling knife, spatula, trailer, grater, drum set, crowbar (breekijzer), anvil, pot, whisk	can become dirty, can stand heat, different types are available, is replaceable, is the same for men and women
Weapon	≥ 4	No	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip, cymbals, stove, shorts, fork, clamp, grinding disc, helicopter, dungarees, nutcracker, chisel, fridge, train, accordion, truck (camion), spoon, jeep, sieve, submarine, plough, scales, pan, electric kettle, organ, place mat, wrench, panties, screwdriver, spatula, grater, anvil, scarf, harmonica, file, tram, microwave oven, bottle, top, pullover, plate, bathing suit, scooter, nail, tongs, lawn mower, piano, adjustable spanner, flute, go-cart, skateboard, double bass, level, tambourine, towel, bassoon, shovel, belt, dress, beanie, trombone, oven, toaster, cello, kick scooter, truck (vrachtwagen), pyjamas, taxi, guitar, shirt, motorbike (moto), cart, drum, boots, coat, sled, violin, trailer, drum set, whisk, colander, bagpipe, bowl, knife, wok, motorbike (brommer), car, glass, vacuum cleaner, socks, trumpet, harpsichord, synthesizer, shoes, wheelbarrow, jeans, drill, can opener, harp, tractor, airplane, scissors, boat, t-shirt, tracksuit, bicycle, pickaxe, plane, filling knife, crowbar (breekijzer), pot, kettle, clarinet, oil can, blouse, sweater, carriage, wire brush, skirt, bus, cap, bass guitar, hovercraft, saxophone, rocket, bra, teaspoon, van, mug, paint brush, banjo, percolator, mittens, mixer, hat, apron, recorder, zeppelin, pan flute, (hot air) balloon, suit, tie, saw, subway train, pants, hammer	different types are available

Table A3. Categories and formal concepts of the animal and artifact domains with exemplar attributes.

Category	Threshold	Is formal concept?	Extent	Intent
Bird	≥ 1	Yes	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker	appears in fairy tales and stories, builds nests, can be aggressive, can be bred, can be caught, can be fed, can do without water for long periods, can turn his head very far, carries over diseases, communicates with its congeners, does not migrate in the winter, does not smell well, doesn't have 1000 paws, doesn't sting, drinks water, eats insects, eats small animals, eats worms, exists for ages, exists in different sizes and kinds, fragile, hairy (harig), has a bill, has a head, has a mouth, has a pointed mouth, has a sharp view, has a tail, has a tongue, has black eyes, has downy hair, has eyes, has feathers, has legs (poten), has round eyes, has sharp claws (nagels), has two ears, has two eyes, has two paws, has two wings, has wings, is a bird, is a carnivore, is an animal, is coloured, is difficult to catch, is eaten by other animals, is edible, is found in Belgium, is found on animals, is not dangerous, is not eaten, is not poisonous, is spectacular, jumps, lays eggs, lives in distant countries, lives in nature, lives in the open air, lives in the wild, lives on land, lives outdoors, makes a sound, neutral scent, occurs frequently, prey, small ears, smaller than a horse, some people are allergic to it, the meat is eaten, there are many kinds of it, you can boil it
Bird	≥ 2	Yes	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker	builds nests, can be aggressive, can be caught, can be fed, doesn't have 1000 paws, doesn't sting, drinks water, has a bill, has a head, has a mouth, has a tongue, has eyes, has feathers, has legs (poten), has round eyes, has two ears, has two eyes, has two paws, has two wings, has wings, is a bird, is an animal, is eaten by other animals, is not poisonous, lays eggs, lives in the open air, lives on land, lives outdoors, makes a sound, neutral scent, prey, small ears, smaller than a horse
Bird	≥ 3	Yes	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker	doesn't have 1000 paws, doesn't sting, drinks water, has a bill, has a head, has a tongue, has eyes, has legs (poten), has two eyes, has two paws, has wings, is a bird, is an animal, is not poisonous, lays eggs, makes a sound, smaller than a horse
Bird	≥ 4	Yes	blackbird, canary, chickadee, chicken, crow, cuckoo, dove, duck, eagle, falcon, heron, magpie, ostrich, owl, parakeet, parrot, peacock, pelican, penguin, pheasant, robin, rooster, seagull, sparrow, stork, swallow, swan, turkey, vulture, woodpecker	has a bill, has a head, has eyes, has legs (poten), has two eyes, has two paws, has wings, is a bird, is an animal, is not poisonous

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Fish	≥ 1	Yes	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale	appears in fairy tales and stories, bites, breaths under water, can be aggressive, can be bred, can be caught, can be fed, can swim, can't fly, communicates with its congeners, does not live in Belgium, does not migrate in the winter, doesn't have 1000 paws, doesn't live on land, doesn't make a sound, doesn't sting, drinks water, eats fish, eats plankton, eats small animals, eats worms, exists for ages, exists in different sizes and kinds, fragile, has a head, has a mouth, has a pungent smell, has a tail, has a tongue, has black eyes, has eyes, has fins, has gills, has no paws, has round eyes, has short paws, has teeth, has two ears, has two eyes, herds, is a carnivore, is an animal, is blue, is cold-blooded, is coloured, is difficult to catch, is eaten by other animals, is edible, is fast, is fished for, is found in Belgium, is found in warm places, is found on animals, is lithe, is not eaten, is not poisonous, is slimy, is slippery, is smooth, is sometimes eaten by man, is spectacular, likes humidity, lives by the sea, lives in Africa, lives in America, lives in Europe, lives in a damp climate, lives in cold areas, lives in distant countries, lives in nature, lives in the ocean, lives in the open air, lives in the sea, lives in the wild, lives in warm countries, lives in water, lives nearby the water, lives outdoors, makes not much noise, occurs frequently, prey, produces blub-sound, some people are allergic to it, stinks, the meat is eaten, there are many kinds of it, wild animal, you can boil it
Fish	≥ 2	Yes	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale	breaths under water, can be caught, can be fed, can swim, can't fly, does not migrate in the winter, doesn't have 1000 paws, doesn't live on land, doesn't sting, drinks water, eats small animals, has a head, has a mouth, has a tongue, has black eyes, has eyes, has fins, has gills, has no paws, has teeth, has two eyes, is an animal, is eaten by other animals, is edible, is not poisonous, is slimy, is slippery, is smooth, likes humidity, lives in a damp climate, lives in nature, lives in the open air, lives in the sea, lives in the wild, lives in warm countries, lives in water, lives outdoors, makes not much noise, prey, the meat is eaten

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Fish	≥ 3	Yes	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale	can swim, can't fly, doesn't have 1000 paws, doesn't live on land, doesn't sting, drinks water, has a head, has eyes, has gills, has no paws, has two eyes, is an animal, is not poisonous, is slippery, is smooth, lives in nature, lives in the wild, lives in water
Fish	≥ 4	Yes	anchovy, carp, cod, dolphin, eel, flatfish, goldfish, herring, orca, pike, piranha, plaice, ray, salmon, sardine, shark, sole, sperm whale, squid, stickleback, swordfish, trout, whale	can swim, can't fly, has a head, has eyes, has two eyes, is an animal, is slippery, is smooth, lives in nature, lives in water
Insect	≥ 1	Yes	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flee, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm	Indians or African, also lives in the city, appears in fairy tales and stories, builds nests, can be aggressive, can be bred, can be caught, can be found in the ardennes, can become pest, can do without water for long periods, communicates with its congeners, does not migrate in the winter, does not taste well, does not have 1000 paws, drinks water, exists for ages, exists in different sizes and kinds, fragile, has a head, has a mouth, has a small head, has a tongue, has black eyes, has eyes, has feelers, has little eyes, has round eyes, has short paws, has teeth, has two eyes, herds, is an animal, is an articulate animal, is an insect, is athrodopal, is coloured, is eaten by birds, is eaten by other animals, is edible, is exterminated, is food for larger animals, is found in Belgium, is found in the garden, is found in warm places, is found on animals, is inconspicuous, is killed by man, is light, is not a pet, is not eaten, is not expensive, is not poisonous, is not very big, is not very popular among man, is small (klein), is spectacular, lays eggs, lives by the sea, lives in Africa, lives in America, lives in Europe, lives in Australia, lives in distant countries, lives in fields, lives in nature, lives in the jungle, lives in the open air, lives in the wild, lives in the woods, lives in tropical areas, lives in warm countries, lives on land, lives outdoors, makes not much noise, neutral scent, occurs frequently, often sits in parks, prey, reproduces fast, small ears, smaller than a horse, some people are allergic to it, the meat is eaten, there are many kinds of it, you can boil it

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Insect	≥ 2	Yes	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flee, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm	can be caught, does not migrate in the winter, does not taste well, does not have 1000 paws, drinks water, has a head, has a mouth, has eyes, has feelers, has short paws, has two eyes, is an animal, is an insect, is eaten by other animals, is found in Belgium, is found in the garden, is light, is not a pet, is not eaten, is not poisonous, is not very big, is small (klein), lays eggs, lives in Africa, lives in America, lives in Europe, lives in nature, lives in the jungle, lives in the open air, lives in the wild, lives in warm countries, lives on land, lives outdoors, neutral scent, prey, smaller than a horse
Insect	≥ 3	Yes	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flee, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm	does not taste well, does not have 1000 paws, drinks water, has a head, is an animal, is an insect, is found in Belgium, is light, is not a pet, is not very big, is small (klein), lays eggs, lives in Europe, lives in nature, lives in the open air, lives in the wild, lives on land, lives outdoors, smaller than a horse
Insect	≥ 4	Yes	ant, bee, beetle, bumblebee, butterfly, caterpillar, centipede, cockchafer, cockroach, cricket, dragonfly, earwig, flee, fly, fruit fly, grasshopper, horsefly, ladybug, leech, louse, mosquito, moth, spider, wasp, wood louse, worm	is an animal, is found in Belgium, is light, is not very big, is small (klein), lives in Europe, lives in the open air, lives on land
Mammal	≥ 1	Yes	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra	can be aggressive, can be bred, can be caught, can be fed, can do without water for long periods, communicates with its congeners, does not lay eggs, does not migrate in the winter, does not smell well, does not have 1000 paws, does not sting, drinks water, exists for ages, exists in different sizes and kinds, fragile, gives milk, good sense of smell, has a fur (vacht), has a head, has a mouth, has a tail, has a tongue, has eyes, has four paws, has legs (poten), has many teeth, has round eyes, has teeth, has two ears, has two eyes, is a carnivore, is an animal, is coloured, is eaten by other animals, is edible, is found in Belgium, is found on animals, is not eaten, is not poisonous, is spectacular, lives in Africa, lives in distant countries, lives in the open air, lives on land, lives on the ground, lives outdoors, makes a sound, mammal, prey, some people are allergic to it, the meat is eaten, there are many kinds of it, thick skin, you can boil it

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Mammal	≥ 2	Yes	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra	can be fed, does not lay eggs, does not migrate in the winter, does not have 1000 paws, does not sting, drinks water, gives milk, has a head, has a mouth, has a tail, has a tongue, has eyes, has legs (poten), has round eyes, has teeth, has two ears, has two eyes, is an animal, is eaten by other animals, is not poisonous, lives in the open air, lives on land, lives outdoors, makes a sound, mammal
Mammal	≥ 3	Yes	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra	does not lay eggs, does not have 1000 paws, does not sting, drinks water, has a head, has a mouth, has a tongue, has eyes, has legs (poten), has teeth, has two ears, has two eyes, is an animal, is not poisonous, lives on land, mammal
Mammal	≥ 4	Yes	bat, beaver, bison, cat, cow, deer, dog, donkey, dromedary, elephant, fox, giraffe, hamster, hedgehog, hippopotamus, horse, kangaroo, lion, llama, monkey, mouse, pig, polar bear, rabbit, rhinoceros, sheep, squirrel, tiger, wolf, zebra	has a tongue, has eyes, has two ears, has two eyes, is an animal, is not poisonous, mammal
Reptile	≥ 1	Yes	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper	Indians or African, bites, builds nests, can be aggressive, can be bred, can be caught, can be fed, can do without water for long periods, can live for a long time without food, can swim, cannot fly, communicates with its congeners, dark colour, does not migrate in the winter, does not taste well, does not have 1000 paws, does not herd, does not sting, drinks water, eats insects, eats plants, eats small animals, eats worms, exists for ages, exists in different sizes and kinds, fragile, has a head, has a mouth, has a tail, has a tongue, has black eyes, has eyes, has round eyes, has scales, has short paws, has teeth, has two eyes, is a carnivore, is a reptile, is an animal, is cold-blooded, is coloured, is eaten by other animals, is found in warm places, is found mainly in southern countries, is found on animals, is green-brown, is not a pet, is not eaten, is spectacular, is ugly, lays eggs, lives in Africa, lives in America, lives in distant countries, lives in grass, lives in nature, lives in the jungle, lives in the open air, lives in the wild, lives in the zoo, lives in tropical areas, lives in warm countries, lives nearby the water, lives on land, lives on the ground, lives outdoors, makes not much noise, neutral scent, occurs frequently, prey, sheds its skin, shy, smaller than a horse, there are many kinds of it, wild animal, you can boil it

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Reptile	≥ 2	Yes	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper	can be aggressive, can be caught, can be fed, cannot fly, does not migrate in the winter, does not taste well, does not have 1000 paws, does not sting, drinks water, eats insects, eats small animals, has a head, has a mouth, has a tongue, has eyes, has round eyes, has two eyes, is a reptile, is an animal, is cold-blooded, is found mainly in southern countries, is not a pet, lays eggs, lives in Africa, lives in nature, lives in the open air, lives in the wild, lives in warm countries, lives outdoors, neutral scent, prey, smaller than a horse
Reptile	≥ 3	Yes	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper	cannot fly, does not taste well, does not have 1000 paws, does not sting, drinks water, has a head, has a tongue, has eyes, has two eyes, is an animal, lays eggs, lives in nature, lives in the open air, lives in the wild, lives in warm countries, lives outdoors
Reptile	≥ 4	No	alligator, blindworm, boa, caiman, chameleon, cobra, crocodile, dinosaur, frog, gecko, iguana, lizard, monitor lizard, python, salamander, snake, toad, tortoise, turtle, viper, <i>hippopotamus</i> , <i>beaver</i> , <i>deer</i> , <i>lion</i> , <i>mouse</i> , <i>kangaroo</i> , <i>polar bear</i> , <i>wolf</i> , <i>elephant</i> , <i>squirrel</i> , <i>tiger</i> , <i>rhinoceros</i> , <i>giraffe</i> , <i>fox</i> , <i>hedgehog</i> , <i>zebra</i>	cannot fly, has a head, has a tongue, has eyes, has two eyes, is an animal, lives in nature, lives in the open air

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Clothing	≥ 1	Yes	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit	both large and small, bought in a store, can be carried, can be coloured, can be decorated, can be held, can be printed with a design, can be seen on television, can be used several times, can become dirty, can break (stuk gaan), can sink, comes in different brands and models, comes in different patterns, comes in different prints, comes in very handy, constitutes a whole, costs money, does not produce sound, does not weigh much, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different forms, exists in different kinds, exists in different materials, exists in different measurements, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, has a dark color, has a plain color, has different patterns (motiefjes), has no engine, has no roof, has no smell, has no taste, has the name of a company printed on it, implement/tool, is a garment, is an object, is available for each price range, is beautiful, is black, is brown, is clothing, is colourful, is for 1 person, is functional, is handy to transport, is invented by man, is lifeless, is light, is made in a factory, is not edible, is not waterproof, is odourless, is pliable, is smaller than a lorry, is used to cover yourself, lies in the cupboard, made of fibres, made of synthetic material, not everyone has it, occurs in comic books, occurs in films, sold in clothes shops, the size is indicated by numbers, used in different cultures, was used in the past, water permeable, worn by people, you do not have to peddle, you have to pay for it

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Clothing	≥ 2	Yes	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit	bought in a store, can be carried, can be coloured, can be held, can be seen on television, can be used several times, can become dirty, can break (stuk gaan), can sink, comes in different brands and models, comes in different patterns, comes in different prints, costs money, does not produce sound, does not weigh much, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, has no engine, has no roof, has no smell, is a garment, is an object, is available for each price range, is clothing, is for 1 person, is invented by man, is lifeless, is made in a factory, is not edible, is odourless, is smaller than a lorry, not everyone has it, the size is indicated by numbers, worn by people, you have to pay for it
Clothing	≥ 3	Yes	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit	bought in a store, can be coloured, can be held, can become dirty, can break (stuk gaan), comes in different brands and models, costs money, does not produce sound, does not weigh much, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different kinds, exists in different types, is a garment, is an object, is clothing, is for 1 person, is invented by man, is lifeless, is made in a factory, is not edible, worn by people
Clothing	≥ 4	Yes	bathing suit, beanie, belt, blouse, boots, bra, cap, coat, dress, dungarees, hat, jeans, mittens, panties, pants, pullover, pyjamas, scarf, shirt, shoes, shorts, skirt, socks, suit, sweater, t-shirt, tie, top, tracksuit	can become dirty, comes in different brands and models, does not produce sound, exists in different brands, exists in different colors, exists in different types, is a garment

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Kitchen utensil	≥ 1	Yes	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok	both large and small, bought in a store, can be dishwashed, can be made of different materials, can be made of different tissues, can be seen on television, can be used by anyone, can be used several times, can become dirty, can break (stuk gaan), can sink, comes in different brands and models, comes in very handy, constitutes a whole, costs money, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different types, has a plain color, has no engine, has no roof, has no smell, has no taste, implement/tool, is an object, is available for each price range, is easy, is easy to work with, is for at least 1 person, is functional, is invented by man, is lifeless, is made in a factory, is not edible, is not sexy, is odourless, is smaller than a lorry, is stainless, is useful, needs to be cleaned sometimes, not everyone has it, occurs in comic books, occurs in films, used by cooks, used by everybody, used by men, used by mothers, used in a restaurant, used in different cultures, used in the house, used in the kitchen, used with your hands, was used in the past, you don't have to peddle, you have to pay for it
Kitchen utensil	≥ 2	Yes	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok	bought in a store, can be used several times, can become dirty, can break (stuk gaan), can sink, comes in different brands and models, comes in very handy, costs money, exists in different brands, exists in different forms, exists in different kinds, exists in different types, has no roof, has no smell, has no taste, implement/tool, is an object, is easy to work with, is functional, is invented by man, is lifeless, is made in a factory, is not edible, is not sexy, is odourless, is smaller than a lorry, is useful, not everyone has it, used in different cultures, used in the house, used in the kitchen
Kitchen utensil	≥ 3	Yes	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok	bought in a store, can be used several times, can become dirty, comes in different brands and models, costs money, exists in different brands, exists in different forms, is an object, is invented by man, is made in a factory, is not edible, is not sexy, is useful, used in the house, used in the kitchen

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Kitchen utensil	≥ 4	No	apron, bottle, bowl, can opener, colander, electric kettle, fork, fridge, glass, grater, kettle, knife, microwave oven, mixer, mug, nutcracker, oven, pan, percolator, place mat, plate, pot, scales, scissors, sieve, spatula, spoon, stove, teaspoon, toaster, towel, whisk, wok, <i>harmonica, cymbals, file, knuckle dusters, rope, crowbar (koevoet), bagpipe, clamp, grinding disc, clarinet, oil can, bathing suit, nail, tongs, lawn mower, hammer, piano, adjustable spanner, flute, wire brush, vacuum cleaner, chisel, double bass, bass guitar, level, tambourine, trumpet, saxophone, accordion, dagger, harpsichord, synthesizer, paint brush, banjo, bassoon, wheelbarrow, shovel, drill, harp, triangle, trombone, club, recorder, cello, pan flute, guitar, wrench, axe, drum, tie, saw, pickaxe, violin, plane, screwdriver, filling knife, drum set, anvil, crowbar (brekijzer), bow, whip</i>	bought in a store, is an object
Musical instrument	≥ 1	Yes	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin	accompanies (other) music, both large and small, bought in a store, can be decorated, can be dishwashed, can be made of different materials, can be played on, can be played upon, can be seen on television, can be used by anyone, can be used several times, can become dirty, can break (stuk gaan), can sink, comes in different brands and models, constitutes a whole, costs money, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different forms, exists in different kinds, exists in different sizes (groottes), exists in different types, for sale in a music shop, has a plain color, has no engine, has no roof, has no smell, has no taste, has the name of a company printed on it, implement/tool, is a musical instrument, is a piece of equipment, is an object, is available for each price range, is firm, is for 1 person, is for all ages, is for few persons, is for fun, is fun, is functional, is hard, is hard to iron, is invented by man, is lifeless, is made in a factory, is not edible, is not sexy, is odourless, is played during concerts, is relaxing, is smaller than a lorry, its vibrations produce sounds, makes a nice sound/noise, makes a special noise, needs to be cleaned sometimes, not everyone has it, occurs in comic books, occurs in films, one has to learn how to play, played by a musician, played by a single person, played with the hands, played with two hands, produces music, produces noise, produces sound, smells neutral, used in different cultures, used solo, used with your hands, using it is fun, vibrates, was used in the past, you can learn it in a school of music, you can play with it, you don't have to peddle, you have to pay for it, you have to read music-scores

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Musical instrument	≥ 2	Yes	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin	bought in a store, can be played on, can be played upon, can be seen on television, can be used several times, can become dirty, can break (stuk gaan), comes in different brands and models, costs money, exists in different brands, exists in different colors, exists in different kinds, for sale in a music shop, has no engine, has no smell, is a musical instrument, is an object, is available for each price range, is for 1 person, is for all ages, is for fun, is invented by man, is lifeless, is not edible, is not sexy, is played during concerts, is smaller than a lorry, its vibrations produce sounds, makes a nice sound/noise, makes a special noise, not everyone has it, one has to learn how to play, played by a musician, played by a single person, produces music, produces noise, produces sound, used with your hands, vibrates, you can play with it, you have to pay for it
Musical instrument	≥ 3	Yes	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin	bought in a store, can be played on, can be played upon, can become dirty, can break (stuk gaan), comes in different brands and models, costs money, exists in different brands, for sale in a music shop, has no engine, is a musical instrument, is an object, is invented by man, is lifeless, is not edible, is played during concerts, makes a nice sound/noise, not everyone has it, one has to learn how to play, played by a musician, played by a single person, produces music, produces noise, produces sound
Musical instrument	≥ 4	Yes	accordion, bagpipe, banjo, bass guitar, bassoon, cello, clarinet, cymbals, double bass, drum, drum set, flute, guitar, harmonica, harp, harpsichord, organ, pan flute, piano, recorder, saxophone, synthesizer, tambourine, triangle, trombone, trumpet, violin	can be played on, costs money, exists in different brands, is an object, played by a musician, produces sound
Tool	≥ 1	Yes	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench	both large and small, bought in a store, can be dishwashed, can be seen on television, can be used several times, can become dirty, can break (stuk gaan), can sink, comes in different brands and models, comes in very handy, constitutes a whole, costs money, especially used by boys, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different forms, exists in different kinds, exists in different measurements, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, has a plain color, has no roof, has no smell, has no taste, implement/tool, is a handtool, is a piece of equipment, is a tool, is an object, is available for each price range, is durable, is easy to work with, is efficient, is for 1 person, is for at least 1 person, is for few persons, is for sturdy guys, is found in a workplace, is functional, is hard to iron, is invented by man, is lifeless, is made in a factory, is not edible, is not for children, is not sexy, is odourless, is smaller than a lorry, is useful, needs to be cleaned sometimes, not everyone has it, occurs in comic books, occurs in films, smells neutral, used by men, used by the handyman, used by work forces, used in different cultures, used to work with, used with your hands, was used in the past, you don't have to peddle

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Tool	≥ 2	Yes	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench	bought in a store, can be seen on television, can be used several times, can become dirty, can break (stuk gaan), comes in different brands and models, comes in very handy, constitutes a whole, costs money, exists in different brands, exists in different colors, exists in different sizes (groottes), has no roof, has no smell, has no taste, implement/tool, is a piece of equipment, is an object, is functional, is invented by man, is lifeless, is made in a factory, is not edible, is not sexy, is odourless, is smaller than a lorry, is useful, not everyone has it, used by work forces, used to work with
Tool	≥ 3	No	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench, <i>stove, sieve, kettle, colander, can opener, fork, scissors, wok, pan, mixer, glass, nutcracker, fridge, spatula, grater, teaspoon, pot, whisk, spoon</i>	bought in a store, can be used several times, can become dirty, costs money, implement/tool, is an object, is made in a factory, is not edible, is not sexy, is useful
Tool	≥ 4	No	adjustable spanner, anvil, axe, chisel, clamp, crowbar (breekijzer), crowbar (koevoet), drill, file, filling knife, grinding disc, hammer, knife, lawn mower, level, nail, oil can, paint brush, pickaxe, plane, plough, rope, saw, screwdriver, shovel, tongs, vacuum cleaner, wheelbarrow, wire brush, wrench, <i>stove, microwave oven, kettle, bottle, colander, canon, fork, shield, bowl, plate, wok, nutcracker, fridge, towel, teaspoon, mug, spoon, percolator, sieve, can opener, grenade, scissors, bazooka, scales, pan, pistol, mixer, bow, electric kettle, oven, apron, toaster, double-barreled shotgun, place mat, rifle, machine gun, tie, spatula, grater, knuckle dusters, pot, whisk</i>	is an object, is made in a factory

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Vehicle	≥ 1	Yes	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin	both large and small, bought in a store, can be coloured, can be made of different materials, can be made of different tissues, can be seen on television, can be used several times, can become dirty, can break (breken), can break (stuk gaan), can crash, can sink, comes in different brands and models, consists of different parts, constitutes a whole, costs money, does not melt in high temperature, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different forms, exists in different kinds, exists in different lengths, exists in different materials, exists in different measurements, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, has a plain color, has no smell, has no taste, has the name of a company printed on it, implement/tool, is a means of transport, is a means of transportation, is a vehicle, is an object, is available for each price range, is durable, is firm, is for at least 1 person, is functional, is grey, is handy to transport, is hard, is hard to iron, is invented by man, is lifeless, is made in a factory, is manned, is not edible, is not sexy, is odourless, is strong, is to be used outside, it has screws in it, its vibrations produce sounds, needs to be cleaned sometimes, not everyone has it, occurs in comic books, occurs in films, smells neutral, transports persons or goods, used in different cultures, vibrates, was used in the past, you have to pay for it
Vehicle	≥ 2	No	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin, <i>pistol</i>	can be coloured, can be made of different materials, can be seen on television, can be used several times, can become dirty, can break (stuk gaan), comes in different brands and models, costs money, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different forms, exists in different kinds, exists in different materials, exists in different sizes (groottes), exists in different types, implement/tool, is an object, is invented by man, is lifeless, is made in a factory, is not edible, is not sexy, is to be used outside, it has screws in it, needs to be cleaned sometimes, not everyone has it

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Vehicle	≥ 3	No	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin, stove, <i>microwave oven, colander, top, shield, bathing suit, lawn mower, blouse, sweater, skirt, dungarees, nutcracker, sword, cap, fridge, bra, percolator, sieve, drill, belt, can opener, spear, dress, scales, pistol, mixer, electric kettle, slingshot, hat, toaster, rifle, shirt, suit, tracksuit, boots, spatula, whisk</i>	can be made of different materials, can be used several times, can become dirty, can break (stuk gaan), costs money, exists in different colors, exists in different forms, exists in different kinds, exists in different types, is an object, is invented by man, is made in a factory, is not edible, not everyone has it
Vehicle	≥ 4	No	(hot air) balloon, airplane, bicycle, boat, bus, car, carriage, cart, go-cart, helicopter, hovercraft, jeep, kick scooter, motorbike (brommer), motorbike (moto), rocket, scooter, skateboard, sled, submarine, subway train, taxi, tractor, trailer, train, tram, truck (camion), truck (vrachtwagen), van, zeppelin, stove, <i>grinding disc, plate, fridge, lawn mower, toaster, glass, paint brush</i>	can become dirty, can break (stuk gaan)
Weapon	≥ 1	No	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip, <i>wheelbarrow, shovel, chisel, plough, saw, plane, screwdriver, tongs, hammer</i>	both large and small, can be dishwashed, can be made of different materials, can be seen on television, can be used several times, can become dirty, can break (breken), can break (stuk gaan), can sink, comes in different brands and models, constitutes a whole, costs money, exists in different brands, exists in different colors, exists in different colors and different forms, exists in different forms, exists in different kinds, exists in different measurements, exists in different sizes (groottes), exists in different sizes (maten), exists in different types, has a dark color, has a plain color, has no engine, has no roof, has no smell, has no taste, implement/tool, is a piece of equipment, is an object, is available for each price range, is dangerous for children, is durable, is efficient, is firm, is for at least 1 person, is for few persons, is for sturdy guys, is functional, is hard to iron, is invented by man, is lifeless, is made in a factory, is not edible, is not for children, is not sexy, is odourless, is smaller than a lorry, is strong, is useful, needs to be cleaned sometimes, not everyone has it, occurs in comic books, occurs in films, smells neutral, used by men, used by strong men, used in different cultures, was used in the past, you don't have to peddle

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Weapon	≥ 2	No	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip, <i>file</i> , <i>wheelbarrow</i> , <i>crowbar</i> (<i>koevoet</i>), <i>shovel</i> , <i>drill</i> , <i>clamp</i> , <i>grinding disc</i> , <i>knife</i> , <i>oil can</i> , <i>nail</i> , <i>tongs</i> , <i>adjustable spanner</i> , <i>wire brush</i> , <i>chisel</i> , <i>wrench</i> , <i>level</i> , <i>saw</i> , <i>pickaxe</i> , <i>plane</i> , <i>screwdriver</i> , <i>crowbar</i> (<i>breekijzer</i>), <i>anvil</i> , <i>hammer</i> , <i>paint brush</i>	can be seen on television, can be used several times, can become dirty, can break (<i>stuk gaan</i>), constitutes a whole, costs money, exists in different brands, exists in different sizes (<i>groottes</i>), has a plain color, has no smell, has no taste, implement/tool, is an object, is functional, is lifeless, is made in a factory, is not edible, is not sexy, is odourless, is smaller than a lorry, not everyone has it, smells neutral, used by men
Weapon	≥ 3	No	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip, <i>harmonica</i> , <i>cymbals</i> , <i>stove</i> , <i>file</i> , <i>tram</i> , <i>microwave oven</i> , <i>colander</i> , <i>bagpipe</i> , <i>bottle</i> , <i>top</i> , <i>pullover</i> , <i>shorts</i> , <i>clamp</i> , <i>tie</i> , <i>grinding disc</i> , <i>helicopter</i> , <i>clarinet</i> , <i>bowl</i> , <i>knife</i> , <i>plate</i> , <i>oil can</i> , <i>bathing suit</i> , <i>motorbike</i> (<i>brommer</i>), <i>scooter</i> , <i>nail</i> , <i>tongs</i> , <i>lawn mower</i> , <i>hammer</i> , <i>piano</i> , <i>blouse</i> , <i>sweater</i> , <i>carriage</i> , <i>flute</i> , <i>car</i> , <i>glass</i> , <i>skirt</i> , <i>go-cart</i> , <i>dungarees</i> , <i>bus</i> , <i>nutcracker</i> , <i>vacuum cleaner</i> , <i>chisel</i> , <i>cap</i> , <i>skateboard</i> , <i>socks</i> , <i>double bass</i> , <i>bass guitar</i> , <i>level</i> , <i>hovercraft</i> , <i>trumpet</i> , <i>tambourine</i> , <i>saxophone</i> , <i>fridge</i> , <i>train</i> , <i>accordion</i> , <i>truck</i> (<i>camion</i>), <i>rocket</i> , <i>bra</i> , <i>van</i> , <i>harpsichord</i> , <i>mug</i> , <i>synthesizer</i> , <i>paint brush</i> , <i>banjo</i> , <i>shoes</i> , <i>bassoon</i> , <i>percolator</i> , <i>jeep</i> , <i>jeans</i> , <i>sieve</i> , <i>submarine</i> , <i>wheelbarrow</i> , <i>shovel</i> , <i>drill</i> , <i>belt</i> , <i>can opener</i> , <i>harp</i> , <i>tractor</i> , <i>airplane</i> , <i>plough</i> , <i>dress</i> , <i>scissors</i> , <i>triangle</i> , <i>beanie</i> , <i>scales</i> , <i>pan</i> , <i>trombone</i> , <i>mittens</i> , <i>electric kettle</i> , <i>mixer</i> , <i>hat</i> , <i>oven</i> , <i>boat</i> , <i>recorder</i> , <i>toaster</i> , <i>cello</i> , <i>organ</i> , <i>kick scooter</i> , <i>truck</i> (<i>vrachtwagen</i>), <i>t-shirt</i> , <i>pyjamas</i> , <i>taxi</i> , <i>zeppelin</i> , <i>pan flute</i> , <i>guitar</i> , (<i>hot air</i>) <i>balloon</i> , <i>shirt</i> , <i>motorbike</i> (<i>moto</i>), <i>tracksuit</i> , <i>panties</i> , <i>bicycle</i> , <i>cart</i> , <i>drum</i> , <i>pickaxe</i> , <i>boots</i> , <i>suit</i> , <i>saw</i> , <i>plane</i> , <i>coat</i> , <i>sled</i> , <i>subway train</i> , <i>violin</i> , <i>screwdriver</i> , <i>pants</i> , <i>filling knife</i> , <i>spatula</i> , <i>trailer</i> , <i>drum set</i> , <i>pot</i> , <i>scarf</i> , <i>whisk</i>	can become dirty, can break (<i>stuk gaan</i>), is an object, is not edible

(continued)

Table A3. Continued.

Category	Threshold	Is formal concept?	Extent	Intent
Weapon	≥ 4	No	axe, bazooka, bow, canon, club, dagger, double-barreled shotgun, grenade, knuckle dusters, machine gun, pistol, rifle, rope, shield, slingshot, spear, stick, sword, tank, whip, <i>cymbals, stove, shorts, fork, clamp, grinding disc, helicopter, dungarees, nutcracker, chisel, fridge, train, accordion, truck (camion), spoon, jeep, sieve, submarine, plough, scales, pan, electric kettle, organ, place mat, wrench, panties, screwdriver, spatula, grater, anvil, scarf, harmonica, file, crowbar (koevoet), tram, microwave oven, bottle, top, pullover, plate, bathing suit, scooter, nail, tongs, lawn mower, piano, adjustable spanner, flute, go-cart, skateboard, double bass, level, tambourine, towel, bassoon, shovel, belt, dress, beanie, trombone, oven, toaster, cello, kick scooter, truck (vrachtwagen), pyjamas, taxi, guitar, shirt, motorbike (moto), cart, drum, boots, coat, sled, violin, trailer, drum set, whisk, colander, bagpipe, bowl, knife, wok, motorbike (brommer), car, glass, vacuum cleaner, socks, trumpet, harpsichord, synthesizer, shoes, wheelbarrow, jeans, drill, can opener, harp, tractor, airplane, scissors, triangle, boat, t-shirt, tracksuit, bicycle, pickaxe, plane, filling knife, crowbar (breekijzer), pot, kettle, clarinet, oil can, blouse, sweater, carriage, wire brush, skirt, bus, cap, bass guitar, hovercraft, saxophone, rocket, bra, teaspoon, van, mug, paint brush, banjo, percolator, mittens, mixer, hat, apron, recorder, zeppelin, pan flute, (hot air) balloon, suit, tie, saw, subway train, pants, hammer</i>	