Elementary pre-service teachers' conscious lack of knowledge about technical artefacts

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Abstract

This study aims at characterizing elementary pre-service teachers' conscious lack of knowledge about familiar technical artefacts and its relation to their knowledge about these artefacts. The participants were asked to state what they knew and also what they did not know about a sample of familiar technical artefacts such as a fan or a lock. The results showed a difference between the structure of the student teachers' lack of knowledge of these artefacts and the structure of their actual knowledge. These differences were analyzed in relation to Kroes' (Camb J Econ 34:51–62, 2010. <https://doi.org/10.1093/cje/bep019>) model of technical artefacts. Firstly, the student teachers' conscious lack of knowledge was mainly focused on the artefacts' behavior rather than on their components and materials. Secondly, the participants found the function features of the artefacts unproblematic. Thirdly, unknown features about the origin of the artefacts were more frequently cited than the corresponding knowledge features. Finally, non-perceptual properties of the artefacts and the causal relations in which they or their parts are involved were important components both of the students' knowledge and of the students' unknowns.

Keywords Technical artefacts · Student teachers' conceptions · Conscious unknowns

Introduction

Knowledge of technical artefacts and the capacity to properly interact with them is an important part of technology education: artefacts are extensions of humans' bodies and minds mediating between persons and the environment (Frederik et al., 2011; Impedovo et al., 2017). Moreover, technical artefacts are a natural component of technology education as they are a salient component of students' conceptions of technology (Bame et al.,

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1993; DiGironimo, 2011). Home appliances and other familiar devices found in everyday activities correspond to a basic category, “common everyday technology” used by students to conceptualize complex technical artefacts (Rücker & Pinkwart, 2018). The present study aims at characterizing elementary pre-service teachers’ conscious lack of knowledge about familiar technical artefacts and its relation to their knowledge about these artefacts. The analysis was done in the context of an undergraduate program where students were being trained to become teachers in the different areas of the primary school curriculum, including basic science and technology.

The teachers’ knowledge significantly influences their instruction and the academic achievement of students (Metzler & Woessmann, 2012; Rollnick et al., 2008). Consequently, the importance of teachers and student teachers’ technological knowledge has been recognized in several studies (Fox-Turnbull, 2006; Jones et al., 2019; Rohaan et al., 2012; Yaşar et al., 2006). In contrast, lower consideration has been given to the importance of teachers and student teachers’ awareness of lack of technological knowledge except perhaps for its undesirable consequences. For instance, Banks (1996) noted that teachers’ limited technological knowledge may result in avoiding relevant but difficult content and limiting students’ inquiry and questioning.

However, the acknowledgment of one’s own lack of knowledge and understanding has positive consequences. It is a first and fundamental step in inquiry and problem-based learning in science and in technology (Brears et al., 2011; Chin & Chia, 2004; Connor et al., 2015; Lewis, 2006; Williams et al., 2008). Phillips et al., (2017, 2018) draw attention to “identifying, articulating, and motivating problems” (p.3), which they call “problematizing”, as being of central importance in the practice of science and in science education. Similar concerns about the importance of teaching and learning about problem definition has been shown in engineering and design education as well (Atman et al., 2008; Cross, 2001; Watkins et al., 2014). Therefore, ascertaining the conscious lack of knowledge that pre-service teachers have about technical artefacts could contribute to a more adequate foundation of inquiry and self-regulated approaches to technology education (Barak, 2010), attuning the technology curriculum to student and teachers’ relatively spontaneous unknowns.

Awareness of lack of knowledge

Researchers in education have generally paid limited attention to conscious lack of knowledge compared to conscious lack of understanding, perhaps due to the fact that knowledge is traditionally placed at the bottom of the pyramid of educational objectives (Krathwohl, 2002). Within psychological research, there have been a number of studies on what individuals know that they do not know and on the variables that influence this awareness (Brown et al., 1977; Coane & Umanath, 2019; Ghetti, 2003, 2008; Glucksberg & McCloskey, 1981; Klin et al., 1997; Liu et al., 2007; Luo et al., 2003). Also, studies in the area of metacognition have examined the correspondence between individuals’ judgments about their own knowledge or lack thereof, and objective assessments of this knowledge—the so-called knowledge monitoring accuracy (Hartwig et al., 2012; Smith & Was, 2019; Tobias & Everson, 2009).

Lack of knowledge has also been considered in the numerous studies on questioning. Question generation, the first step in the process of question asking, involves the detection of anomalies such as knowledge gaps or comprehension barriers (Graesser & McMahan,

1993). A substantial number of studies have examined student questioning, including questions in science education (Chin & Osborne, 2008). Some of these studies consider the relation between the questions asked and the anomalies that cause this questioning, including lack of knowledge about the questioned topic. For instance, some question taxonomies are based on the type of information sought and include categories for questions caused by lack of knowledge. Examples of these are “Information” questions in the taxonomy of Good et al. (1987), or “Feature Specification” and “Definition” questions in the taxonomy of Graesser et al. (1992). However, to the best of our knowledge, no questioning studies based on these taxonomies have attempted a precise characterization of the lack of knowledge triggering questions about an object such as a technical artefact or a technical system.

Some research in the area of technology education has dealt with the awareness of lack of knowledge from different viewpoints. Christensen et al. (2019) remarked upon the importance of middle-school students' awareness of their limitations to deal with the “wicked nature” of real-world design problems. Many students erroneously perceive these difficult problems as simple and well-defined. The researchers argue for a stance towards inquiry, including awareness of unknowns and difficulties, as essential to students' design literacy. Other studies approach lack of knowledge with a more general focus, looking at teachers' opinions about their own technological knowledge or lack thereof. In the survey conducted by Yaşar et al. (2006), K-12 teachers acknowledged being unfamiliar with design, engineering and technology, and felt unsure of their abilities to appropriately teach about these areas. Nordlöf et al. (2019) examined teachers' perceptions of teaching technology and the attitudes towards this teaching. Some teachers were aware that lack of subject knowledge was a source leading to low self-efficacy.

Regarding technical systems in particular, lack of knowledge was indirectly examined in a study of Mioduser et al. (1996) about 6th grade students' perceptions of opening-closing systems. The students had to analyze this kind of systems and then they had to design and build a working model of an automatic door. The analysis of students' reports showed deficiencies in structural and functional knowledge, for instance about the operation of some components. Although most of the students ended up knowing the system's components and structure, at the design stage only 15% were able to recognize its specific control features, i.e. the “how and why” of its behavior. Also, Hallström and Klasander (2017) conducted a survey study on student teachers' conceptions of technological systems such as mobile phones or electricity grids. A main conclusion about the students' lack of knowledge was that they “knew rather well what components, devices, and systems *do*, but to a much lesser degree how they work and why” (p. 401).

In this study we directly analyze the content of student teachers' conscious lack of knowledge about technical artefacts challenging a seemingly obvious premise: that a void could only be found when analyzing an absence of knowledge. Instead, a basic assumption of this study is the constructed nature of conscious lack of knowledge. The assumption builds on the extensive work done on the related notion of “ignorance” in sociology, history of science and other disciplines (for basic perspectives, see Bammer & Smithson, 2008; Gross & McGoey, 2015; Proctor & Schiebinger, 2008). We base our approach on Smithson's (1989; Bammer et al., 2008) fundamental distinction between “conscious ignorance”, unknowns one is aware of, and “meta-ignorance”, the term coined by Smithson (1989) to refer to unknown unknowns. According to this view, conscious lack of knowledge of an object such as a technical artefact results from a discovery process that turns sections of the essentially infinite reservoir of unknown unknowns into known unknowns. This is a relatively little known process described within sociology of science by Merton (1987) as consisting in the transition from a general, vague lack of knowledge to “specified

ignorance”, i.e., defined portions of the unknown that are amenable to scientific research. The aim of the study is limited to the analysis of students’ conscious lack of knowledge, as an end product of this process. This was done in a situation where pre-service teachers were asked to explicitly state their unknowns, as well as their knowledge, about a sample of familiar technical artefacts.

Direct precedents of our approach regarding the content of what is not known are the studies on the lack of knowledge of artefacts and natural objects by Greif et al. (2006), Kemler-Nelson et al. (2004), and Vaz-Rebelo et al. (2016). The aim of these first two studies was to determine the type of information sought by preschool children when they ask “What is...?” questions about unfamiliar artefacts and animals. Among other results, the experiments showed that function was a central component of the young children’s lack of knowledge about the artefacts. Vaz-Rebelo et al. (2016) also directly examined the conscious lack of knowledge that 7th grade and 12th grade students had about a sample of natural objects and artefacts. The study showed that the proportion of unknown intrinsic features of natural objects (i.e., features of an entity considered in isolation) was greater than the proportion of these unknown features concerning artefacts, but the opposite held true about the proportion of unknown function features.

A framework to characterize what is unknown about a technical artefact

One key issue in the attempt at characterizing the structure of what is not known about an artefact, or in fact about any entity, concerns the categorization of the unknowns made explicit at the request of experimenters. In this study, this categorization is made at two levels of analysis. At the more concrete level, it is based on the featural view of semantic memory found in a substantial part of the extensive work done on conceptual representations. Both the declared unknowns, as well as the pre-service teachers’ knowledge about the technical artefacts, were decomposed into smaller elements, or features, following the componential approach to the study of concept structure (Moss et al., 2007). A feature generation task such as those used to examine conceptual content (Cree & McRae, 2003; Garrard et al., 2001) was used to elicit these elements. In this type of study, participants are provided with a term such as “sofa” and they have to verbally express what they know about the corresponding concept. For instance, McRae and Cree (2002) used this approach to categorize features of 594 living and non-living entities, the latter including things such as bookcase, hammer or bottle. The features were classified according to a hierarchical coding scheme developed by Wu and Barsalou (2009) consisting of four main categories: (a) properties of the entity, (b) properties of the situation in which the entity normally appears, (c) introspections, including contingency relations, and (d) taxonomic categories such as superordinate or coordinate. Entity properties of the non-living things were the most frequently cited followed by situation properties, taxonomic categories, and introspection features. Besides, in a study on artefacts using Wu and Barsalou’s (2009) taxonomy, Djalal et al. (2017) found that entity properties were the most frequently generated by adults, followed by situation, taxonomic, and introspection features as in McRae and Cree’s (2002) study.

In an extension of this approach, the participants in the present study were asked to explicitly state not only what they knew but also what they did not know about technical artefacts such as a lock or a refrigerator. This had to be done with the specific

purpose of helping in the selection of appropriate content for a planned textbook. Both the known and unknown features were initially categorized using a detailed coding scheme that Bolognesi et al. (2017) developed based on the Wu and Barsalou's (2009) taxonomy described above. It consists of the same four main categories corresponding to features of the Entity (termed "Concept" in the Bolognesi et al.'s [2017] scheme), Situation, Introspection, and Taxonomic types. These are subdivided into a number of more concrete categories such as "Perceptual properties", "Function" or "Contingency", further described in the Method section.

At a more general level, various conceptualizations exist regarding students' knowledge about technical artefacts that could be adapted in order to describe also their unknown features (Rücker & Pinkwart, 2018; Svensson & Ingerman, 2010; Svensson et al., 2017). In this study, both the artefacts' unknown features and knowledge features were interpreted in terms of the model put forth by Kroes (2010), based on the way engineers conceive artefacts. It is based on the intrinsic dual nature of artefacts as physical structures, but also as intentional objects designed to fulfill a function (Kroes, 2002, 2010). Three components are included in the model: the physical structure of the artefact, its function, and the context of human action. Technical artefacts, such as a refrigerator, have physical constituents such as components (a compressor), materials and substances (refrigerant), and physical processes operating on these components and materials (evaporation). Secondly, these physical constituents are organized into a certain structure in order to perform a function—in this case cooling food or other products. In the third place, two types of contexts of human action are distinguished in the model. The context of design refers to the activity of the designer, an inventor or manufacturer who sets up the physical structure in order to perform the desired function. The context of use corresponds to the activity of the users who achieve some end with the help of the artefact—the interaction of people with refrigerators.

According to this, the aim of this study, stated in more precise terms, is to know both how the unknown features and also the known features of a sample of familiar technical artefacts are arranged in the Bolognesi et al.'s (2017) categories and, ultimately, how this arrangement can be interpreted in terms of the three basic components of the Kroes' (2010) scheme.

Method

Participants

Twenty-nine pre-service teacher education students (20–22 years old) in the 2nd or 3rd years of an undergraduate program in Primary School Teaching from a Spanish university participated in the experiment. There were 22 women and 7 men, representing the gender distribution in this university program. The students did not have a specific background in science since about 85% of them came from a secondary school curriculum focused on social sciences and humanities, rather than science and technology. In their second academic year, they had taken a compulsory, 90-h course in general science and technology, including basic physics, chemistry, biology, Earth sciences and technology. They did not have any other specific training in science, technology, or engineering.

Materials

Two mechanical artefacts, lock and faucet, and two electric artefacts, fan and refrigerator, used in everyday activities were chosen as target artefacts. Household familiar technical artefacts were selected in order to avoid basic questions such as “I do not know anything”, or “What is it for?”.

Four-page booklets that included a short introduction to explain the aim of the study at the top of the first page were prepared:

A group of science professors, in partnership with instructors of technology, intends to write a textbook about common artefacts, such as locks or refrigerators. In order to include appropriate content, we ask for your help to find out what you KNOW about four common artefacts.
Thank you very much for your help!

Then, there were instructions to write about each artefact: “In order to help us to prepare the textbook, please state three important things you know about [artefact]”. The instructions were followed by a blank space of approximately half a page for each of the four artefacts that were arranged in counterbalanced order in the two first pages of the booklet.

The next two pages had a similar layout and were intended to find out students’ lack of knowledge, instructing them to state what they did not know about the artefacts: “... we ask for your help to find out what you DO NOT KNOW about the four artefacts cited above” and “...please state three important things that you do not know about [artefact]”.

In order to avoid fatigue, only three known ideas and only three unknowns were requested. However, many students provided less than three responses regarding knowledge or regarding unknowns. Also, as explained in the measurements section below, there could be more than one feature conveyed in a student’s response. This resulted in a variable number of features generated by each participant.

Procedure

The experiment was done in a regular 60 min class. The professor of the class introduced one of the researchers who explained the aim of the study and asked the student teachers for their assistance. They were informed that their participation in the study would not have any personal academic consequence. Anonymity was guaranteed at every step of the investigation. Although all the students agreed to participate, data from two uncooperative students had to be discarded, as explained in the results section.

The students were informed that they would have ample time and that they could answer at their own pace. Then, queries about the procedure were answered, and the students were handed the booklets. Typical time for completion was 35 min, and no student needed more than 55 min.

Measurements

As stated above, features were categorized following the scheme of Bolognesi et al. (2017). In a preliminary inspection of the data, taxonomic features of the synonym and

antonym types were found to be very few. Therefore, they were merged into a single category. Also, a “Miscellaneous” category was added, as in Wu and Barsalou’s (2009) taxonomy, to account for responses such as non-grammatical statements that could not be classified into the other categories. This resulted in the 20 feature types shown in Table 1, with the original descriptions provided by Bolognesi et al. (2017) summarized, and some examples taken from the students’ responses.

Data analysis

The scheme shown in Table 1 was used to categorize both the participants’ knowledge and unknowns. For instance, “It [fan] is made of plastic and metal”, “Pins rise and fall when a key enters the lock”, and “It [fan] is useful in summer because it provides fresh air”, would be categorized as knowledge features of the types “Components, materials and substances”, “Entity behaviors”, and “Contingency and cognitive operations” respectively. In turn, “What is it made of?”, “What is the mechanism of a lock?”, and “Why does ice sometimes form?” are examples of unknown features of the same types.

The instructions provided to the students placed few constraints on the form and extent of their responses. Therefore, relatively long statements were produced especially regarding knowledge features. In order to achieve appropriate reliability, the main clause was identified in each complex sentence. Then, only a main feature was considered within each of the sentences. For instance, “It [refrigerator] has different compartments with different refrigeration” was categorized as a “Components, materials and substances feature” (E-comp), although it provided an additional perceptual property feature of these components (E-perc).

In an initial trial phase, the two authors independently classified 151 features to develop a written protocol with precise categorization criteria. Then, a second set of 145 features (24.3%) were independently classified with a good inter-rater agreement: Cohen’s kappa was 0.90 both for knowledge features and unknown features. Discrepancies were settled by discussion in this phase.

According to the instructions given to the participants, there were a limited number of known and unknown elements to be written in the answer sheets. Therefore, proportions rather than frequencies were used in the analysis of distributions through repeated measures ANOVAs. Multivariate analyses were made when the sphericity assumption was violated.

Results

Two students provided nonsensical responses and their data were discarded. Therefore, there were 27 actual participants in the experiment who generated 310 knowledge features (K) and 287 unknown features (U) about the four artefacts (approximately 11 features of each type per participant). A Wilcoxon matched-pairs signed-ranks test did not show a significant difference between the number of K and U generated per student ($Z = -1.04$; $p = 0.297$).

Figure 1 shows the proportions of K in the four Bolognesi et al.’s (2017) main categories compared to the results of the McRae and Cree’s (2002) study about features of non-living

Table 1 Slightly modified Bolognesi et al.'s (2017) scheme used to categorize knowledge and unknowns about the target artefacts

Macrocategory	Nested category	Nested Category	Description and Examples of K features and U features
Concept properties (E)	Perceptual properties (E-perc)	Sensory properties	Global systemic properties of an entity or its parts <i>It [faucet] can provide hot or cold water</i>
	Non-perceptual properties (E-sys)		<i>How much energy does it [refrigerator] consume?</i>
	Components, materials and substances (E-comp)		Components, materials or substance of an entity <i>It [lock] is made of metal</i> <i>What is inside a faucet?</i>
	Larger wholes, thematic larger wholes, and disciplines (E-whol)		A whole to which the entity belongs
Situation properties (S)	Entity behaviors (E-beh)	A typical behavior of an entity <i>The blades rotate</i> <i>How is cold generated?</i>	A typical behavior of an entity
	Objects (S-obj)		Objects and entities that appear in a situation together with the target concept
	Participants (S-par)		Humans and animals associated with a situation in which the concept appears <i>Who invented it [refrigerator]?</i>
	Actions (S-act)		An action performed by an agent in a situation in which the target concept appears <i>Don't stick your fingers in it [fan]!</i> <i>How is it [lock] manufactured?</i>
	Properties of contextual entities (S-other)		A physical state of a situation or any of its components
Locations, containers, and buildings (S-loc)	Function (S-fun)	Goal or role that an entity serves for an agent <i>It cools food</i>	Goal or role that an entity serves for an agent
	Time and events (S-time)		A place in a situation in which the entity can be found
			A time period or an event associated with a situation. <i>What is its [lock] history?</i>

Table 1 (continued)

Macrocategory	Nested category	Nested Category Description and Examples of K features and U features
Introspections (I)	Evaluations (I-eval)	A positive or negative evaluation of a situation or its components
	Emotions (I-emo)	An affective or emotional state toward a situation or its components
	Contingencies and complex cognitive operations (I-cont)	A contingency or a cognitive operation that relates different aspects of a situation. Cognitive operations include conditional and causals and explicit negations <i>Filters should be cleaned regularly to remove lime/faucet]</i> <i>How does the light turn on when you open the fridge's door?</i>
Taxonomic properties (T)	Synonyms, Antonyms (T-syn/ant)	Synonyms and antonyms of the target concept
	Superordinates (T-sup)	A feature describing a category placed one or more levels above the target concept
	Subordinates and instances (T-sub)	A feature describing a category placed one or more levels below the target concept, in a taxonomy
	Coordinate (T-coor)	A feature describing a category that shares the same direct superordinate with the target concept in a taxonomy
Miscellaneous	Miscellaneous	Statements not matching any of the previous categories or incomprehensible expressions

Fig. 1 A comparison of knowledge features in the present study and McRae and Cree's (2002)

things mentioned above. Features in the miscellaneous category are not included, as they were very few in our study—a proportion of 0.01.

Features in many nested K and U categories were scarcely mentioned and had very low proportions. In order to focus on important information, categories with proportions of knowledge features and unknown features lower than the expected mean value ($1/20=0.05$) were discarded in further analyses. The eight remaining categories, shown in Table 2, included 84% of the knowledge features, and 89% of the unknown features.

A repeated measures ANOVA was performed on an arcsine-square-root transformation of the proportions of knowledge features and unknown features in the eight selected categories. There was no significant interaction artefact $\times$ category, either for K ($F(18,9)=1.13$, $p=0.438$), or for U ($F(18,9)=1.26$, $p=0.373$). Therefore, the feature count was merged across the artefacts for subsequent analyses. There were no knowledge features in the “Participants” category and no unknown features in the “Function” category. They both were excluded from the corresponding analysis due to their null variance. A 2 (K,U) $\times$ 8 (selected categories) repeated measures ANOVA on the transformed proportions showed

Table 2 Proportion of knowledge features and unknown features (nested categories with significant differences between knowledge and unknowns are highlighted in bold)

Most frequent categories	Knowledge features (K)	Unknown features (U)
Non-perceptual properties (E-sys)	.19	.12
Components, materials and substances (E-comp)	.18	.08
Entitybehaviors (E-beh)	.01	.16
Participants (E-Par)	.00	.05
Actions	.02	.07
Function (S-fun)	.18	.00
Time and events (S-time)	.00	.06
Contingencies and complex cognitive operations (I-cont)*	.27	.35
Total (features in most frequent categories)	.84	.89

(*) The overwhelming majority of features in this category consisted of causal relations: .26 out of a proportion of .27 K, and .33 out of a proportion of .35 U

a significant main effect of category ($F(7,20)=25.35$, $p<0.001$; $\eta^2=0.90$, $P=1$), a non-significant effect of the variable K/U ($F(1,26)<1$), and a significant interaction with a large effect size ($F(7,20)=42.80$, $p<0.001$, $\eta^2=0.94$, $P=1$): the distribution of K was significantly different than the distribution of U in the eight most frequent categories.

Post-hoc contrasts with paired-t tests using Bonferroni correction (α level adjusted to 0.006) yielded significant differences between K and U in the categories “Components, materials and substances” ($n_K > n_U$; $t(26)=3.88$, $p<0.001$), “Entity behaviours” ($n_K < n_U$; $t(26)=-6.99$, $p<0.001$), “**Participants**” ($n_K < n_U$; $t(26)=-3.44$, $p=0.002$), “Function” ($n_K > n_U$; $t(26)=9.96$, $p<0.001$), and “Time and events” ($n_K < n_U$; $t(26)=-0.20$, $p=0.004$).

Discussion

The above results show a different structure of student teachers' knowledge about a technical artefact compared to the structure of their conscious lack of knowledge. The following discussion considers knowledge results in terms of Bolognesi et al.'s (2017) categories first, comparing these results to some previous featural analyses. Next, the participants' conscious lack of knowledge is compared to their knowledge following the three components of Kroes' (2010) model for technical artefacts.

According to the results above, the proportion of knowledge features of non-living things in three of the main categories -concept, situation, and taxonomic features-, parallels the results found in both the McRae and Cree's (2002) study and the Djalal et al.'s (2017) study. However, although there is coincidence with these studies regarding the importance of knowledge features of the concept and situation categories and the small relevance of taxonomic properties, the result concerning introspection features is markedly different. This is specifically due to the large number of contingency relations generated in our study. However, the discrepancy could be explained by differences in the task that the participants face in a feature listing study compared to ours. In the former, participants had to explain the meaning of terms by generating isolated features [See Appendix B in McRae et al. (2005) for an example of instructions]. Some of these studies even include a standardized format with suggestions about the type of responses expected from the participants (Garrard et al., 2001). However, the student teachers in our experiment faced a much less delimited task as they were asked to write “important things that you know” in relation to the artefacts. Therefore, one could expect that these instructions would elicit semantic knowledge beyond isolated features, including relations between these features as well (see Cree & McRae, 2003, p. 167 for a similar warning).

The interpretation of students' knowledge and unknowns in terms of Kroes' (2010) scheme shows that the generated features were related in varying degrees to the three basic components of the model. According to the proportions found, the students described the physical structure of the artefacts mainly in terms of two types of features: their components, materials and substances (for instance “It [fan] has blades” [Student #7]), and their non-perceptual, systemic properties (for instance “Its [refrigerator] temperature can be regulated” [Student #10]). However, components, materials and substances were found in a significantly lower proportion in students' unknowns. In contrast, the opposite was true for features of the “Entity behaviors” type: there was a small proportion of these features in the students' declared knowledge (an example is “It [lock] has pins that go up and down when the key is introduced” [Student #8]), but they

played a major role in characterizing the unknowns. The students frequently declared a lack of knowledge about the artefacts' working processes, such as "How does it [fan] collect air and transform it into cold air" (Student #28). In other words, the students were aware of the need of mechanistic explanations, i.e., "how an artefact is able to show the behavior linked with fulfilling (one of) its function(s)" (De Ridder, 2006). This result can be related to findings in the survey study of Hallström and Klasander (2017) mentioned above regarding student teachers' lack of knowledge about how technological systems work and why. Although Hallström and Klasander (2017) research focused on complex technological systems, the result about the ignorance of underlying mechanisms coincides with our finding. Also, this salient difference between unknown features and known features of the entity's behavior can be related to the results of an exploratory study by Koski and de Vries (2013) on primary pupils' system thinking. In this study, the authors describe the students' approach to a familiar technical artefact such as a bread maker. The students were influenced by their experience as users interested in the interaction with the system in order to obtain an end result. There was a focus on the visible parts and experiences with the device and a limited attention to the inner parts and their operation. In our study, there was little mention of the internal behavior of the technical artefacts also, but our older participants evidenced substantial awareness of their lack of knowledge of the inner mechanisms. This result suggests doing further analyses, beyond the aims of this study, of the students' lack of knowledge about these mechanisms in order to ascertain the type of explanation that would more appropriately meet students' needs: top-down from the artefacts' global behavior to more specific sub-behaviors or alternatively bottom-up from the physical components to the global behavior of the artefact (De Ridder, 2006). This would have obvious implications in order to match curricular structure and instructional procedures to students' spontaneous needs of knowing (and ultimately understanding) artefacts.

Function features correspond to the second component of Kroes' (2010) scheme. Bolognesi et al (2017) define "function" as "A quite abstract property that describes the typical goal or role that an entity serves for an agent (often human) in a given situation" (p. 1997). According to this definition, function was conceptualized in this study as "what a technical artefact is expected to do... 'the goal served'" rather than as "a desired physical property or capacity of the technical artefact" (Vermaas et al., 2011; pp.14–15). Functions, understood in this way, were the third most frequently cited features of the students' knowledge. This importance of function is consistent with the results of a study by Kieras (1982) where experts and novices were asked to describe familiar devices such as a radio, and other less familiar devices such as an audio-frequency attenuator. Although the classification categories in the Kieras' (1982) study are more general than those used here, idea-units on function were the most frequently mentioned by novices in two of the three familiar devices considered in that study.

There was a complete absence of unknown features about functions in contrast with their important position within knowledge features. However, this result has been obtained as regards artefacts that are relatively well known to the participants and would probably be different if we had chosen other artefacts less familiar to the students.

That was the case in Vaz-Rebelo et al.'s study (2016) where functions were an important component of what was unknown about artefacts compared to natural objects. The artefacts (LED, Ultrasound, Scanner, Satellite, etc.) used in that study with younger students were less familiar than the ones used here. Also, knowing the function of artefacts was a primary concern for young children in the study by Kemler-Nelson et al. (2004), mentioned above, but the selected artefacts were completely unknown to the participants.

Third, a salient result concerns the third element of Kroes' (2010) scheme. Features that refer to the context of human action basically correspond to the categories "Participants" and "Actions" in the present study. Knowledge features in these categories were conspicuously absent in the results: there were none in the "Participants" category and a negligible proportion in the "Actions" category (an example is "The fingers should be kept out [of the fan]" [Student #2]). Remarkably, humans and their interaction with familiar technical artefacts were ignored in students' statements of their knowledge. This suggests a depersonalized, "hardware-like" conception (Dusek, 2006) of technical artefacts in the context of the particular academic task of this study.

In contrast to the scarcity of knowledge features related to the context of human action, there was a significantly greater proportion of this type of features in the students' declared lack of knowledge. Features of the category "Participants" were found in a significantly greater proportion in the students' unknowns than in their knowledge. An examination of the data in this category showed that 100% of these features were related to the inventor or the producer of the artefact (for instance, "Who invented locks?" [Student #12]). Also, the proportion of unknown features in the category "Time and events", describing "when or in which circumstance the concept appears" (Bolognesi et al., 2017, p. 1997), was found to be significantly greater than the proportion of knowledge features in this category that, in fact, was zero. A recount showed that all these unknown features were related to the time of the artefacts' invention or to their history ("When was it [faucet] invented?" [Student #5] or "What is its [refrigerator] history?" [Student #8]). Therefore, the combined results of the "Participants" and "Time and events" categories reveal a special role for features related to the origin of the artefacts in the students' lack of knowledge. The student teachers put an important focus on Kroes' (2002) context of design when generating unknowns about these familiar technical artefacts compared to their knowledge about the artefacts. This interest is consistent with the findings of Schooner et al. (2018) about technology teachers' views on the assessment of technological systems. The historical context and the development of technological systems was one of the three main themes, together with the systems' structure and the systems relations outside the system's boundary, on which Swedish technology teachers judged that they had to focus their assessment.

Finally, features of the "Contingency and cognitive operations" type, that basically consisted in causal relations, were the most frequently cited both as a part of students' knowledge and of their unknowns. These features may correspond to a variety of elements in Kroes' (2002, 2010) model. For instance, there may be unknowns about the cause of properties of the physical structure such as "Why are the blades shaped like this?" (Student #4), but also unknowns about contingency relations between different components of the model such as human actions and the artefact's function: "What to do if it [refrigerator] does not cool down sufficiently" (Student #6). A useful analysis of these relations could be made along the lines suggested by Kroes' (2006) study of coherence relations between the structural and functional descriptions of technical artefacts. Although it lies beyond the scope of the present study, it could reveal differences between known and unknown features not found at the coarse level of our analysis.

In sum, the above results show a difference between the structure of student teachers' conscious lack of knowledge of familiar technical artefacts and the structure of their knowledge. These differences may be summarized in relation to the three dimensions of Kroes' (2010) model. First, the students' lack of knowledge about the artefacts' physical structure was basically focused on the artefacts' behavior and the need of mechanistic explanations—what their working mechanism is or how the artefact internally operates—rather than on its components and materials. In contrast, the latter, together with the non-perceptual, systemic properties

played a major role in characterizing the students' knowledge. Second, not surprisingly, the function features of these familiar artefacts were considered unproblematic: no unknown function features were mentioned. Third, the design context involving the origin of the artefacts (their invention and history) played a significantly greater role in these students' unknowns compared to their declared knowledge. Finally, non-perceptual properties of the artefacts and the contingency relations in which the elements of the physical structure, function, or context of human action are involved were important components both of students' knowledge and students' unknowns. Further, more detailed analyses may reveal differences between known and unknown features in these categories.

Some educational implications derive from the previous results. As shown above, pre-service teachers are differentially aware of their lack of knowledge of various artefacts' features. Taking into account these differences in declared lack of knowledge would help in the selection of curricular content and in the formulation of "research" questions in the classroom focusing on the students' genuine unknowns. Also, knowing and taking into account conscious lack of knowledge such as the one examined in this study is expected to have a positive motivational effect. Students prefer investigating their own questions, including those related to their lack of knowledge, over answering questions posed by others (Chin & Kayalvizhi, 2002).

To conclude, at least one more limitation of the present study should be pointed out. The alleged goal of the task proposed to the participants in the study was to provide suggestions about possible content to be included in a textbook. Goals have been shown to influence the difficulties found when readers process expository texts (Ishiwa et al., 2013; Morgado et al., 2014). Therefore, the particular task in this study probably had an effect on the participants' declared lack of knowledge, as they may have felt encouraged to generate unknowns that could conceivably be resolved by textbook content. In consequence, the results should be interpreted with this restriction in mind. However, this may be an unavoidable limitation of any study about a person's conscious lack of knowledge, as it would probably be always dependent on the purpose guiding the generation of unknowns.

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Declarations

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