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ORIGINAL RESEARCH

Representation and artefactualism: towards a synergic understanding of scientific modelling

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Abstract
In their investigation on the epistemic role of scientific models, many philosophers of science have historically focused on scientific representation. In this received view, a model serves as a system that represents a target system – a portion of phenomena of interest. However, this representational view has been criticised, particularly by proponents of so-called artefactualism. This view contrasts models' artefactual nature with the representational perspective. This paper has two aims. First, it clarifies the points of disagreement between artefactualism and the representational view I support, which bases representation on interpretation, denotation, exemplification and de-idealisation functions – rather than similarity or isomorphism. Second, it offers a synergistic solution that incorporates several insights of artefactualism within a more sophisticated representational account.

Keywords Artefactualism · Scientific representation · Models · DEKI

1 Introduction

In the last few decades, philosophers of science have thoroughly investigated the epistemic uses of models in science, with particular attention to representation. For many philosophers interested in modelling, a model is a system employed as a representation of a target system, namely a portion of phenomena in which we are interested. The idea is an intuitive one: Bohr's model represents the hydrogen atom, the

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Lotka-Volterra model represents prey-predator populations, and the Phillips-Newlyn machine represents national economic systems.[1]

The representational approach to models, however, has been seriously criticised. An important school of thought within the quite broad antirepresentational camp is *artefactualism*.[2] The artefactualist camp is broad and diverse: starting from a general artefactualist approach to models conceived as tools put forward by Morrison and Morgan (1999), relevantly artefactualist proposals can be found in Knuuttila (2005, 2011, 2021), Currie (2017), and Sanches de Oliveira (2021, 2022). To my knowledge, no representationalist has ever replied to the artefactualists' challenges.[3] The only "side" of the debate that has emphasised the disagreement so far is the artefactualists' one. A thorough analysis of such a disagreement from a representational perspective, and an attempt of reconciliation between the two views is thus opportune. Particularly, it seems crucial for a representationalist to explore how their account can be improved and defended by some of the many criticisms moved by the artefactualists.

The aim of this paper, then, is to clarify where the disagreement between artefactualism and representationalism lies, and to offer a positive proposal to integrate the best aspects of artefactualism into a broadly representationalist framework, so that the discussion on models between representationalists and artefactualists can move forward.

The paper is structured as follows. In Sect. 2, I clarify the exact version of representationalism that I endorse in this paper, the so-called DEKI account of scientific representation (Frigg & Nguyen, 2020, pp. 159–214). Then, Sect. 3 presents five challenges to representationalism from the artefactual approach, and tackles them one by one. Here, I will mostly focus on the issues raised by Knuuttila (2011, 2021, 2024) as a departure point for my reconciliation.

My analysis reveals that part of these criticisms are only apparent and dissolve when one adopts a plausible concept of representation, like the one expressed by the DEKI account. However, even with a good concept of representation at our disposal, some of the artefactualist's worries remain serious, and need to be addressed. The paper then in part defends DEKI from the these worries, and in part improves the account in the light of the artefactualist's critique. My paper then both allows artefactualists and some representationalists to move on, beyond their disagreement,

[1] Both mathematical and material models are part of the scope of this paper, because virtually all parts in the debate, artefactualists included, agree that a philosophical account of models should deal with both types of models.

[2] For non-artefactualist criticisms to representation, see Callender and Cohen (2006), Isaac (2013), and Khalifa et al (2022). For a discussion, see Frigg and Nguyen (2020, pp. 23–30) and my doctoral dissertation (Sartori, 2024, pp. 170–175 and 191–212).

[3] One noteworthy exception is Stegmann (2021), who briefly argues for compatibility between representational approaches and artefactualism. However, Stegmann's analysis of artefactualism is very sketchy and does not take into consideration most of the recent artefactualist literature against representation, as I do in the present work. His argument is also restricted to one case study – Gamow's diamond diagrams – and does not aim to talk about models in general, like mine here. Finally, Stegmann argues that his example shows that representationalism and artefactualism are associated with different stages of the modelling process (*ibid.*, p. 2692), which is not really my point of view on the matter.

and provides a constructive synergy between these two approaches to scientific modelling.

2 A representational framework

2.1 Representationalism

Most, if not all papers introducing an artefactual approach to models begin from a general scepticism of what one could call representationalism, which is a view of models hinged upon the concept of representation. For example, Knuuttila writes:

> Representation as ‘standing for’ is embedded in representationalism. The term was originally coined in the philosophical discussion on perception to refer to a position according to which immediately experienced sense-data, combined with the further beliefs […] constitute representations of the independently existing external objects […] the term representationalism has loosened its ties with perception and also covers […] ideas, observations, beliefs, concepts, propositions, neural states, or scientific models […]. (Knuuttila, 2011, pp. 263–264)

Also, in her recent review of artefactualism in general, she writes that this approach starts from a sceptical attitude towards representation as a useful concept to understand scientific modelling, and presents itself as a viable alternative:

> What is common to the artifactual approaches […] is their pragmatic approach to modeling, and the loosening of what could be called the representational bind, the idea that models give knowledge because they represent their supposed target systems more or less accurately (Knuuttila, 2024, p. 111)

Similar remarks to motivate artefactualism as a response or a reaction to representational approaches to models can be found at the beginning of virtually all the works of artefactualists, even recent ones – e.g., Knuuttila (2021, pp. 2–4), Currie (2017)[4] and Sanches de Oliveira (2021, 2022).

The problem in assessing the artefactualists’ scepticism is that with “representation” people mean very different things, and a good definition of representationalism that satisfies all parts is arduous to find.

In a study on Dewey’s anti-representationalism, Godfrey-Smith offers a very general characterisation of what has been traditionally called “representationalism” and was the target of Dewey’s snipes:

[4] The case of Currie (2017) is complex because his general artefactualist effort springs from a critique of a peculiar conception of representation, combined with fictionalism about models. Still, many of his examples are in agreement with the rest of the artefactualists concerning their scepticism about representation more generally.

Representationalism$_{(def)}$: "Representationalism about an epistemic medium [e.g., scientific practices] is the claim that there is a relation *R* between epistemic devices [e.g., models] in that medium and a subject-matter [e.g., a target system] that these devices are used to deal with,

1. That is an achievable goal in the production of those epistemic devices, in a given context of interpretation, and is hence a standard of assessment for the devices themselves,
2. That involves

   (2a) veridicality, in the sense of satisfaction by the [target *T*] of a condition specified by the [model *M*], and/or

   (2b) copying, picturing, or some other preservation of structure, between device and subject-matter,

3. And that has a causal relation to success (theoretical or practical) in the use of these epistemic devices, where this link to success is part of why relation *R* provides a goal and standard of assessment, as in (1)." (Godfrey-Smith, 2017, p. 153)

This definition is very broad and may apply to different things: perception, thoughts, language, scientific theories, and naturally, models too. Also, it seems to correctly match with contemporary representational accounts of models in its core tenets, and it expresses the sort of historical embedding within a representationalist approach to mind and language expressed by Knuuttila.

It is important to notice that while representationalism here acknowledges a relation of representation, it does not understand representation as an intrinsic or universal aspect of models. This means that models *can* and do represent target systems, but they do *not need* to: in principle, they can be defined independently of this relation. I thus take point (3) charitably: representation is important to understand the successful use of models in many contexts, but it is not deemed as a necessary condition for all instances of model success, nor a sufficient one for any sense of "success".

One further clarification about representationalism, specifically about the veridicality condition (2a). Here, Godfrey-Smith clearly intends to put veridicality as a goal, and not as a requirement, of representation. A representationalist about models, then, is committed to the idea that models *aim* at being correct about their target, but she can perfectly grant that sometimes (or even often) models fail in this respect.

Now that we have a general idea of representationalism, we need to provide a more precise concept of representation, in order to test it under the artefactualist criticisms. A complete review of each single account of scientific representation that has been offered in the last two decades would be an enterprise far beyond the scope of this article. For this reason, I narrow down my analysis to an account of scientific representation that I take to be particularly promising for a reconciliation between representationalism and artefactualism: the DEKI account of scientific representation. My choice is motivated on the plausible assumption that DEKI strikes a good balance between being an adequate representative of representationalism and nevertheless possessing the resources to be compatible with main insights of artefactualism.

Before delving into the account, there are two warnings. First, it is not my goal here to faithfully vindicate the original intentions and or formulations of the originators of the DEKI account. In contrast, my aim is to provide a formulation and development of the account that is more explicitly "artefactualism-friendly". Therefore, I will ignore many details which are irrelevant for the present discussion, and I will feel free to develop and improve the account when necessary.[5] Second, I don't want either to argue in favour of the DEKI account against other representational accounts of models, or to suggest that other accounts of representation would not be reconcilable with artefactualism. Hopefully, my analysis will in fact indicate a viable route applicable also to other representational views of models.

2.2 The DEKI account

Schematically, the DEKI account defines epistemic[6] representation as follows:

DEKI epistemic representation$_{\textbf{(def)}}$: Given a model system *M*, defined as an object *X* endowed with an interpretation *I* that makes *M* a *Z*-representation; *M* epistemically represent a target system *T* iff:

(i) *M denotes T*,
(ii) *M exemplifies* properties $P_1 \ldots, P_n$,
(iii) $P_1 \ldots, P_n$ are associated with a second set of properties $Q_1 \ldots, Q_n$ via a *key*,
(iv) $Q_1 \ldots, Q_n$ are *imputed* to *T*.

The four conditions – *d*enotation, *e*xemplification, *k*eying-up, and *i*mputation – give the account its name. In the rest of this section, I provide a very general characterisation of the account, clarifying the four conditions one by one.

Let us start from some intuitive examples: Watson and Crick's model, th representationalist suggests, is a representation of the DNA; Bohr's model is a representation of hydrogen atoms; and the Phillips-Newlyn machine is a representation of a national economy. DEKI states that in all of these examples, "representation of" is meant to express a two-place referential relation: the model is "about" a target system, meaning that the model refers to the target in the same way a symbol refers to the thing that the symbol stands for. Following Goodman (1976) and particularly the later developments of his theory provided by Elgin (1983, p. 19), the DEKI account identifies the

[5] For more details about the account, the reader can consult Frigg and Nguyen (2020, pp. 159–2014), and Nguyen and Frigg (2022b, pp. 50–73). There, the reader will also find useful comparisons between DEKI and other representational accounts of models.

[6] The account does not rule out the possibility that some artistic representations may function in a similar way, so the account does not imply a demarcation criterion for representations used in science specifically. Rather, it aims at illustrating the fundamental characteristics of representational systems with some epistemic import, whether in science, in art, or in any field of application. From now on, I will use "scientific representation" and "epistemic representation" interchangeably.

relation of representation-of as *denotation*, i.e., the same type of symbolic reference relating a name to its bearer, or a term to its class.[7]

Denotation can simply come to be by fiat or arbitrary stipulation, but this does not seem to be enough to characterise epistemic representation entirely. Watson and Crick's model, for example, does not simply denote the real DNA, in the sense that we limit ourselves to saying that one object stands for the other. The model represents the DNA *as* a double-helix structure constituted of two spiral chains of nucleotides, horizontally connected pairwise by couples of nitrogenous bases. In other words, the model is meant to give us epistemic access to certain specific characteristics on which we are supposed to focus. Those privileged features are the ones that will hopefully be useful for our investigation of the target system.

Following Goodman's (1976, p. 27) lesson, DEKI acknowledges that the term "representation" is ambiguous, and it can mean representation-of, or representation-as. While representation-of is a two-place referential relation connecting a symbol with what the symbol stands for, representation-as is not to be understood as a relation: rather, it is a monadic predicate which indicates the theoretical domain or field of enquiry of a representation. In the example of the model of DNA, the theoretical domain could be described as molecular biology. Epistemic representation, in DEKI, results from a combination of both representation-of and representation-as. We can then understand representation as a three-place relation: a model *M* represents its target *T* as *Z*. Or, better, *M* is a *Z*-representation of *T*. In our example, Watson and Crick's model would then be a molecular-biology-representation of the DNA.

One can of course be more specific and say that the *Z*-representation in the case of Watson and Crick's model is a double-helix structure of two chains of nucleotides, which are horizontally linked by bonds between pairs of nitrogenous bases. Or for short, we could say something along these lines: Watson and Crick's model is a double-helix-representation of the DNA. The degree of granularity and specificity we adopt in the definition of the *Z*-properties depends on the purpose of the taxonomic system that we wish to employ. This flexibility should not surprise us, as it is analogous to the different levels of specificity one deals with when categorising objects more generally. There is nothing special, then, when it comes to a classification system for representations.

Now, we need to explain how *M*, understood as a *Z*-representation, provides epistemic access to relevant features of *T*. As an interpreted object, Watson and Crick's model allows an agent to recognise, and focus on, certain properties that would be possessed by actual DNA: the spiral structure, the bonds between pairs of nitrogenous bases, and so on. Similarly, Newton's model of the Solar System allows us to derive Kepler's three laws governing the motion of the planets, and the Lotka-Volterra model suggests useful predictions about real-world prey-predators populations, among which the famous Volterra property – namely, that when a biocide occurs in both populations, the relative amount of the prey population increases (Volterra, 1926, p. 558; Weisberg & Reisman, 2008, p. 113).

The DEKI account makes sense of this capacity of models to highlight certain properties by employing the concept of *exemplification*, which was coined in its tech-

[7] For this "unorthodox" expansion of the concept of denotation beyond proper names, see Elgin (1983).

nical sense by Goodman (1976, pp. 52–57) and developed by Elgin (1983, pp. 71–95 and Elgin, 1996, pp. 171–183). Samples are paradigmatic instances of exemplification. For example, when you enter a shop to choose the new curtains for your room, you are shown a series of samples of cloth. These swatches instantiate an indefinite number of properties we are not interested in. For example, suppose that all of them had been produced in China, with raw materials from Brazil, had been transported to the UK by boat, and are all now displayed in the same room. All these properties are in fact possessed by the swatches, but given the specific context of the curtain shop, they are not exemplified. In that context,[8] the swatches are not intended to point to those properties, but rather to the properties which are salient to us as we make our choice regarding the type of curtains we want in our house: the colour they instantiate, the fabric, the material, and so on.

More rigorously, exemplification is defined as follows: an object exemplifies a certain property A if and only if the object instantiates A and the object also refers to A. Instantiation, or possession, is thus a necessary condition for exemplification. If an object does not possess a property, it cannot exemplify it. However, instantiation is not in itself sufficient: an object will always instantiate an indefinite number of properties that are not exemplified. The system must also refer to certain properties, thus making them epistemically accessible and salient.

An object can have its own properties highlighted in different ways, and different factors contribute to it. Certainly, the interests and goals of a user are very important, but this is not sufficient: one has to also to consider the combination of three further factors: (i) the way in which the object itself presents its properties; (ii) the surrounding context; and (iii) the perceptual and psychological features of the agents.

Concerning (i), an object may instantiate certain properties that we are interested in for our goals, but these properties are just not made explicit or highlighted enough. Elgin (2010, pp. 11–12) gives a historical example she draws from Tufte (1997), where certain reports about a space shuttle did contain important information about the risk of explosion, but it was virtually impossible to notice because mixed with tons of other data, tables and comments.

As a simple example of (ii), notice that a coloured chip for choosing paint in a shop can exemplify a certain shade of red mostly because it is put together with chips of different colours the illumination in the room is good enough, and so on.

Finally, as regards (iii), exemplification strategies importantly depend on background abilities and features of human beings. For example, the fact that certain colours are employed in visual representations like diagrams and maps derives from the specific perceptual and cognitive skills of human beings.

Exemplification, like denotation, is a referential relation: an object refers to a property that the object itself possesses. While denotation flows from a name, or category, to an object, exemplification runs in the opposite direction, from an object to a category.

Let us move to a further condition of DEKI, namely *imputation*. In DEKI, imputation is understood as mere ascription of properties, thus not entailing the correctness

[8] Were the context different, the system may exemplify different properties, or not exemplify at all.

of such attribution. This is necessary, because misrepresentations should still count as representations. An incorrect model of the Solar system is still a representation of it. This is not only necessary for a working definition of representation, but it accurately reflects scientific practice: much of what is true in the idealised world of the model is to be only tentatively attributed to the target system, under the form of a (justified) hypothesis.[9]

In some cases, the properties exemplified by the model are imputed to the target system directly. For example, in most applications of Watson and Crick's model, the properties exemplified by the model are simply imputed to the actual DNA. However, the imputation of model properties to the target system is not always so smooth: due to idealisations and simplifications in our models, model systems often distort many properties of the target system. Of course, some of these distortions will be taken care of by the selectivity of exemplification: some properties of the model are just to be ignored. However, models often distort *relevant* properties – namely, those properties that constitute the respect in which we study models as surrogate systems of our targets. As an example, consider the harmonic oscillator model of a pendulum:

$$\frac{d^2\theta}{dt^2} = -\frac{g}{l}(\theta)$$

The left side of the equation expresses the second derivative of the angle of deflection θ, g is the gravitational constant, l corresponds to the length of the rope, and t is time. In this way, the equation above becomes a model of oscillating objects in the real world.

Suppose the model is used to predict the motion of a child oscillating on a swing. The model ignores many aspects that we are happy to consider irrelevant (for example, the colour of the rod). At the same time, the model also distorts *relevant* properties of the target system. For the model is supposed to give us a story about the dynamics of the pendulum, and therefore to explain it in terms of forces. However, the model ignores friction, thus distorting the description of the forces involved. This simple example is by no means an exception, as models distorting relevant properties of their targets abound in all scientific disciplines.

Now, the philosophical use of terms like approximation, abstraction, idealisation and distortion is extremely varied across different authors.[10] For the purposes of my current argument, it will be useful to regiment the language and conceptually distinguish between these terms. First, I use "distortion" as a general umbrella concept that encompasses approximation, idealisation and abstraction. To distinguish these three terms, I follow the distinctions drawn by Frigg (2022, Chap. 11). I refer the reader to Frigg's book for a detailed illustration, but in a nutshell: *approximation* expresses quantitative, mathematical closeness between values, whereas abstraction and ideali-

[9] With denotation, exemplification and imputation, we obtain the basic ingredients of model representation as developed by Elgin (2010).

[10] Recent discussions of idealisation and approximation can be found in Batterman (2009), Cartwright (1983), Elliott-Graves and Weisberg (2014), Jebeile and Kennedy (2015), Nguyen (2020), Norton (2012), Portides (2007), Potochnik (2017), and Saatsi (2013).

sation are not necessarily expressible in mathematical terms. Furthermore, I take it that *abstraction* involves the omission of properties that do not pertain to a respect (or a dimension) that is represented by the model – for example, the colours of the swing are ignored in our harmonic oscillator model. In contrast, an *idealisation* consists of any distortion (even omission) of a property that, unlike in the case of abstraction, falls under a respect that is meant to be represented by the model.

In our example of the harmonic oscillator, ignoring friction counts as an idealisation, because friction is a force, and the model is meant to represent the forces acting on a system. In this example, I chose a respect that has been completely omitted, but there are cases where the property is idealised in the sense that is described in a non-realistic way. For example, the Lotka-Volterra model of a prey-predator system is meant to tell us how the populations change over time, but they represent them in real number values, while populations are made of discrete individuals.

Approximations and abstractions do not seem particularly troublesome. Approximation implies a quantitative measure of the "distance" between the model and the target, so if the model is not accurate, we can specify how inaccurate it is. Furthermore, abstraction is already explained by exemplification: certain properties are relevant and thus presented in the model, while others are ignored or distorted because they are not relevant, in the sense that they are not difference-makers and thus remain negligible. However, we have also a specific type of distortions, idealisations, that are particularly problematic for a *factive* epistemology of scientific representation: if the properties that we are meant to attribute to the target system on the basis of the model are also distorted, but scientists keep using those models, then it seems that the role of models is not (only) to provide accurate knowledge of their target system.

Some philosophers, like Elgin (2017) and De Regt (2017), tackle this problem by appealing to the concept of understanding and define it in non-factive terms: the model can be epistemically useful even if it represents the relevant properties of its target in an inaccurate way.[11]

This move is not an easy one, as it forces us to separate the success of a model from its accuracy and, in turn, from truth and the related concept of knowledge. So, it would force us to abandon the veridicality condition (2a) of representationalism. However, there is still a way to run with the idealisations and hunt with the factivity/veridicality of models. The solution, proposed by Frigg and Nguyen (2021), is the introduction of the concept of a *key*. The key is a function that systematically maps the properties exemplified by an idealised model system onto the properties we actually want to impute to its designated target system. A scale model of a bridge, for example, will also need an associated scale factor to translate the dimensions of the model system into those of the designated actual bridge. Sometimes, this factor will not be a matter of dimensions, but of time, as in the case of very brief cycles in the Phillips-Newlyn machine representing long periods of time in real-world economies (Frigg & Nguyen, 2020, p. 174). In mechanical models, the limit values of certain parameters will have to be translated

[11] The literature on understanding through modelling is vast and will not be analysed in detail here. Besides the literature already mentioned, relevant entry points include Bokulich (2017), Doyle et al. (2019), Frigg and Nguyen (2025), Illari (2019), Khalifa (2017), Kostić (2019), Le Bihan (2021), Reutlinger et al. (2018), and the papers collected in Grimm et al. (2017). As I will show below, what matters to the present discussion is that the type of understanding we aim at achieving when using models is a factive one.

into non-limit values (Nguyen & Frigg, 2020). Geometrical projections are another example of keys, mapping the properties of two-dimensional pictures and maps onto those to be imputed to three-dimensional systems. For example, the so-called Mercator projection is a key employed, among other things, to translate distances on the planisphere to actual distances on Earth (Nguyen & Frigg, 2022a), and geometrical projections are employed all the time in two-dimensional pictures of 3D objects (cf. my 2025 paper on the picture of a black hole).

While keys so understood are ubiquitous in scientific modelling, a translation of the sort is not necessarily required by the DEKI account. When the properties exemplified by the model are exactly the ones that we impute to the target system, the key will simply be an identity key, mapping the properties exemplified in the model into themselves.

Therefore, in the DEKI account, model distortions (in a broad sense) do not necessarily undermine a model's representational capacity. Thanks to the selective nature of exemplification, and the translation operated by the key, the lack of direct similarity between a model and its target does not necessarily imply a failure of the model as a representation. So, we are not required to posit any reference to picturing, copying, or preserving structures (2b).

As I said above, imputation is simply property attribution. Therefore, even with the key in place, representation does not imply *accurate* or correct representation. This is, again, a fundamental requirement of the concept of representation: misrepresentations still count as representations. For example, imagine a treasure map where the treasure is indicated with the classic "X". We interpret the map correctly, which in DEKI means that we apply all the relevant keys involved (geometrical projections, conventional symbols understood as routes and cities …). Still, the treasure may not be there. We read the map as we were supposed to: it is just that the map was a bad one. Therefore, a representational relation in DEKI does not imply representational accuracy, even though the aim of epistemic representation will always be accurate representation – this is why we have included exemplification and the keys in the first place.

Yet, our veridicality condition (2a) logically requires a definition of accurate representation, in order to specify what makes R successful or not. In order to make R somewhat responsible for the successful use of models, the T has to satisfy the conditions stated by the inferences we make through the model. Therefore, we still need a definition for representational *accuracy*, or correctness. In previous work (2023b) I have proposed to simply specify that the designated target system T in fact possesses the properties that we impute to T on the basis of the model are in fact possessed:

Accurate representation$_{\mathbf{(def)}}$: A model system M is an accurate representation of a designated (i.e., denoted) target T regarding a set of properties $Q_1 \ldots, Q_n$ iff (1) M exemplifies a set of properties $P_1 \ldots, P_n$; (2) $P_1 \ldots, P_n$ are converted via a proper key into $Q_1 \ldots, Q_n$;[12] (3) $Q_1 \ldots, Q_n$ are imputed to T; and (4) T actually possesses $Q_1 \ldots, Q_n$.

[12] I remind the reader here that the key may also be a relation of identity, mapping a property P_i onto itself.

In this way, we have fulfilled the condition of veridicality (2a).

It is important to stress that my definition of accurate representation does not require similarity or isomorphism between models and their targets, nor are they sufficient for it. They are not required, because the presence of the key (when not an identity function) makes similarity unnecessary. They are insufficient, because accuracy requires all four of DEKI's components to obtain.[13]

Besides accuracy, I need to say a few words about the justification of model inferences. Model inferences can be correct in two distinct senses: they may be internally correct or externally correct.[14] Internal correctness concerns how we are supposed to understand and interpret the model. In DEKI, the justification of this type of correctness comes from the key, and how the key relates to the building assumptions of our model. External correctness, instead, concerns whether the imputations we draw about the target on the basis of the model are in fact correct. Such correctness, then, does not depend on the model, but on states of the matter in the real world. The justification for such correctness is always (at least in part) extrinsic to the model taken in isolation. If we cannot check the target directly, as in most cases, the only way to justify our inferences from the model to the target is to look outside the model itself. We will then have to check whether the model follows from certain theories that have already found empirical confirmation, or if the model's results are coherent with the results of other models, as well as with the rest of the available empirical and theoretical knowledge. Because modelling is an ampliative method of investigation, this is all we can achieve from a philosophical account of representation with models.

2.3 A definition of model

At this point, we need a story of how an object becomes a model – that is, how an object becomes a *Z*-representation. The most natural way to think about this, as Frigg and Nguyen (2020, p. 166–171) suggest, is a form of *interpretation*. First, let's call the material part of the representation the *carrier X* of the representation, which is to be conceptually distinguished from the *Z*-representation.[15] Specifically, one has to endow different parts of *X* with some theoretical interpretation of those parts. For example, the two spiral strings in the material instantiation of Watson and Crick's model will have to be interpreted as chains of nucleotides, and the sticks connecting them horizontally as bonds between couples of nitrogenous bases. The recognisable spiralling structure has to be interpreted as a DNA molecular structure.

[13] By detaching accurate representation from similarity, I agree with Nguyen (2020, section 4) and with those accounts he calls "interpretational" in that failures of similarity do not imply failure of representational success.

[14] See Frigg and Nguyen (2022), who call these two types of correctness "derivational" and "factual", respectively.

[15] Here, I focus on the case where the model's carrier is a concrete object, like in the case of the Phillips-Newlyn machine. However, carriers may not be concrete, like in the case of the Lotka-Volterra model, or the Newtonian model of the Solar System. This is not a problem for DEKI: non-concrete carriers can be understood either as fictional objects (the view preferred by the originator of DEKI) or as abstract mathematical structures; both are identifiable by textual, pictorial, or mathematical descriptions. Both options are viable – see Frigg and Nguyen (2020, pp. 185–190). For a solution to the problem of denoting fictions, see Salis et al. (2020).

Here, I call the interpretation "theoretical", because I do not want to presume that the resulting *Z*-representation is necessarily identical to the target system. In this sense, "nucleotides", "nitrogenous bases" and "molecular structure" are first of all theoretical constructs: they may not exist in the real world, or if they do, they may be importantly different from how they are shown and exemplified in the model system. And this is why we may still need a key, in the technical sense I have illustrated in the previous section.

The fact that models are objects endowed with an interpretation seems to be the case in most scientific models. The water flowing through pipes into different reservoirs in the Phillips-Newlyn machine must be interpreted as an abstract, possibly idealised flow of money between different sectors of an imaginary, highly theoretically constructed national economy. The same with the material example of Newton's model of the Solar System, where balls are interpreted as perfect spheres interacting with each other only in terms of gravitational forces, with no friction involved.

Interpretation, Frigg and Nguyen argue, can be conceived simply as a function *I*, which associates the different material elements of the carrier *X* with properties of the *Z*. By applying the *I*-function to the carrier *X*, we obtain the actual model system *M*. It is *M*, and not simply *X*, that represents a designated target system *T*. So, in addition to a definition of representation, we can also offer a definition of model:

Model$_{\text{(def)}}$: a model system *M* is an object *X* endowed with an interpretation *I* that makes it a *Z*-representation – namely, an object used to exemplify a set properties P_1 …, P_n.[16]

It is important to clarify that this definition implies that models can also not represent anything. Therefore, representation-of is not a necessary feature of models. But *Z*-representation is, in the sense of interpretation and exemplification. This disambiguation will help us respond to the artefactualists' objections.

Besides detaching the notion of model from that of representation-of, while retaining the central role of *Z*-representation, this definition has three interesting consequences. First, it does not define models *only* on the basis of intrinsic features of an object, like the properties it instantiates, but mainly by appealing to the interpretation we give to it and its referential use (namely, exemplification). Second, while being very general, the definition is not vacuous: even if anything *can* be in principle used as a model, it does not follow that everything will be in fact interpreted in that specific way, as a *Z*-representation exemplifying certain features, or even it is always so.[17] Third, while a model is defined in terms of its interpretation and exemplification (and thus remaining importantly mind- and context-dependent), it is not itself defined in terms of one specific (set of) purpose(s),[18] leaving it flexible enough to be used in

[16] The definition of model originally offered by the originator of the account simply defined a model as a *Z*-representation (Frigg & Nguyen, 2020, p. 169) and, in my opinion, did not stress enough the importance of exemplification, leaving it implicit. I amended this lacuna in the definition above.

[17] This is analogous to Goodman's (1978, pp. 57–70) suggestion that it is pointless to ask what counts as an artwork, and it is instead better to ask "when" an object counts as such.

[18] This does not clash with the arguments given by Alexandrova (2010) and Parker (2020), who argue that the *adequacy* of models should always be evaluated in the consideration of the use we want to make of

different contexts for different purposes while remaining the same model if the interpretation and the set of exemplified properties do not change.[19] Thus, according to the definition, representation in the sense of denotation, exemplification, keying-up and imputation is only one possible use/purpose of a model. This will turn out to be useful in Sect. 3.1, where I consider non-representational uses of models from the perspective of DEKI's framework. At the same time, representation retains its conceptual role, because models are defined as *Z*-representations – that is, symbols used to exemplify (and thus, refer to) certain properties.

Let us sum up the take-home messages of Sect. 2. The DEKI account holds that a model system *M*, understood as a carrier *X* endowed with an interpretation *I*, epistemically represents a target system *T* iff *M* denotes *T* and exemplifies certain properties that are imputed to *T* after a possible application of a key. Furthermore, the resulting account of representation fits the bill of our definition of representationalism (2.1). The realisation of a relation of representation is achievable (1) via interpretation, denotation, exemplification, and keys. While all of these elements are mind- and context-dependent, they are not ad hoc: they are developed in the light of our previous background knowledge, with the aim of representational accuracy and predictive and/or explanatory success. Furthermore, the definition involves veridicality (2a), as all different types of model distortions can be dealt with via exemplification and the key. However, neither representation nor representational accuracy require similarity or structure preservation, or *a fortiori* copying, replicating or mirroring. Therefore, the account rejects condition (2b), and this is allowed by the definition of representationalism via the "and/or" before condition (2b). Finally, concerning condition (3), the intuition is that accurate representation is an aim of modelling, and when this is the case, the relation of representation is related to models' success. This is because, the account suggests, models exemplify interesting properties that we can impute to their targets once properly translated with a key, under the form of working hypotheses. As one of the main criticisms against representation moved by the artefactualists concerns exactly this last point, I will come back to it in Sect. 3.2.

With our account of representation and model set up, let us now look at the challenges moved to representation within the artefactualist camp.

3 Artefactualism and its challenges to representation

In the current debate, the positions developed within the artefactualist camp are quite diverse from each other, but as I mentioned in Sect. 2.1, all these positions have been presented in more or less stark contrast to representationalism, which was taken as the received view about models and their use in science. In contrast, artefctualists suggest, models should be understood first of all as *artefacts* and *tools*. The use of these two terms vary across the literature, but there are some core features shared among our authors of interest. An artefact is an artificial object, usually designed, built, manipulated, and used. A tool is a specific type of artefact (Currie, 2017), namely, a

them.

[19] For an entry point to the literature on model transfer see Herfeld (2024).

(material) object that is used to manipulate other (material) objects. Paradigm examples here are hammers and screwdrivers, but also telescopes and thermometers.

In his broad reconstruction of the various artefactual views of models present in the literature, Sanches de Oliveira (2022) lists three general insights that are broadly shared by most artefactualists. First, a fundamental independence of models with respect to both theories and data and their role as "mediating instruments" – as it was put in Morrison and Morgan's (1999) seminal work on models as mediators. The second insight, in the effective way Sanches de Oliveira puts it, is that "matter matters" (Sanches de Oliveira, 2022, p. 5): models' semantic and epistemic features crucially depend on their material realisation, and without it no mediation between theory and phenomena is possible. In the words of Knuuttila, "without materiality, mediation is empty" (2005, p. 1266). Accordingly, the criticism against the representational approach to models is that "with its focus on the formal, or general, features of a representational relationship between a model and a target system it also neglects the actual representational means with which scientists go on representing" (Knuuttila, 2011, p. 263). The third insight of artefactualism is that it provides an "understanding [of] model*ing* as a tool-building *practice*" (Sanches de Oliveira, 2022, p. 6, original emphases). This means that models should be analysed first of all as instruments used by someone and for specific purposes and evaluated in their epistemic contribution to science *vis a vis* these purposes and the agents that are supposed to use them.

In her review of the artefactualist approaches to modelling, Knuuttila (2024) tries to summarise their common core explicitly as follows:

> What is common to the artifactual approaches discussed below is their pragmatic approach to modeling, and the loosening of what could be called the representational bind, the idea that models give knowledge because they represent their supposed target systems more or less accurately. From the artifactual perspective, and in agreement with the pragmatic accounts of representation (Suárez, 2004; Giere, 2010; Hughes, 1997), the representational model–target pair is too restrictive a unit of analysis. However, while the pragmatic approaches to representation make room for subjects and communities, the artifactual approaches reach further in not assuming, as Isaac has put it, that "representation [is] conceptually prior to success". (Isaac, 2013, p. 3612)

Here, one can identify two main points. First, artefactualism aims to relax the focus on the relation between model and target system in terms of accurate representation. Second, and relatedly, the success of the model should not always be given in terms of representation.

So, it should be clear how artefactualism, at its core, is identified by its very proponents as an anti-representationalist view. However, "loosening [...] the representational bind" and "not assuming representation [as] conceptually prior to success" are admittedly quite general worries, and it is not immediately clear what are the specific challenges moved to representationalism. In the next subsections, I will thus identify five more specific problems that arise from artefactual views of models against a representational view of models. Two challenges are *prima facie* more substantial problems for a representationalist view, while the other three seem more easily addressed, once the first two are clarified and a proper notion of representation is provided:

1. Some models are simply not used as representations in any meaningful sense.
2. Representation is an inert concept to understand the epistemic value of models.
3. Representationalism does not sufficiently emphasise the dynamic nature of modelling.
4. Representational views are unable to fully express the independence of models from theories and data.
5. Representational views do not capture the importance of the material features of models *qua* tools that are designed, built, manipulated and used.

The first two statements are meant to be direct objections to, or problems for, a representational view of models, while the others are a matter of degree and concern the general spirit of the artefactual approach in contrast with the representational one. Let us now deal with these five challenges, one by one. The goal is to modify and enrich the DEKI account in the light of the most serious issues raised by the artefactualists, or in some cases to show that it already has the resources to resist them.

3.1 Non-representational uses of models

One of the main issues motivating artefactualism is the quite straightforward fact that many models do not seem to represent anything, but are still widely used in science and successfully so. If representationalism involved a universal statement of the sort "all models are representations", then, representationalism would be falsified.

It is true that some philosophers have taken and still take the relation between models and representation as universally in place. For example, Hughes writes that "[t]he characteristic – perhaps the only characteristic – that all theoretical models have in common is that they provide representations of parts of the world" (1997, p. 325); Portides asserts that "a model is meant to represent something else" (Portides, 2008, p. 385); and Barberousse and Ludwig hold "that all scientific models have some properties in common: all of them are representations, in the sense that they stand for something else" (Barberousse & Ludwig, 2009, p. 57).

However, most of these claims about a necessary link between model and representation have been made by people studying models but not representation per se – or, like in the case of Hughes, they have written before that most current views about scientific representation were put forward. In fact, most contemporary accounts of scientific representation make it clear from the outset that representation does *not* (intend to) provide the full story about models. The originators of DEKI, for example, introduce this *caveat* at the very start of their opinionated introduction to model representation:

> Our discussion is neither premised on the claim that all models are representational, nor does it assume that representation is the only function of models […] Our point of departure is that some models represent and that therefore representation is one of the functions that these models perform. We believe

> that this is an important function and that it is therefore a worthy endeavour to enquire into how models manage to represent something beyond themselves. (Frigg & Nguyen, 2020, p. xii)

As we have seen in Sect. 2.3, the DEKI account provides a definition of model which is independent of representation. A model is defined as an interpreted object that functions as a *Z*-representation, thus exemplifying certain properties that it instantiates. Therefore, a model is a symbol able to refer to certain properties and thus make them epistemically accessible and salient. The definition then retains some minimal sense in which representation is still in the picture (*Z*-representation) but it also allows the possibility of targetless models – which would be models that denote nothing in the real world – and consequently, models that do not in fact represent at all.

In this way, one has already avoided the objection per se: if representational accounts like DEKI circumscribe their scope of application only to representational models, then they cannot be criticised because they do not deal with non-representational uses of models. Non-representational models simply lie outside the focus of such accounts.

However, by doing this, the representationalist would simply admit a sort of defeat. By excluding non-representational models from the enquiry, representational accounts seem particularly wanting, and non-representational uses of models may appear to be classified as "second rank" sort of models, or even not epistemic at all. So, artefactualists and other philosophers may remain unsatisfied: if representation is all that representational accounts of models are concerned with, what about the other possible uses of models in science? Can a representational account like DEKI tell us something more about non-representational models, besides that they are not representations?

This section addresses this worry. I do not want to show that DEKI, as it is, works just fine with non-representational uses of models – it would be surprising if it did, as it is an account of scientific representation. I just want to suggest that, if one adopts the framework of the DEKI account, one can employ some of its concepts and say something more about non-representational uses of models than merely the fact that they are not representational. Let us, then, consider some examples of these non-representational uses of models from the artefactualist perspective, and see how DEKI and its conceptual resources can be used to shed some light on them.

In the philosophical literature, the number of "types" of models identified is immense: Frigg (2022, p. 466) reports more than 100 distinct categories of scientific models emerging from philosophical works on the topic – and the author highlights that the list is far from being exhaustive. For reasons of space, I cannot analyse this elephantine (and quite intricate) amount of models in its entirety. Rather, I will focus on a few categories that I find particularly representative of what artefactualists and other philosophers have in mind when they talk of non-representational models. The hope is that my analysis will show how the conceptual toolkit of DEKI can be applied outside representational cases, and pave the ground for further applications.

In my review of the artefactualist literature and the general debate on modelling, I identified at least five general non-representational categories of models:

1. Preliminary models,
2. Models of a theory,
3. Design models,
4. Preparative experimentation models, and
5. Measurement/detection models;

These uses are not mutually exclusive, and even if I tackle them one by one, I am not suggesting that these analyses cannot be combined and integrated, case by case. This also means that the same model, in the sense of an interpreted object exemplifying certain properties, may be used in different ways, representational or not, depending on the context. Therefore, even if below I use the expression "non-representational models" to make my writing less cumbersome, it would be more correct to talk about non-representational *uses* of models.

I will now analyse these categories one by one. For each category, I will critically assess whether, from the perspective provided by the DEKI account, they actually count as non-representational models, and if yes, how so. At the same time, I will show that the definition of model (2.3) provided by DEKI still applies to all cases. Then, I will show for each of them how the conceptual framework of DEKI described in the previous section is not completely useless even with these cases, and some interesting features of each category will emerge.

Preliminary models. Preliminary models are very simplified models used to explore new domains of investigation, to develop more sophisticated models or even theories. However, in themselves, they are not really representing anything in the real world. Currie (2017, p. 770) makes the example of highly simplified hydraulic models that are not representational in any obvious sense, but that are extremely useful as a theoretical starting point to develop more sophisticated models that will in turn be used to represent actual wells and pumps. These preliminary models are very common in science: outside the artefactual camp, Hartmann (1995) discusses a series of very idealised models used to build new, more complex models that will then become the core of the contemporary theory of chromodynamics. He calls them "toy models" and specifies that it would be wrong to understand them in a representational way: they only set the boundaries for the construction of other more refined models. Of course, nothing preserves these preliminary models from serving other functions too. Concerning toy models in chromodynamics, Hartmann adds that these they are also useful to test the implications of idealised assumptions (keep this in mind for when I will discuss models of a theory, below), and to implement mathematical techniques, like renormalisation (see my considerations about normative models, below). Of course, these different functions can interact with each other.

From the point of view of DEKI, preliminary models do not count as representations. They do not denote actual target systems, or even any class of them: there simply is no intended reference to real-world systems. Also, we do not impute any properties to any target system in the real world. Nevertheless, preliminary models are correctly acknowledged as models in the DEKI framework: they are objects endowed with an interpretation and they are particularly useful because they exemplify a certain set of properties. In this way, they contribute to improve scientists' *conceptual* clarity of a domain: for example, they can observe and study the functional relationships between different variables, which make them helpful in order to create new models.

As one can see, the DEKI account here gives us the resources to distinguish representation per se from preliminary models (the difference being in the presence or absence of denotation and imputation), while at the same time accepting both types as instances of modelling by pointing at the common features – particularly, interpretation and exemplification.

Also, this helps us understand the intuitive reason for which preliminary models can and in fact are used to create future *representational* models. This is usually because a certain set of exemplified properties will be retained through the sophistication process. Therefore, instead of taking these preliminary models in isolation, and as simply different from representational models, we can now see them as a first step in the complex and troubled process of trying to represent more accurately real-world phenomena when we lack a solid theoretical structure in the background.

This reconceptualisation of preliminary models as (often) only one part of a representational process, in perfect harmony with the artefactualist spirit of modelling as a practice and a process (see below, sect. 3.3), is obviously showing only a weak connection between representational views of models and artefactualist. So, my remarks about the importance of representation here are to be understood in minimal terms. Still, further emphasis on the synergy between the two perspectives, motivated by the importance of studying models and representation in a dynamic sense, can provide a more complete understanding of scientific models and their use, and opens new interesting lines of investigation.

Models of a theory. Let us consider the second type of non-representational models. A model M of a theory $\mathfrak{T}$ is a system (of objects and relations) that makes the axioms and theorems of $\mathfrak{T}$ true (Frigg & Hartmann, 2018). These models are useful not just for predicting outcomes within the model but for exploring the implications of overarching theories that inform the model. Such models of a theory are widespread in science. Currie, for example, talks of hydraulic models used to calculate values within the model itself (2017, pp. 775–776), rather than actual water flows or pump pressures. In Currie's example, basic physical equations about water flow and pump pressure are used to define the model (thus, a model of those equations), then integrated with hypothetical values for their variables and parameters.

Knuuttila (2021) offers another example: Tobin's (1970) ultra-Keynesian model exhibited cycles between monetary policies and inflation that were also present in the monetarist models of Friedman (1961, 1970) and colleagues. Thus, Tobin demonstrated that entirely different theoretical assumptions could produce the same patterns, challenging Friedman's causal hypotheses about monetary decisions and inflation. The correlation and temporal cycles did not imply causation. Knuuttila suggests that it is hard to identify an actual target system for Tobin's model. Instead, Knuuttila argues, it highlights objective possibilities (2021, p. 9). Agreeing with this view, these models would then illustrate what is possible within a set of (theoretical) assumptions. In Tobin's case, the model shows that multiple economic theories can explain the same behavioural trends, preventing a clear preference for one theory based solely on observations.

What can we say about models of a theory, if we endorse the DEKI account? Once again, there is no denotation for either a particular target system or a class of objects. In addition, and consequently, there is no imputation carried out. So, models of a theory do not count as representations. However, we can nevertheless see how the DEKI account's representational framework is helpful for our understanding of models of a theory. First, again, these systems are acknowledged as models: they are objects interpreted so as to exemplify certain interesting properties (of a theory, in this case). Appealing to interpretation and exemplification, we can also make sense of the epistemic worth of these models: similarly to preliminary models, they improve our *conceptual* understanding. For example, they help us clarify the concepts included in our theories, how they conflict or integrate well with different theories, and the conceptual implications of our background theoretical frameworks.

A further interesting aspect of DEKI is that it can combine models of a theory with representational functions quite naturally: once we have the *Z*-representation, we can always *in principle* use it to represent some target system, if we define a working key that translates the ideal properties of the model into plausible[20] properties of the target. In this sense, the DEKI account offers us a clear indication of how to understand potential interactions between the use of a model of a theory and its representational use.

Artefactualists may want to insist with the intuition that some models are simply too idealised (in my technical sense) to represent anything. However, the artefactualist's appeal to idealisation here gains traction from an implicit assumption of defining *accurate* representation in terms of similarity of faithful description. However in DEKI, a model can accurately, hence successfully represent its target system even if it distorts it importantly.

Let us look at Knuuttila's case of Tobin's model a bit more in detail in order to illustrate my last few points. To begin with, in DEKI's framework, Tobin's model is epistemically valuable because it exemplifies certain features that follow from the endorsement of a certain theory. Actually, the exemplified property here is the fact that certain cycles of monetary policies and inflation follow from ultra-Keynesian assumptions.

One may further object to Knuuttila that, for Tobin's model to count as a genuine competitor to Friedman's models, one is in fact forced to assume a shared target system in the real world. If the two models are not talking about the same kind of phenomena, how could Tobin's model provide a good argument against Friedman's one?[21]

The objection has some traction, but I want to grant Knuuttila's intuition that Tobin's aim was not to provide the *actual* mechanism, but just a possible one, alternative to Friedman's. The goal was not to get the mechanism right, and thus impute a specific property to real economies, but to show that Friedman's model (and general theoretical assumptions) could not be vindicated by empirical adequacy alone: very different models, like Tobin's one, *could* be motivated as well. In this sense, denotation and particularly imputation do not immediately appear to be involved for

[20] Plausible, that is, in the light of our interpretation of the model.

[21] I thank an anonymous reviewer for pointing this to me.

the relevant properties, namely the underlying mechanism which would explain the phenomenon.

So, as Knuuttila herself argues, this model is important because it exemplifies an objective possibilities. Something that *could* happen, given certain conditions, in the real world. But then, if put in these terms, I am sure that also Knuuttila would be happy to grant that these models are also informative about the world of phenomena itself, if indirectly. These models thus aim at provide, as she would put it, informative claims about what is theoretically possible, yes, but possible where? *In our economic world*. Then, if we take the *key* in DEKI in a general enough way – and nothing in the account forbids it – we can use it to clarify how this occurs: we can impute properties to actual target systems in *modal* terms. So, a real economic system *could* function in the way the model describes, given certain initial and boundary conditions. This is analogous to what Nguyen (2020) does with certain highly idealised toy models, saying that we need to translate what is actually true in the model into "susceptibility" claims concerning the target system. In previous work (2023b), I have suggested something similar when it comes to scientific thought experiments. Further arguments about how highly idealised systems can still provide information about real-world systems can be found in Batterman and Rice (2014) and Reutlinger et al. (2018).

In this way, we have also vindicated the previous objection: Tobin's model is a genuine competitor of Friedman's proposal as they have the *same* target system in the real world, but they suggest different *modal* claims about it.

Now, the point I want to make here is simply that, contrary to what Knuuttila suggests, once we understand representation in the sense of the DEKI account and we abandon the intuition that representation is related to copying, mirroring, or preserving the structure of a target, we can deem even highly idealised models as representational, if we have a good translating function at our disposal.[22]

Again, I grant that some models of a theory will simply *not* represent anything, because we cannot, or do not want to find a proper key to convert information from the model to a target system. In that case, we will deem them as simply targetless *Z*-representations. Still, my analysis show that very idealised models can and do turn out to be very useful tools to investigate real target systems, granted that we have a proper way to translate the exemplified properties into imputable ones via a plausible key.

Design models. The third item of my list of non-representational models function as instructions to build things, like bridges and ships and cities, that do not exist yet. Given that relations obtain only if the *relata* do, denotation fails to realise if the target system does not exist. If the denotation condition fails, according to DEKI, design models by definition do not represent anything in the world (yet). One can even imag-

[22] In her 2021 paper, Knuuttila gives a second example of a model that does not represent any real target but only a possibility: the so-called repressillators—bio-synthetic oscillators (Elowitz & Leibler, 2000; Gao & Elowitz, 2016). These concrete systems aim to demonstrate the biological realisability of intracellular feedback oscillatory mechanisms. Even in this case, we can see that we have a (concrete) model of a theory, and if we can find an adequate key translating factual claims in the model into possibility claims in a target, we also have a representation of real target systems.

ine the extreme case where the system resulting from the design model is never built, as for instance in the case of Norton's dome (2008).

As in previous cases, the DEKI account acknowledges design models as models. They are objects, like miniatures and blueprints, interpreted in a specific way to instantiate interesting properties (like proportions, materials and so on). As we have said above they do not denote anything, at least not yet. They may do in the future, when the designed object has been built, and we may use the design model as a representational one. But even when studying them *qua* design model, the DEKI account can offer some further insight.

Again, by exemplifying certain properties and relations, they will increase our conceptual understanding. For example, the type of materials and shapes that will result as possible or necessary for a bridge, or a car, in order to meet our purposes. Moreover, these models will highlight the relation and order between the different steps of construction. Indeed, peculiarly to this type of models, they will prompt a reflection about keys, because a key will have to be conceived when one moves from the abstract algorithm provided by the model to the factual realisation of the material system to be built. In this case, though, we do not eventually impute properties to any target system – as it does not exist, yet. The key provides a list of de-idealised instructions, and not a list of imputations. I will talk more about this sort of "normative" dimension in my discussion of preparative experimentation in a moment. What I want to highlight here is that interpretation, exemplification, and keys are still important aspects of design models that make them closer to representations and allow for interactions between the two different uses.

The remaining two uses of models of my list are inspired by philosophical work on model organisms. Both of these functions do not appear prima facie representational,[23] and they also align well with the artefactual approach because they are closely tied to the material aspects of models and the practices of creating, manipulating, and using them as tools (see Sect. 3.4, below). Therefore, they seem suitable for the present discussion.

Preparative experimentation. Model organisms are genetically manipulated organisms used for various epistemic purposes in biomedical research. While many model organisms can be seen as representations (cf. Ankeny & Leonelli, 2020 and my paper 2023a), they also serve non-representational roles. One such function, theorised by Weber (2004, pp. 154–187), is "preparative experimentation" (*ibid.*, p. 174). In this view, model organisms are not representations of other life forms, but rather provide the material and conceptual framework for developing experimental methods, which can later be applied to different organisms.

Within the DEKI's framework, while systems used for preparative experimentation count as models, as they are also interpreted objects exemplifying interesting properties (this time, methodological and experimental procedures), they do not count as representations. Even intuitively so: If I exercise my use of hammer and nails on tables, and then I use the same know-how on chairs, this does not require me to think of tables as a representation of chairs in the representation-as sense.

[23] Other examples from the artefactual camp closely appeal to these two categories (cf. e.g., Sanches de Oliveira, 2022).

Particularly, there is no imputation involved, concerning either particular or general target systems, as we are not (necessarily) attributing properties to any other system besides the model one. Preparative experimentation simply means that I can do similar actions and interventions on two different systems.

However, while preparative experimentation is conceptually independent of representation, I want to suggest that there is an interesting interaction between these two functions of model organisms. For, when the know-how transfer requires a great deal of theoretical knowledge about the systems involved, representation, in the relevant sense, becomes again crucial. For in order to export techniques and experimental methodologies, like genomic manipulations, from, say, a fruit fly to a mouse, one has to assume that the preparative experimental scenario and the application scenario are matching in the relevant respects. Otherwise, my exportation of know-how may turn out to be a total failure. This is not meant to be a concession to the similarity view of representation: we simply need a key that helps us correctly translate the methods and experimental procedures from one context to another. The dependence of preparative experimentation on representational assumptions will of course be a matter of degree. The more our techniques require theoretical knowledge, the more justificatory role some theoretical assumptions will play in our know-how transfer. In addition, our representational assumptions will be affected by our progress on the know-how too: the more we improve our experimental techniques, the more refined theoretical understanding will be.

As a preparative experimentation device, a model organism would then not work as a surrogative system to inform us about the properties of a designated target, but rather as a way to identify practical guidelines for a user. An analysis through DEKI then, allows us to understand such models as something analogous to *normative* models, like the ones that we sometimes find in economics, ethics, or normative epistemology (Beck & Jahn, 2021; Roussos, 2022, 2025). Instead of describing a target, all these models tell us what to do with it.

Normative models are not representations in DEKI's definition. First, imputation is absent, and it would have to be replaced with an alternative concept from the philosophy of language, like Austin's concept of an "exercitive" speech act (Austin, 1975, p. 154), so that the model's result is not an attribution of properties but a recommendation for action. The further question of whether the model denotes something at all will also be a matter of dispute. One may take, say, an ideal socialist economic model to be: (a) a model of a (political-economic) theory; (b) a literal description of an abstract entity; or (c) a symbol that denotes an actual economic system in the world but represents it in a distorted way to make inferences about it (say, what is wrong with it) or to change it. I do not wish to take a stance on this issue here, but simply point the reader to the interesting new lines of investigation that open in front of us when we start to put in connection the DEKI account with the artefactual emphasis on other sorts of model uses.

Denotation may also be the relevant aspect to distinguish normative models from design models. Indeed, while both categories replace imputations with prescriptions or instructions, design models clearly lack denotation, while this is not necessarily true with normative models.[24]

Measurement/detection models. The final non-representational model type I will mention concerns the use of animal organisms as diagnostic, detection, or measuring devices. As an example, let us consider the organism *Daphnia* (water flea), which acts as an detection instrument and indicator of environmental toxicity levels (Abdullahi et al., 2022). A few authors consider these uses as clearly non-representational (e.g., see Green, 2024, p. 40). This is because they generally assume a similarity view of representation, based on shared features between model and target, or because they simply take for granted that measuring and detecting is a different epistemological category than representing.

Contrary to this scepticism, once we take representation in DEKI's terms, measurement and detection instruments do in fact count as genuine examples of representational models. Specifically, these instruments can be interpreted as providing representations of the systems the values of which we want to measure/detect. For example, the *Daphnia* organisms are used as a representation of levels of toxicity in the surrounding environment. By looking at the water flea, we observe certain salient properties, chemical and behavioural, and on the basis of them, we impute a certain level of toxicity to the surrounding environment. Here, the concept of the key is crucial, as the properties possessed and exemplified by the *Daphnia* have to be translated into levels of toxicity in the surroundings.

Does this mean that measurements like diagnostic animal models, astronomic pictures, and litmus papers work exactly the same way models do? All we can say is that they are all representations in the sense expressed by the DEKI account. However, there may be further aspects in which measurement representations are relevantly different from other models. For example, in previous work (2025) I have argued that while both models and measurement systems can count as representations in the DEKI sense, they fundamentally differ when it comes to the justificatory strategy one has to employ to support their inferences from the representation to the target system. The same thoughts could be applied here to the case of model organisms when employed as measurement devices instead of representations of other organisms. This is a further enrichment of our understanding of models and measurement devices. They do not differ because some represent and some other do not. They differ in that we justify our representational inferences from them in different ways.

In summary, I have listed five uses of models that were at least *prima facie* non-representational: design, preliminary construction, theory-modelling, preparative experimentation, and measurement. This list is not meant to be exhaustive, but the point was simply to reject some stronger, unrealistic understanding of representationalism. This radical version of representationalism would take representation to

[24] Also, there seems to be a relevant difference regarding the source of normativity. Design models inherit normativity from factual aspects concerning what we want to do. In economics, epistemology and ethics, the justificatory source of normative models will tend to be assumptions that include explicitly normative concepts (e.g., equality, happiness, rationality), or assumptions that include thick concepts (Alexandrova, 2017). The demarcation is however not a sharp one, as these different types of normative source may often interact – think of cases where the model is meant to tell us how to "construct" a new, better society, or when the designed artefact has to do with agents' wellbeing.

be more important than other model functions, or even a universal feature of all the epistemic uses of models. It is evident from all the examples above that it is simply not true that “if we want to understand how models allow us to learn about the world, we have to come to understand how they represent” (Frigg & Nguyen, 2017, p. 49).

However, stopping at this point would be short-sighted, because, as I have argued, there is much potential for philosophical analysis of how representation interacts with other uses of models. For each non-representational type of models, interesting reflections emerge when put in relation with the concept of representation in the terms provided by the DEKI account.

There are three general implications one should draw from this section. First, interpretation and exemplification are a general *fil rouge* peculiar to all types of model uses, a fact that also allows us to understand their epistemic function. For, while representational models teach us something about their target systems, non-representational models are epistemically useful because, by exemplification, they inform us about useful, relevant *concepts*. Either about a theory, a new domain of enquiry, or about how to build things and implement novel procedures, models aim at providing conceptual clarity and highlight new salient features of our theories and practices via exemplification. In this way, the full-fledged epistemic value of non-representational models is vindicated, within a representational perspective. Therefore, non-representational models still have something to do with knowledge, plausible hypotheses, or understanding: it is simply knowledge/hypotheses/understanding about different things (theories, concepts and procedures).

Second, representationalism in DEKI’s milder terms is not in opposition to artefactualism, because it allows for non-representational, targetless models. Relevantly, the account further provides useful conceptual resources for any comparative analysis of different uses of models in science, by allowing clearer distinctions and at the same time recognising the common features among them. At the same time, we retain the intuition that representation plays an important role in all aspects of modelling, but only in the sense of *Z*-representing. In these terms, the “representational capacity” of a model, in a very broad sense, is now crucially related to its capacity to refer to certain properties (namely, the properties exemplified by the model), and this function seems to be still in play even with non-rep uses of models.

Third, once the DEKI account is in place, we can see how some irreducibly non-representational models interact in interesting ways with representational working hypotheses. Other prima facie non-representational uses, like measurement, turn out to be instances of representation. So, the apparent contrast of focus and emphasis that seemed to divide the representationalist and the artefactualist is now less stark than it appeared at first sight.

There is no space here to argue for the superiority of the DEKI account in dealing with non-representational models with respect to other accounts of scientific representation. My fear, though – but this is only a suggestion, awaiting further investigation – is that similarity-based accounts (Giere, 2004; Weisberg, 2013) will struggle with non-representational models, as there seems to be no intuitive sense of similarity or structure preservation to be applied. This is true even if we assume, like these authors do, pragmatic factors like the user’s interpretation and selection of the relevant properties. In DEKI, the key breaks the condition of similarity and allows to translate the salient properties of the model into working hypotheses about a target or practical instructions, when it comes to design models and normative models like the ones used for preparative experimentation. A paradigmatic case of the difference made by the key is measurement models, where there is no similarity between model and target, but instead we have a function that translates properties of the model into values of the measured observable in the target system. For example, the colours exemplified by a litmus paper must be translated via a key into levels of acidity of a solution, but colours and acidity levels are not the same thing, nor are they similar to each other in any meaningful respect.

This is relevant to the artefactualist's worries: once we detach representation from similarity, it is much easier to see how models represent target systems even when they are very different from each other, even when we are concerned with relevant properties under investigation, as we have also seen with Knuuttila's case of Tobin's economic model.

Concerning inferential accounts, and this is again a conjecture in need of more substantial reflection, they are clearly applicable to all model types mentioned here and very well matching with artefactualism overall. However, inferentialism does not seem able to differentiate among different uses of models: all the examples of this list would indiscriminately count as instances of scientific representation, because they all count as cases where some inferences are drawn about a target system on the basis of a surrogate system.[25]

Interestingly, the same problem seems to haunt artefactualism. Knuuttila holds that one "of the benefits of the artifactual approach is precisely its ability to cover many different types of models and modeling practices" (2024, p. 114), but there seems to be little conceptual arsenal available to the artefactualist to partition the different uses of models while also see the existing connections between them.

The artefactualist may be content to just refer to all models as artefacts, and to not taxonomise models any further. However, I simply take it as a virtue, and not a shortcoming, the fact that the DEKI account allows us to distinguish different uses of models, while at the same time shedding light on the conceptual affinities and interactions between them. The partitioning that I began to develop in this section will hopefully be seen with favour also within the artefactual circles, as a first step towards a reasonable organisation of the uses of models as epistemic tools in science. This section shows how this can be done and indicates the way to further develop the synergies between the various functions served by scientific models.

[25] In response to the worry of an anonymous reviewer, I want to clarify the contrast between the DEKI account and inferentialism. DEKI defines representation via referential and interpretive notions, like *I*-functions, denotation, exemplification, and keys. In contrast, inferentialism either excludes denotation (see Suárez, 2024; Khalifa et al., 2022), or exemplification and the keys (Contessa, 2007; Díez, 2020). Also, inferentialism gives surrogative reasoning priority and explains representation in terms of the former. In DEKI, explanation goes in the opposite direction: surrogative reasoning is explained on the basis of referential, semantic relations and interpretive activities.

3.2 Representation as an inert concept?

There is a more fundamental criticism raised within the artefactualist camp against the concept of representation when applied to scientific models. Namely, both Knuuttila (2011, 2021, 2024) and Sanches de Oliveira (2021, 2022) seem to suggest that the concept of representation is to be considered philosophically inert as regards the epistemic value of models: it does not really play any role in a philosophical understanding of how scientific models work and why they are successful. Let us analyse the argument as originally elaborated by Knuuttila in her earlier work (2011).

First, she identifies two questions about models and representation that have to be answered for any representational account of models: what the relation of representation exactly consists of, and what makes a model an accurate or successful representation of its target (*ibid.*, p. 264).[26]

Knuuttila considers two general families of responses to the first question: the strong accounts and the deflationary approaches. The first group tries to reduce the concept of representation to some form of similarity or morphism between model and target. These views of representation thus "revert solely to the properties of the model and its supposed target system" (Knuuttila, 2011, p. 264), often mathematical-structural properties. Knuuttila then proceeds to criticise these reductionist attempts. As we have seen in Sect. 2.1, representationalism allows but does not require this appeal to similarity, or structure preservation. The DEKI account, in particular, rejects this condition, and Knuuttila herself grants that also other accounts avoid this commitment to a more "substantive", "mind-independent" relation. Therefore, I ignore this line of Knuuttila's argument.

The second family of responses, Knuuttila suggests, take representation to be (at least) triadic, in that not only they consider the model system and the target system but also include an agent or user. These views, Knuuttila argues, do not necessarily depend on substantive relations like similarity or isomorphism. In contrast, while some sharing of properties may be relevant, these views assume that the representational relation has been defined in terms of the intentions or purposes of the user. The problem with these accounts, Knuuttila argues, is that they end up putting all the burden on the user's intentions and purposes:

> When representation is grounded primarily on the specific goals and representing activity of humans instead of some specific properties of the representative vehicle and the target object, it is deprived of much of its explanatory content: if one opts for a pragmatist deflationary strategy, not much is gained in claiming that models give us knowledge *because* they represent their target objects. (*ibid.*, p. 266, original emphasis)

All the work, so to speak, would be done by the specifications relative to the user, and the concept of representation would become conceptually inert. This criticism seems a bit uncharitable with respect to many representational accounts – even those that combine similarity or isomorphism with the agent's intentions (Giere, 2004; van

[26] The explicit formulation of this distinction can be traced back to Suárez (2010).

Fraassen, 2008). However, Knuuttila's words reveal what I believe is a general worry among philosophers of science when it comes to scientific representation. In a nutshell, representation would not be a particularly useful concept for our philosophical investigation of models and other scientific practices. Also, given that nobody in the field replied to Knuuttila on this point, it seems important to address this issue.

Knuuttila's doubts about representation have grown milder with respect to this original formulation, in part also in reaction to more sophisticated accounts proposed in the literature like the DEKI account. However, even in more recent works, she still holds principled suspicions against the representational approach altogether. In a more recent paper (Knuuttila, 2021), she repeats that "[p]ragmatist [representational] approaches [to models] tend to be deflationary in that they do not explain how and why models give us knowledge" (Knuuttila, 2021, p. 4). And, among the deflationary accounts, she mentions the DEKI account explicitly (*ibid.*, p. 3).

Again, in her most recent illustration (Knuuttila, 2024) of the value of artefactualism, Knuuttila quotes Isaac (2013) and holds that we can well explain the success of models without a prior conceptualisation of representation (Knuuttila, 2024, p. 111). In that paper, she also continues to express her scepticism towards what she calls pragmatic accounts of representation:

> […] pragmatic accounts of representation do not […] have resources to tackle the question of what makes scientific modeling epistemically rewarding (apart from referring to surrogate reasoning). The DEKI account of representation […] goes further than other pragmatic accounts of representation in this regard [but] nevertheless relies on imputing some features of the model to a target system, though it also admits that a model may not have a target system. (*ibid.*, p 112)

While Knuuttila starts here with the same problem she was raising in her previous papers, when she talks about DEKI she simply reports that the account allows for targetless models. This is odd, as the possibility of targetless models should count as a positive aspect of the DEKI account. In any case, while not further motivated, Knuuttila's scepticism towards representation seems to persist, and the improvements offered by the DEKI account are eventually deemed as insufficient to insist opting for a representational framework.

In his 2021 paper with the very explicit title "Representationalism is a dead-end", Sanches de Oliveira puts forward an argument very close to Knuuttila's. He argues that any representationalist account of models (DEKI included: *ibid.*, p. 221) will not work because of the inevitable tension between two methodological assumptions, which however irremediably inform any representational account of models:

> *Ontological component of representationalism (OC)*: models are representations; i.e., models stand in a representational relation to target phenomena.

> *Epistemological component of representationalism (EC)*: modeling is epistemically valuable because of its representational nature; i.e., the representational

> relation between model and target is what secures the epistemic worth of modeling. (*ibid.*, p. 213, original emphases)

Sanches de Oliveira then argues that the tension can be shown both in the case that we assume representation to be mind-independent relation (for example, simply a matter of similarity or isomorphism) and in the case that it is instead conceived as mind-dependent. Given that basically all current accounts of representation acknowledge that representation is mind-dependent, DEKI included, I will focus on the second case only.

Sanches de Oliveira argues that mind-dependent accounts of representation acknowledge that models are representations (thus endorsing OC), but in order to do that, they inevitably allow the possibility that models misrepresent their targets in relevant ways. However, the author argues, this move turns out to “undermine” EC: if models can misrepresent, it is not clear how representation helps us understand models’ epistemic fruitfulness (*ibid.*, p. 222). Therefore, if we get OC, we end up losing EC. But this is problematic of course, because by renouncing EC we also remove the motivation of theorising about models in representational terms in the first place. This is because, Sanches de Oliveira suggests, what we are fundamentally interested in is models’ epistemic success, and representationalism, by sacrificing EC, does not explain this success.

I take Knuuttila’s and Sanches de Oliveira’s worries about representation to be fundamentally alike: if we want a good definition of representation, we sacrifice its explanatory value when it comes to model success.

The first thing to say in response, is that the DEKI account is very different from other “pragmatic” accounts of representation mentioned by Knuuttila (2011, 2024) in that it does not put so much burden on the user. Of course, it implicitly requires users, because without users there would be no interpretation, denotation, exemplification or keys. Still, exemplification requires instantiation, and interpretation relates actual properties of the carrier with properties of the *Z*, which will then be imputed to the actual target system via a key. More generally, the context importantly goes beyond the user and their intentions or goals: particularly in the scientific context, what counts as relevant in the interpretation, or what counts as exemplified or not, depends not on the single user and their subjective idiosyncrasies, but on the disciplinary field of enquiry, the relevant programmes of research, and most importantly, the more general theoretical and empirical background. Therefore, the account does not imply that the intentions and goals of users do *all* the explanatory work. In contrast, the concepts of interpretation, exemplification and keys allow us to disentangle the various aspects of modelling practice. Indeed, these concepts help us organise and analyse these activities and evaluate them with respect to the epistemic value of the model in use.

Let us move to Knuuttila and Sanches de Oliveira’s more general doubts about the role of representation in accounting for the epistemic value of models. It is true that being a representation, according to DEKI, does not per se imply any success. This is, again, a *desideratum*, because, in fact, many models fail to be accurate, even when they were meant to be employed as representation. In other words, we have to allow for misrepresentation. Therefore, we at least need that the model represents the target accurately. All this being said, I want to insist that a representational treatment of models is still relevant epistemically. Even though representation does not by itself secure our inferences from a model to a target, it is not the case that representation is a useless concept. If a model is epistemically successful it is *because* one has given a valuable interpretation of the model, the model succeeded in exemplifying certain properties – that is, making them cognitively salient for us –, and we have managed to impute these properties accurately to a properly designated target via a suitable key. Then, our imputations result in an epistemic advancement, in the form of working hypotheses, regarding what we want to learn about the target. So, it seems that the disarticulation of representation according to the view developed here *is* undeniably useful to understand model epistemic success.

This of course is not the end of the story: we are not satisfied with lucky guesses in science. We will find reasons to justify our success, and also hypothesise that the strategies employed in successful cases will be successful in other cases. Of course, our reasoning will always be tentative and conjectural, but this is to be expected by a form of ampliative reasoning like the one in play with modelling practices.

So, we can see that the ontological and epistemic conditions of representational accounts are not in tension in the DEKI account.[27] In fact, it appears that representation, while not being a sufficient condition for model success, is actually crucial to understand the epistemic use of a model when employed to draw inferences about some real target system. As I have said before, I do not argue that representation is necessary for model success *tout court*: there are other uses of models, and consequently also different ways to assess their success which are not representational. The point is that representation is still pivotal to understanding a specific way to use models, which is to make inferences about a certain target system. Particularly, while being a representation is no guarantee of a model's representational accuracy, a representational account allows us to frame the question clearly and puts us in the position to answer whether a model represents accurately or not. Moreover, given the synergies observed in the previous section, it would be reasonable to investigate how the success of some non-representational models would in fact depend on some background representational assumptions. For example, a successful preparative experimentation of a model organism will often depend on representational assumptions about how certain mechanisms exemplified in that model organisms are imputable, with a proper approximation, to the target organisms.

In response to my argument in the foregoing paragraph, Sanches de Oliveira might express further doubts about my shifting from representation *simpliciter* to representational accuracy. In fact, he explicitly raises this point and states that "the same problem would arise of whether accuracy should be defined in mind-dependent or mind-independent terms" (Sanches de Oliveira, 2021, p. 225). However, Sanches de Oliveira does not explain this problem further, and it is not clear in what sense it would be a problem at all. In the DEKI account, whether a model is representationally accurate or not is a mind-*in*dependent fact: either the target system in fact possesses the properties we are imputing to it, or it does not. The pencil in front of me, even

[27] They may well be for a non-sophisticated, similarity-based account. But if one specifies that the model and the target system do not need to be similar in all respects but only in the relevant ones, similarity views may also be able to escape the objection.

if taken to be a model of the universe (mind-dependent fact), is still not an accurate model of the universe (mind-independent fact), if we do not specify some suitable sense in which the pencil would exemplify certain aspects that are also instantiated by the universe. Simply, it is a bad representation, no matter what my purposes are, or how much I believe otherwise. The same holds for success: whether or not a model is successful is an objective fact, whatever notion of objectivity one wants to endorse. Of course, success will always be *relative* to a certain purpose of an agent or an epistemic community, and purposes are of course mind-dependent things. But whether a purpose-relative result matches successfully those purposes or not is nevertheless a question independent of our intentions.

Summarising, *pace* Knuuttila and Sanches de Oliveira, representation is very far to be inert philosophically when it comes to understanding model success. This is because of the useful disarticulation of representation in concepts like interpretation, exemplification, denotation, keys, and imputation. These concepts help us look for the crucial information: how was the model interpreted? Did it exemplify certain interesting properties? Which ones? Can we associate these properties with properties of the target system? Is this association justified by our understanding of the model, as well as by our background knowledge? Therefore, representation, if not by itself sufficient to explain model success, gives us a useful perspective and guide to start explaining it.

The artefactualist could still complain that DEKI does not give an ultimate answer to why model inferences do in fact succeed. This is because it concerns only the justification of the internal correctness of the model's inferences, not the external, factual one (see above, sec. 2.2). But, even if it is true that the external correctness of our inferences can be justified only by looking outside the individual model framework, (i) we still benefit from the unpacking obtained via the DEKI account, and (ii) there cannot be a universal, ultimate answer to the question about factual correctness, due to the ampliative, conjectural nature of scientific modelling.

If my answer to the question of knowledge from models does not satisfy the artefactualists, so be it. But then, they would still have to offer a valid alternative reply to the knowledge question. Knuuttila (2024, p. 115) and Sanches de Oliveira (2022, p. 26) both argue that models are artefacts created to answer scientific questions or to support scientific reasoning. All parties certainly agree on that, but this seems terribly general, and it does not really provide an informative answer to the question about the epistemic success or value of models. We need to look at the details. Artefactualists would then benefit a lot from DEKI and its concept of representation, as it offers a general schema to start explaining the epistemic success of models.

3.3 The dynamic nature of representation

After granting the artefactualist that representation is only one of the many functions that models can serve, but nevertheless defending the value of a representational approach from the suspicion of philosophical inertness, it is now time to move to the three further, less radical challenges listed at the beginning of Sect. 3: the dynamic nature of modelling practice; the importance of the material aspects of models; and their independence from theory and data. In this section, I develop a dynamic understanding of representation-as accounts. In the next section, I tackle the other two challenges.

The artefactualists have often insisted that the representational analyses of models, and philosophical reflections about models more generally, tend to excessively objectify models: we should not talk about models so much as about *modelling*; less about representations, and more about *representing*. In short, we should conceptualise models as processes and activities, as this better captures the actual practice of science. The underlying suggestion is that, by considering the object of analysis an activity or a process, instead of a static object, we will also be able to solve some more fundamental issues concerning the understanding of how science actually works.

Here, I want to suggest that the DEKI account, even if its originators did not emphasise this aspect in their original formulations, can be easily reconceptualised so that it can address this dynamic nature of representation.

First, the interpretation of the carrier as a *Z*-representation should not be understood as a fixed, once-and-for-all association of elements of the carrier with elements of the *Z*-representation. Rather, interpretation is a dynamic, reiterative and fallible process carried out by an agent or a group of agents.

Second, exemplification may appear static as concerns instantiation, but the process with which we come to define the relevant system of categories and classifications of properties in a given field of enquiry is also the result of a ceaseless process. Moreover, exemplification has always been conceptualised as dynamic in its second, referential dimension, as it strongly depends on the context (and thus also on the purposes, questions, and cognitive abilities of the users).

Third, the key can also be easily re-defined not as an ultimate, perfectly defined mathematical function, but rather as the provisional and conjectural product of an interpretive activity on the part of the scientists, who constantly try to de-idealise properties of the model on the basis of their current understanding of it. Similarly, imputation was from the beginning understood as a tentative form of property attribution, sensitive to conceptual and theoretical changes and apt for consequent revision.

Fourth, as a consequence of these dynamics, the identification of the target itself will be affected.[28] The more we study and understand a model, the more precise we will be about the respects in which it functions as an accurate representation of a target system, thus clarifying the conceptualisation and the boundaries of the target itself. Therefore, even denotation, which may start as a more or less simple ostensive act of stipulation, will in part be a dynamic process, and we can reasonably talk about *moving target systems*.

An aspect I particularly want to emphasise here is the evolution characterising the *I*-function. It seems to me quite plausible that there will be a temporal dimension of the interpretation of a representation. A lay person, or even an inexperienced scientist, may not be able to immediately interpret, say, a medical scan or an astronomical picture correctly. They will certainly be able to detect colours in the astronomical image, or changes of continuity and homogeneity between different shades of grey in a brain scan. Therefore, what the picture exemplifies for them is in fact just the

[28] See Price (2019) for a similar argument when it comes to exporting a model from one domain to a new one.

colours and their distribution. Given the cognitive nature of exemplification, only with time and practice will a beginner start to “see”, say, colours *as* chemical and electromagnetic properties of astronomical objects, or discontinuities in colour in a medical scan *as* the (likely) presence of a tumour. The distinct *Z*-representation, then, as a way of classifying the type of representation according to certain respects that are relevant to the specific context of enquiry, will emerge progressively through a continuous process of adaptation of the agent to a certain interpretation of the carrier. Not only do we have moving targets, but also evolving *Z*-representations.

Finally, the dynamic of representation in DEKI is of course not exhausted by the sum of the individual evolution of each component – interpretation, denotation, exemplification, (keying-up) and imputation – but is also a product of the mutual interaction between them, as well as of the interaction between the representation system as a whole with the rest of our empirical and theoretical knowledge. This is particularly true when it comes to justifying the correctness of the inferences we draw from representations about our target systems. If we do not have direct access to a target system, all we can do is to check whether the results of our representation fit well with other results obtained from other experiments, measurements, models, and theories.

This dynamic way to think of representation can help us address another point raised by the artefactualists, namely, that models are not isolated atoms, but they are usually used in combination. The standard attempts of application of the traditional accounts of representation may have focused on a single model, or representational system, and this was an inevitable idealisation of actual scientific practice. In this respect, the artefactualist’s point is correct: models are very often used in a very integrated, synergic way. And not only are other models used to justify our inferences: overarching theories and experimental results are also part of the process of the justification and the inferential activity.

Yet, my representational approach about models does not rule out the possibility of complicating the picture and making it closer to actual scientific practice. We can still understand the relation between a model and a target in representational terms, while at the same time consider the more complex aspects of modelling practices. In fact, nothing rules out complex, multi-system forms of representational activity, where inferences are made on the basis of the comparison and integration of more than one representational system (multiple models, experimental specimens, pictures …). At the same time, given the dynamic nature of the representational activity just illustrated, it becomes clear that theories and data are also involved in the production of the interpretation of the model as a *Z*-representation, and of the required key used to de-idealise. The standard focus on a single model, thus, taken in isolation from the rest of our scientific knowledge and tools as a unit of philosophical analysis, is now reconceptualised as limited but useful abstraction; useful, insofar as it provides a first step for a more sophisticated description of modelling activities overall.

While perhaps implicitly entailed by the original formulation of the DEKI account, the dynamic nature of representation had not yet been made explicit by its originators. I put this development forward as an explicit response to address the artefactualist’s solicitations.

3.4 Mediation and materiality

Among the artefactualist's ammunition against representational approaches to models, there are at least two further criticisms. One is the fact that models should be interpreted as mediators (Morgan & Morrison, 1999), and thus importantly independent of both overarching theories and data. Second, and in part related to the first issue, models should be understood as systems in their own right, with specific peculiarities, material and theoretical constraints and affordances, somewhat independent of their designated target system (Knuuttila, 2005; 2024; Sanches de Oliveira, 2021).

The first worry should be easily avoided, once representation is understood correctly. Until proven otherwise, representation-as accounts do not seem to collapse models either on theories or empirical observations: models are systems endowed with an interpretation, which can be informed by theories and data but do not need to. Particularly, interpretation and the very construction of models can include all sorts of what we usually call idealisations and distortions, which do not directly follow from either theoretical background or empirical evidence. Certainly, the interpretive function I that allows us to obtain the Z-representation will often be informed by our scientific theories, as well as by the knowledge obtained via other modelling and empirical means. Also, our keys will derivatively depend on our theoretical interpretation of the model system. Still, nothing in the representation-as approach stops us from making further assumptions that do not follow or align with our overarching theories. In this sense, models often provide a space for free imagination, as well as experimentation on different assumptions, only some of which will pass the test of usability.

Let me focus now on the second constellation of problems, concerning the materiality of models, as well the importance of their specific constraints and affordances. In order to systematically deal with this multifaceted challenge, I refer here to Knuuttila's (2011) disarticulation of aspects that an artefactual approach would allow us to emphasise, and a representational one would not. Knuuttila lists four[29] aspects that the artefactual view of models emphasises and that representational views ignore or do not address satisfactorily. I will analyse these four points one by one and show that there is a substantial convergence between my representational approach and Knuuttila's artefactual perspective. The four aspects listed by Knuuttila are:

> (i) the constrained design of models, (ii) non-transparency of the representational means by which they are constructed, (iii) their result-orientedness, [and] (iv) their concrete manipulability. (Knuuttila, 2011, p. 267)

Concerning (i), Knuuttila emphasises that models are objects in their own right, at least partially independent of their targets, and as such they possess specific affordances and limits that depend on how they were constructed. In this context, Knuut-

[29] The fifth element of Knuuttila's list, concerning how models' "justification is distributed so as to cover both the construction and the use of models" (Knuuttila, 2011, p. 269), actually concerns the fact that models should not be taken as static and isolated systems, but as dynamic processes that also involve other bits of our scientific knowledge, a point that I have already addressed in the previous section, as well as when I distinguished between justification for internal and for external correctness, at the end of Sect. 2.2.

tila also insists that, in her artefactualist perspective, we can appreciate the value of idealisations: far from being mere shortcomings, they are valuable in their own way because they are part of a system that as a whole afford us new knowledge and understanding.

I take it that the DEKI account fully acknowledges the partial independence of models from their targets, by recognising the properties of both the carrier and the *Z*-representation, and explicitly distinguishing them conceptually by any potential target system. This "distance" between the model and the target system is an important aspect of the DEKI account, which tries to fix it with the key. In both cases, the model and the target system are not a direct, unmediated relation of similarity or isomorphism, but a dynamic process of interpretation, with the aim of finding out ways to interpret the model as to answer questions about the target system. Moreover, DEKI sheds light on the role of idealisation by highlighting the role of exemplification. In this account, idealisations are epistemically fruitful because they allow and produce epistemic salience, so that certain properties are exemplified. Then, one has to clarify how certain properties are made salient in particular contexts by a certain model system, giving a more detailed account of how idealisations (with respect to the target system) of the models positively partake in this process of salience-making.

Knuuttila's second aspect (ii) concerns what she calls representational *means*, which she later explains are the result of a combination of a certain representational *medium* (paper and ink, digital pixels, living tissues …) with a certain representational *mode* (which can be linguistic or symbolic, pictorial, or diagrammatic) (Knuuttila, 2011, p. 269). Representational means and their potential, Knuuttila argues, are often non-transparent to scientists from the start: they have to explore those means and find out what they can be used for. This seems in perfect continuity with the general of the DEKI account. Given its skeletal nature, DEKI does not specify the characteristics of each single carrier, or the resulting *Z*-representation: it is the work of a philosopher of science to illustrate each case in detail. While I concede to Knuuttila the importance to remember the non-transparency of representational means, there is nothing in DEKI that leads us to underestimate this factor: on the contrary, with its disarticulation of representation in many dimensions of a complex interpretative activity, the account gives us all the motivation to appreciate it.

With *result-orientedness* (iii), Knuuttila means the fact that "the starting point [of modelling] is often the output and effects that models are supposed to produce" (*ibid.*, p. 268). This is also in line with her point that models "are constrained in view of answering a pending scientific question" (Knuuttila, 2021, p. 5). Here, there may be some tension with her previous point that models are somewhat independent of their target systems in the first place. Certainly, when we model we often start with some questions about the target, but it may be the case that the model we designed does not answer those questions, and it instead opens new puzzles and possibly solves them, or at least frames the old problems in a different way. In short, modelling is much more an open-ended process than Knuuttila seems to suggest with her third point. The account of epistemic representation presented in this paper easily avoids this issue by not building specific questions into the representation activity, letting them arise in a dynamic way.

The concrete manipulability of models has sometimes been neglected by philosophers of science, mostly interested in abstract or mathematical models. This may have been true for certain approaches specifically, like the structuralist view of model representation, which focused on mathematical structures (Da Costa & French, 1990; Da Costa & French, 2000; French & Ladyman, 1999). In contrast, the DEKI account was born first of all as an account of material representations and material models,[30] then adapted to non-material ones,[31] and nothing in the account seems to privilege abstract, mathematical models with respect to the concrete ones. Furthermore, in the case of abstract models, there is no problem with saying that models are manipulable, granted that we have a clear sense of what manipulation is in that case (for instance: changes in the relevant assumptions, logical derivation, and so on). But if the problem was to provide a clear definition of manipulability that works well with abstract objects, this would be probably shared by all accounts of scientific modelling, the artefactual approach included.

4 Conclusion

In this paper, I have clarified the main points of disagreement between artefactual views of models and the representational view I support, which bases representation on interpretative activities and referential relations – rather than similarity or isomorphism. Once this disagreement has been fully expressed, I offered a defence of my representational framework from many criticisms raised by artefactualists, and adapted my proposal to meet other concerns from the artefactual camp. In this way, I provide a synergic solution that retains the main intuitions of a representational account of models and integrates it with the most insightful aspects of artefactualism. In this way, I hopefully amend the conflict among the two camps and make our philosophical discussion of scientific models move forward.

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Declarations

Conflict of interest I confirm that I have no conflict of interest and that I adhere to all the requirements of the COPE guidance.

[30] Cf. Frigg and Nguyen (2016, 2019, and 2020, pp. 159–184).

[31] Cf. for example Frigg and Salis (2017) and Salis Frigg and Nguyen (2020).

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