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ASSESSING DESIGN CREATIVITY: REFINEMENTS TO THE NOVELTY ASSESSMENT METHOD

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1. Introduction

Creativity is highly important in designing products and supporting companies to capture large market share [Eisentraut and Badke Schaub 1995], [Cropley et al. 2011], [Jagtap et al. 2014]. As a consequence, considerable research efforts have been directed towards understanding and assessing creativity [Amabile 1996], [Sternberg and Lubart 1999]. Assessment of creativity is essential to select innovative products, to evaluate the degree of innovation taking place in companies, and to identify better inventors and designers [Sarkar and Chakrabarti 2008]. 'Novelty' is a key characteristic of a creative idea, and is therefore considered as one of the core components of creativity [Sarkar and Chakrabarti 2008]. For example, to Davis [1992], "creativity appears simply to be a special class of psychological activity characterized by novelty." As novelty is a key component of creativity, its measurement is essential to assess creativity of products [Sarkar and Chakrabarti 2008].

Novelty is also an important metric used to evaluate idea generation methods in engineering design [Jagtap et al. 2015]. Idea generation methods can be evaluated through process-based and/or outcome-based approaches [Shah et al. 2003]. Since process-based approaches are time consuming and difficult due to the inherent complexity of examining cognitive processes responsible for creative thought, outcome-based approaches are frequently used [Shah et al. 2003]. In outcome-based approaches, the designs/outcomes produced by designers are evaluated by using some metrics, including the metric 'novelty' [Shah et al. 2003].

Sarkar and Chakrabarti [2011] developed a method to assess novelty of products and ideas as well. They argue that their method overcomes the inadequacies found in the novelty assessment methods developed by Shah et al. [2003], Saunder [2002], and Lopez-Mesa and Vidal [2006]. Their method has received attention in design research, as indicated by a number of studies referring to or using their method (e.g. [Borgianni et al. 2012], [Snider et al. 2013], [Fuge et al. 2013]).

While Sarkar and chakrabarti's novelty assessment method has received attention, deficiencies were found in it when it was applied in our own studies. It is the purpose of this article to address these deficiencies to refine the method. In total, four modifications have been proposed to their method, and are supported by drawing on examples of products and ideas.

2. Background literature

There is large body of literature reporting a variety of creativity definitions (e.g. [Amabile 1983], [Sternberg and Lubart 1999]. To develop a 'common' definition of creativity, Sarkar and Chakrabarti [2008] analysed the creativity definitions, by using 'majority analysis' and 'relationship analysis'. The 'majority analysis' ensured that the 'common' definition utilized the most frequently used concepts in the current creativity definitions, and the 'relationship analysis' was aimed to capture the rich underlying relationships among the concepts used in the various definitions. The results from these two analyses were compared to propose this 'common' definition: 'Creativity occurs through a process by which an agent uses its ability to generate ideas, solutions or products that are novel and valuable.' This definition indicates that novelty is a core component of creativity, and therefore novelty assesment is prerequisite to assess creativity.

Because idea generation is important in engineering design, many research studies are devoted to evaluate idea generation methods by using a set of metrics, including the metric 'novelty' [Shah et al. 2003], [Jagtap et al. 2006]. Novelty is a measure of how unusual or unexpected an idea is as compared with other ideas [Shah et al. 2003]. In terms of a design space, which includes all possible options to a given problem [Ullman 2009], novelty is a measure of whether the exploration of ideas occurred in areas of the design space which are well travelled or little travelled [Nelson et al. 2009]. Lopez-Mesa and Vidal [2006] and Linsey [2007] suggest 'infrequency' as a measure of novelty.

There are several novelty assessment methods. Lopez-Mesa and Vidal's [2006] novelty assessment method is based on identifying similarity of solutions at the level of function, conceptual structure and detail structure. Shah et al. [2003] proposed two approaches to measure novelty. The first approach uses '*a priori*' perspective in which the universe of ideas for comparison is obtained by defining what is usual or expected, preferably before analyzing any data. In the second approach, called '*a posteriori*' perspective, ideas generated by all participants from all methods are collected and analysed.

Sarkar and Chakrabarti [2011] identified several deficiencies in the novelty assessment methods developed by the researchers: Lopez-Mesa and Vidal [2006], Shah et al. [2003], Saunder [2002], and Redelinghuys [2000]. The deficiencies that were identified include: the methods do not consider the timeline of invention, most of the methods do not assess how novel a product is (i.e. the degree of novelty), and the methods use arbitrary abstraction levels to assess product novelty. Sarkar and Chakrabarti [2011] developed a novelty assessment method to overcome the limitations of the current methods. Their method has received attention in design research as indicated by a number of studies referring to or using their method (e.g. [Borgianni et al. 2012], [Snider et al. 2013], [Fuge et al. 2013]), and also by the number of citations to their article. For example, their article is one of the most cited articles published since 2010 in the journal 'Design Studies'.

Sarkar and Chakrabarti's [2011] method employs FBS (Function – Behaviour – Structure) and SAPPhIRE models. The FBS model is employed first to identify whether a product is very highly novel or not. Then, the SAPPhIRE model is used to assess relative degree of novelty of a product with respect to previous products. Their novelty assessment method can be used not only for products, but also for solutions and ideas.

In the FBS model, Function is what a system does and it is intentional. Behaviour is how a system accomplishes the function, and Structure represents the elements and interfaces constructing the system and its interacting environment. In assessing product novelty, the FBS model is used first (Figure 1):

- A recently generated product is assigned 'very high' novelty if it fulfils a new function, which is not fulfilled by any of the existing products. For example, the X-ray machine, when it was introduced first time, is an example of a very high novelty product.
- A recent product is 'not novel' if its structure matches with that of any other available products. A recent product has some degree of novelty if its structure is different from that of other products.

The use of FBS model helps to identify 'very high' novelty products, and to ascertain whether or not a product has some degree of novelty. Next, the SAPPhIRE (State-Action-Part-Phenomenon-Input-oRgan-Effect) model of causality is used to assess the relative degree of novelty of a product. The SAPPhIRE model provides a rich causal explanation of physical phenomena and attempts "to reach a non-arbitrary degree of detail of behavioural explanation" [Chakrabarti et al. 2005].

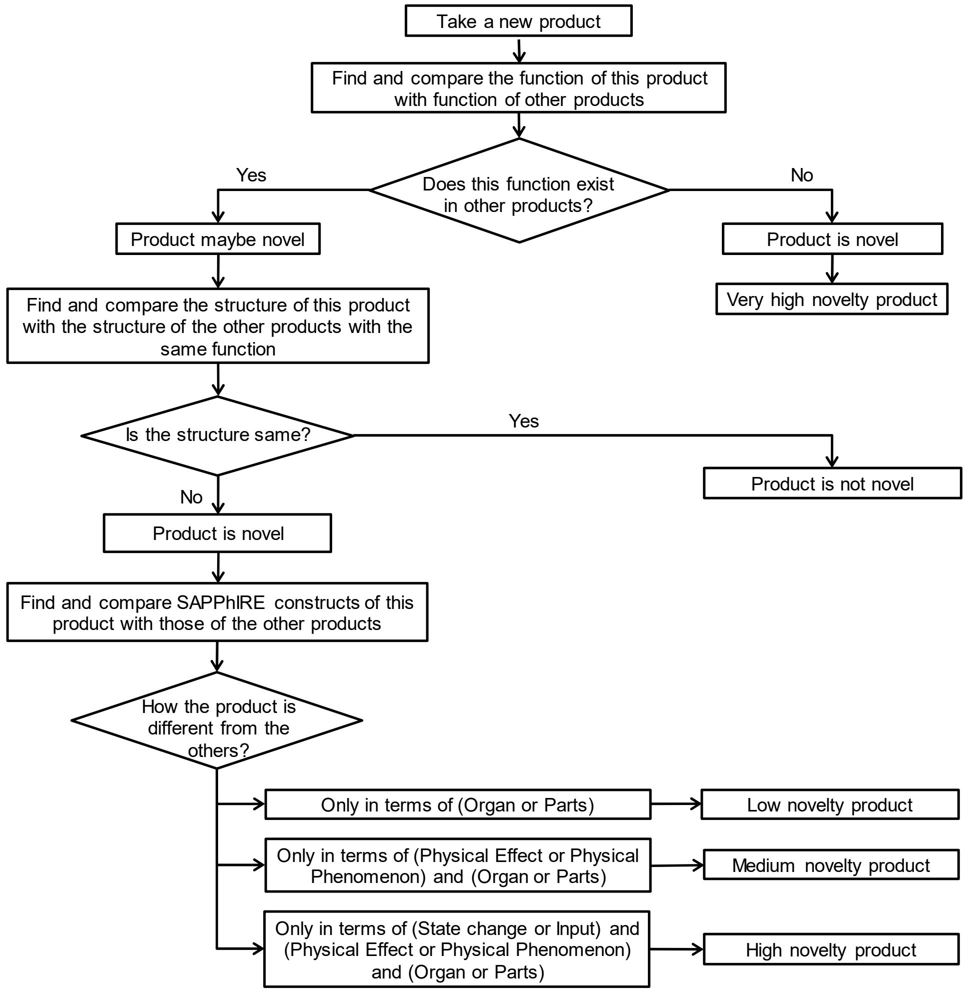

Figure 1. Steps in the novelty assessment method of Sarkar and Chakrabarti [2011]

The SAPPhIRE model explains the relationships between the following seven constructs (See Figure 2):

- Parts - "a set of physical components and interfaces constituting the system and its environment of interaction";
- State change- "the attributes and values of attributes that define the properties of a given system at a given instant of time during its operation";
- oRgan - "the structural context necessary for a physical effect to be activated";
- Effect - "the laws of nature governing change";
- Input - "the energy, information or material requirements for a physical effect to be activated; interpretation of energy / material parameters of a change of state in the context of an organ";
- Phenomenon - "a set of potential changes associated with a given physical effect for a given organ and inputs"; and
- Action - "an abstract description or high level interpretation of a change of state, a changed state, or creation of an input".

The relationships between the above constructs are: parts *create* organs; organs and inputs *activate* physical effects; physical effects *create* physical phenomena and changes of state; and changes of state are *interpreted* as actions or inputs, and *create or activate* parts. Sarkar and Chakrabarti [2011] have mapped SAPPhIRE model to FBS model. The construct 'action' in SAPPhIRE is considered as 'function' in FBS; 'parts' in SAPPhIRE is interpreted as 'structure' in FBS; the other constructs of SAPPhIRE work together to create 'behaviour' in FBS.

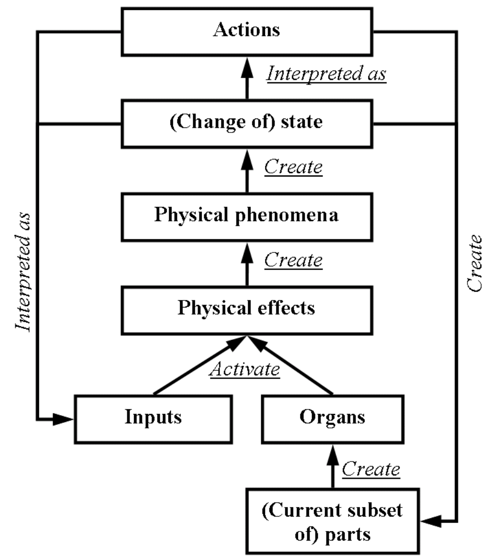

Figure 2. SAPPhIRE model of causality [Chakrabarti et al. 2005]

In their novelty assessment method, which uses FBS and SAPPhIRE models, products are assigned degrees of novelty as follows (see Figure 1):

- A new product with a difference at the level of function (action) is assigned 'very high' novelty.
- If a new product fulfils the function (action) already satisfied by some other products, and differs from other products in terms of all the other six constructs (except 'action'), the new product is assigned 'high' novelty.
- A new product is qualitatively attributed with 'medium' novelty if it differs from existing products only in terms of 'physical effects' or 'physical phenomena' plus 'organs' or 'parts'.
- A new product is taken as a 'low' novelty product if it differs from existing products only in terms of 'organs' or 'parts'.

To illustrate products with different degrees of novelty, Sarkar and Chakrabarti have provided an example of cooking appliances. For instance, wood burning ovens are taken as 'very high' novelty products because before the invention of these ovens, the function of controlled burning of fuel to cook food was not fulfilled. After the wood burning ovens, coal, kerosene, gas burning and electric ovens were invented. Electric oven is not taken as 'very high' novelty product since the function of controlled burning of fuels to cook food was already satisfied by its predecessors. Electric ovens are assigned 'high' novelty because for the same function, these ovens differ from all its predecessors (e.g. wood, coal, kerosene, gas burning ovens) in terms of input (electricity), physical phenomena, physical effect, organs and parts (see Figure 1).

3. Modifications

The novelty assessment method of Sarkar and Chakrabarti [2011] has received attention; but deficiencies were found in their method when it was applied in our own studies. In this section, we present these deficiencies and propose modifications to address them. In total, four modifications have been proposed, and are supported by drawing on examples of products and ideas. While this section presents these modifications separately, they are integrated in Sarkar and Chakrabarti's method, as presented further in Section 4.

3.1 Modification 1: Differences in inputs

Some four stroke Internal Combustion (IC) engines can be operated on petrol as well as blend of petrol and 10% ethanol [FCAI 2015]. Thus, there are two products: four stroke IC engine running on 'petrol' (petrol engine), and four stroke IC engine running on the 'blend of petrol and 10% ethanol' (petrol-ethanol engine). These two products have the same structure (i.e. organ or parts), but they are operating on different inputs, namely 'petrol' and 'blend of petrol and ethanol'. The physical phenomena in these two engines are the same; e.g. combustion of fuel in the cylinder creates pressure and this pressure operates a slider and crank mechanism. In addition, the physical effects in both engines are also the same; e.g. heat transfer laws and Newtonian laws of motion.

The petrol-ethanol engine came after the petrol engine. In order to assess the novelty of petrol-ethanol engine by using Sarkar and Chakrabarti's method, it needs to be compared with the petrol engine. This comparison, by using Sarkar and Chakrabarti's method (Figure 1), shows that the petrol-ethanol engine is not novel because for the same function, its structure is identical to that of petrol engine.

Thus, according to Sarkar and Chakrabarti's method, a product is not novel if it differs from other products only in terms of inputs. We argue that two products, achieving the same function, but differing only in terms of inputs, should have different degrees of novelty because: inputs coming from outside the system are essential for interaction between the system and its environment; inputs are essential to accomplish the function of a product; and 'inputs' is one of the elementary constructs in the SAPPhIRE model, which is used as a theoretical foundation to assess relative degree of novelty of products [Sarkar and Chakrabarti 2011]. We argue that the petrol-ethanol engine should have some degree of novelty when it is compared with the petrol engine, since it operates on different inputs. We, therefore, as shown in Figure 3, add a step in Sarkar and Chakrabarti's method to consider products differing only in terms of inputs.

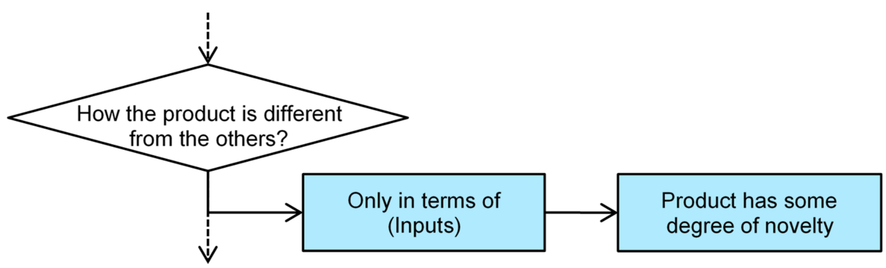

Figure 3. Modification 1: Addition of a step to consider differences only in terms of inputs

3.2 Modification 2: Determining if a product has some degree of novelty

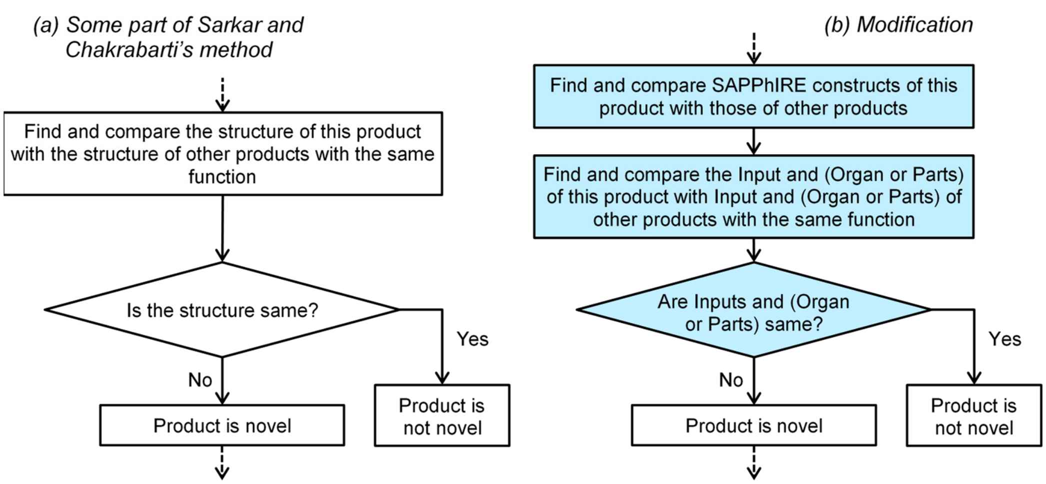

Figure 4. Modification to ascertain whether or not a product has some degree of novelty

In their novelty assessment method, Sarkar and Chakrabarti have used the FBS and SAPPhIRE models. The construct 'parts' in the SAPPhIRE is interpreted as 'structure' in the FBS. The FBS model is used first to ascertain whether or not a product has some degree of novelty. For this purpose, the structure of a recent product is compared with that of previous products. If the structure is same, the product has no novelty. However, as mentioned above in Section 3.1, a recent product can have some degree of novelty even if its structure is same as that of previous products, achieving the same function. This leads us to propose the second modification: a recent product is not novel if its both 'inputs' and 'structure' (i.e. organ or parts) are same as those of previous products, fulfilling the same fuction. Therefore, as shown in Figure 4, we add a modification to Sarkar and Chakrabarti's method, replacing the FBS model by the constructs of the SAPPhIRE model, to ascertain whether or not a product has some degree of novelty.

3.3 Modification 3: Differences in inputs and physical effects

Consider a function of warming a small quantity of water (e.g. to increase temperature of water from 15°C to 20°C). This function can be fulfilled by using two products, as illustrated in Figure 5. The structure of these products is same - a small metal bowl containing water, as shown by the system boundary in Figure 5. To fulfil the same fuction, product-1 and product-2 respectively use solar energy and heat transfer from a hot metal plate. Thus, in product-1, input in the system is solar energy; whereas, in product-2, it is heat energy from a hot metal plate. In product-1, water is warmed by the physical effect of radiation; and in product-2, it is warmed by the the physical effect of conduction (heat transfer by conduction thorough the metal wall of the bowl) [Yunus 2003]. In product-1, the physical phenomenon to warm water is absorption of radiation by water; and in product-2 it is transfer of heat through the wall of the bowl [Yunus 2003]. Products 1 and 2 thus differ in terms of physical effect or physical phenomenon and input to achieve the same function.

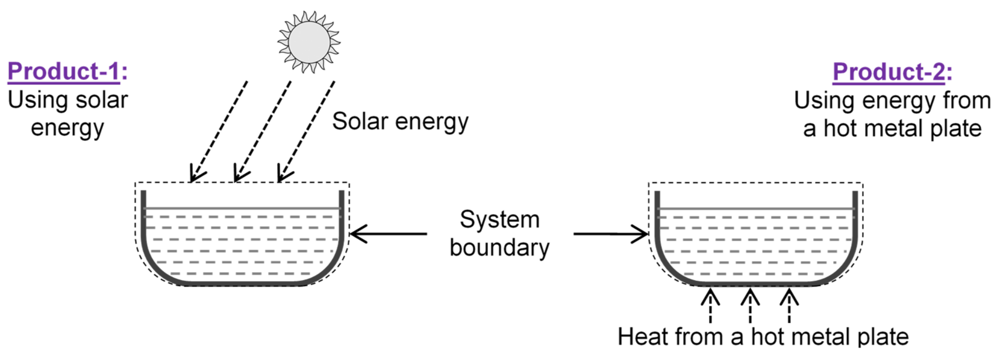

Figure 5. Illustration of products with different inputs and physical effects

According to Sarkar and Chakrabarti's method, product-2 is not novel when it is compared with product-1, as they have the same structure. However, product-2 is different from product-1 in terms of physical effect or physical phenomenon and input, which are elementary constructs in the SAPPhIRE model used as a theoretical foundation to assess product novelty. We therefore argue that if a product is different in terms of physical effect or physical phenomenon and input from existing products to achieve the same function, it should have some degree of novelty. As a result, as shown in Figure 6, we add a modification to Sarkar and Chakrabarti's method to consider products differing only in terms of physical effect or physical phenomenon and input.

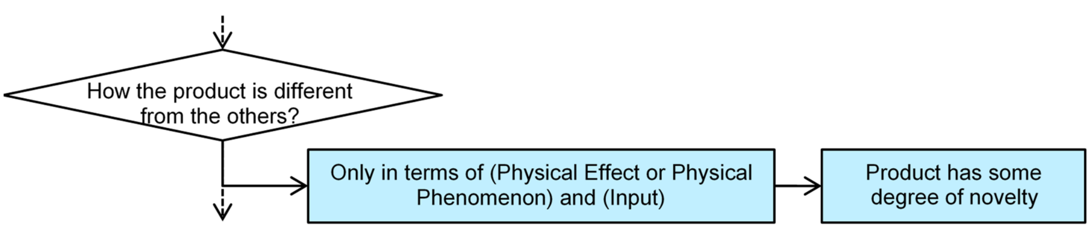

Figure 6. Modification 3: Addition of a step to consider differences in physical effects and inputs

3.4 Modification 4: Differences in inputs and parts/organs

Figure 7 shows two conceptual solutions to perform the function of lifting a moderately heavy object. In solution-1, this function is fulfilled by applying a force at the end of the lever. This force is due to the weights attached at the end of the rope. Thus, in solution-1, the input is force due to the gravity. In solution-2, the input is a force exerted by a human. In both of these solutions, the physical effect is the same, namely the lever effect [Pahl and Beitz 2007]. However, the organ or parts to activate this physical effect are different in these solutions. Thus, to fulfill the same function, solutions 1 and 2 differ only in terms of organ or parts and input.

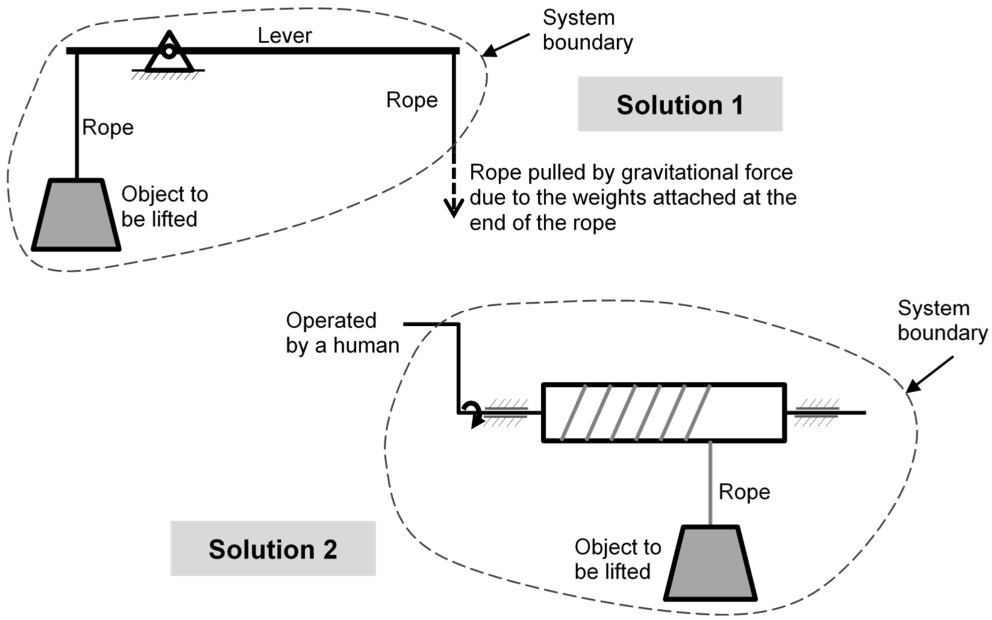

Figure 7. Conceptual solutions to lift a moderately heavy object

Sarkar and Chakrabarti's method does not include a step to assess the degree of novelty of a product differing from existing products only in terms of organ or parts and input. In other words, their method cannot be used to compare the above solutions 1 and 2. To overcome this deficiency, we add a modification to their method, in order to consider products differing in terms of organ or parts and input (see Figure 8).

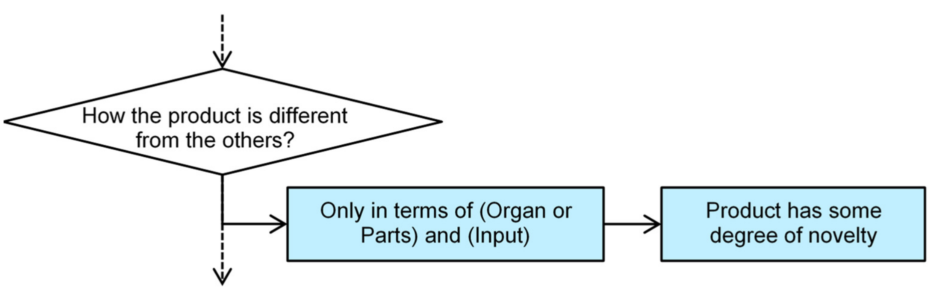

Figure 8. Modification 4: Addition of a step to consider differences in inputs and parts/organs

4. Refined novelty assessment method

In Section 3, four modifications were developed separately. In this section, these modifications are integrated in Sarkar and Chakrabarti's method, taking into account their rationale to qualitatively assign different degrees of novelty at various levels of the SAPPhIRE model (see Figure 9). To detect relative degree of novelty in products, Sarkar and Chakrabarti attribute products with a difference at the level of function (action) as 'very highly novel'. They argue that products that are different from existing products at 'physical effects' or 'physical phenomena' level, are more novel than those that are different only at the 'organ' or 'part' level. They thus assign qualitatively higher degree of novelty to products that are different from existing products at higher level constructs (e.g. action, physical effects, physical phenomena) of the SAPPhIRE model than those that are different only at the lower level constructs (e.g. parts, organs, inputs).

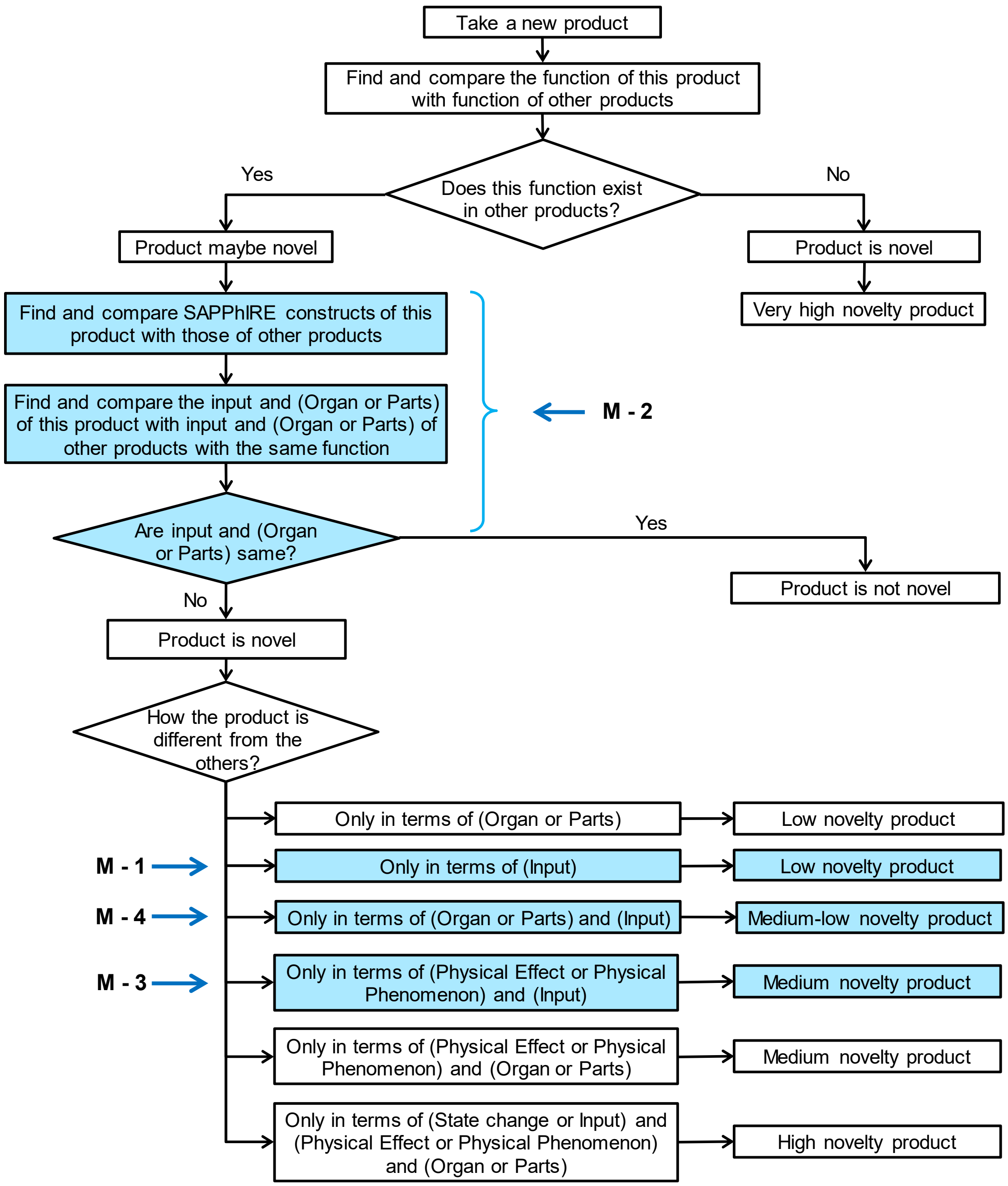

Figure 9. Refined novelty assessment method (Legend: M – Modification, see Section 3 for details)

By following Sarkar and Chakrabarti's justification to qualitatively attribute products with different degrees of novelty, we assign degrees of novelty to products, as shown in the blue coloured boxes on the right side of Figure 9. We assign 'low' novelty to a product differing from existing products only in terms of input (M - 1). If a new product is different from existing products only in terms of organ or parts and input, the product is qualitatively taken as of 'medium-low novelty' (M - 4). Similarly, if a new product differs from existing products only in terms of physical effect or physical phenomenon and input, the product is qualitatively considered as of ‘medium novelty’ (M - 3). The refined method provides more clarity and detail to ascertain whether or not a product has some degree of novelty, by using the constructs ‘inputs’ and ‘organ’ or ‘parts’ of the SAPPhIRE model, and thus eliminates the need of FBS model (M - 2).

5. Conclusions

As novelty is a key component of creativity, its measurement is essential to assess creativity of products, and to evaluate idea generation in engineering design. Sarkar and Chakrabarti [2011] developed a method, which uses FBS and SAPPhIRE models, to assess novelty of products, solutions, or ideas.

This paper identified deficiencies in their method, and proposed four modifications to address them. These modifications are supported by drawing on examples of products and ideas. Of the four modifications, three are needed to assess the novelty of a product differing from other products: (1) only in terms of inputs (‘low’ novelty product); (2) only in terms of organ or parts and inputs (‘medium-low’ novelty product); and (3) only in terms of physical effect or physical phenomenon and input (‘medium’ novelty product). In addition to these three modifications, we proposed a modification to ascertain whether or not a product has some degree of novelty – that is – a product is not novel if its inputs and organ or parts are same as those of other products.

We integrated the four modifications in Sarkar and Chakrabarti’s method, taking into account their rationale of qualitatively assigning different degrees of novelty. The refined method provides more clarity and detail in ascertaining whether or not a product has some degree of novelty, by replacing the FBS model with the constructs of the SAPPhIRE model. Furthermore, the refined method has the capability to consider the cases of product novelty assessment, which could not be recognised in the original method of Sarkar and Chakrabarti. Thus, the overall achievement of the refined method as presented in this paper is its contribution to a better assessment of product novelty.

Acknowledgement

This work would not have been possible without Sarkar and Chakrabarti’s [2011] foundational work on the development of their novelty assessment method.

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