Design Science

Uses of the novelty metrics proposed by Shah *et al.*: what emerges from the literature?

Lorenzo Fiorineschi [1] and Federico Rotini [1,2]

[1] *Department of Industrial Engineering, University of Florence, Firenze, Italy*
[2] *Department of Industrial Engineering, Università Degli Studi di Firenze, Firenze, Italy*

Abstract

Several concepts and types of procedures for assessing novelty and related concepts exist in the literature. Among them, the two approaches originally proposed by Shah and colleagues are often considered by scholars. These metrics rely on well-defined novelty types and a specific concept of novelty; however, more than 20 years after the first publication, it is still not clear whether and to what extent these metrics are actually used, why they are used and how. Through a comprehensive review of the papers citing the main work of Shah, Vargas-Hernandez & Smith (2003a, 2003b) (the main study where the metrics are comprehensively described and applied), the present work aims to bridge this gap. The results highlight that only a few of the citing papers actually use the assessment approach proposed by Shah *et al.* and that a nonnegligible number uses a modified or adapted version of the original metrics. Furthermore, several criticalities in the application of the metrics have been uncovered, which are expected to provide relevant information for scholars involved in reliable and repeatable novelty assessments.

Keywords: novelty, creativity, design, ideation effectiveness, unusualness, unexpectedness

1. Introduction

The term 'creativity' is often misused, especially by industrial practitioners when promoting their own products and/or design processes. However, the problem is not limited to industry, since in academia, the term is sometimes used as a buzzword. Although creativity is often defined in different ways, making a shared definition unlikely (Doheim & Yusof 2020), a plethora of studies provide comprehensive definitions, allowing us to clarify at least the fundamental pillars of creativity. More precisely, in the context of design, creativity has been defined by Amabile (1983) as the ability to create ideas that are novel, useful and appropriate, while Moreno *et al.* (2016) define creativity as the ability to generate novel and valuable ideas. In other definitions, novelty is always present and can thus be considered the main pillar of any concept of creativity.

Unfortunately, the term 'novelty' has a multifaceted meaning, at least in the context of engineering design (Fiorineschi & Rotini 2021). For instance, Verhoeven, Bakker & Veugelers (2016) mentioned 'technological novelty', Boden (2004) considered both 'historical novelty' and 'psychological novelty' and Vargas-Hernandez, Okudan & Schmidt (2012) referred to the concept of 'unexpectedness'.

However, the nature of each of these definitions is quite different, which could generate misunderstandings because some of them refer to the 'concept of novelty' (i.e., to what is expected to be novel), while others refer to the 'novelty type' (i.e., to the reference to be considered for establishing the novelty of ideas). Indeed, according to Fiorineschi & Rotini (2021), while 'unexpectedness' is a concept of novelty, 'historical novelty' and 'psychological novelty' define two possible novelty types.

The motivation for this work is the perceived need to improve the understanding of how and why novelty metrics are actually used in practice. Unfortunately, it is impossible to perform an in-depth analysis of the literature for all the available metrics in a single paper. Therefore, we decided to focus on one of the most cited contributions related to novelty metrics. More precisely, this literature review is performed by considering all the contributions that cite the article by Shah, Vargas-Hernandez & Smith (2003a), commonly referenced and acknowledged by engineering design scholars (Kershaw et al. 2019), with 739 citations on Scopus (at March 2021). In particular, Shah et al. (2003a) provided two families of novelty assessment procedures, namely the 'a priori' and the 'a posteriori' procedures. The 'a priori' approach can be associated with 'historical novelty' since it requires a reference set of solutions to assess the novelty of ideas. The 'a posteriori' approach does not require a set of reference solutions because the ideas to be assessed constitute the reference itself. In this specific procedure, novelty is calculated by counting the occurrences of similar ideas generated in the same session. Therefore, the a posteriori procedure is associated with 'psychological novelty' and with the 'uncommonness' or 'unexpectedness' of a specific idea.

The first article mentioning these two assessment approaches was published more than 20 years ago (Shah, Kulkarni & Vargas-Hernandez 2000), just 3 years before the publication that more comprehensively demonstrates the validity of the metrics (Shah et al. 2003a). However, notwithstanding the wide diffusion of these seminal contributions, it is still not clear whether and to what extent the mentioned metrics are actually used. To bridge this gap, this work presents a comprehensive literature review of the articles and conference papers (in English) that cite the contribution of Shah et al. (2003a) (hereinafter called SVS), since it is acknowledged to be the reference in which the metrics are comprehensively explained and tested. In this way, it is our intention to provide a clear picture of the actual usage of the two novelty assessment procedures (i.e., the a posteriori and the a priori procedures). More specifically, the objective of this work is to determine the acknowledged applications of the mentioned assessment procedures and provide insightful considerations for future developments and/or applications by discussing the observed criticalities.

This work does not perform an in-depth analysis of each paper, as this activity is unnecessary to accomplish the claimed objective. Rather, it performs an analysis of the literature contributions and is focused solely on the extraction of the specific information needed to build a clear representation of the use of SVS novelty metrics. Therefore, the review intentionally overlooks any paper that could present (in our opinion) certain flaws. Indeed, providing a reference to a contribution that presents a questionable application of the metrics without preforming a comprehensive discussion about the research work would surely appear defamatory for the authors and not ethically appropriate. The references of the reviewed works are of course listed in the following sections.

The content of the paper is organised as follows. A description of the two SVS metrics is provided in Section 2 together with a brief overview of the works that perform a literature analysis of novelty metrics in the engineering design field (i.e., the context where the work of Shah, Vargas-Hernandez & Smith 2003*a* is mostly cited). The research methodology is comprehensively described in Section 3 together with a detailed description of the key parameters used to perform the analysis of the literature. Section 4 presents the obtained results, which are subsequently discussed in Section 5. Finally, conclusions are reported in Section 6. It is also important to note that it was not possible to retrieve all the citing documents. Accordingly, a detailed list is reported in Appendix Table A1 about the documents that we were unable to retrieve.

2. Background

2.1. The novelty metrics proposed by SVS

The well-acknowledged set of metrics proposed by SVS constitutes a milestone for design creativity research. SVS considered four parameters affecting 'idea generation effectiveness' – that is, the novelty, variety, quality and quantity of generated ideas – proposing metrics to facilitate the assessment of these ideas. It is not in the scope of this paper to describe each parameter and the related metrics. For additional information, the reader can refer to the original work of SVS (Shah *et al.* 2003*a*), but it is also relevant to acknowledge that important analyses and improvements have been proposed in the literature about some of the SVS metrics (e.g., Nelson, Wilson & Yen 2009; Brown 2014; Fiorineschi, Frillici & Rotini 2020*a*, 2021).

The key of the SVS novelty metrics is in the equation used to assess the overall novelty of each idea (M) in a specific set of ideas. More precisely, the novelty is calculated through Eq. (1):

$$M_{SNM} = \sum_{i=1}^{m} f_i \sum_{j=1}^{n} S_{ij} p_j \qquad (1)$$

where f_i is the weight of the ith attribute and m is the number of attributes characterising the set of analysed ideas. The parameter n represents the number of design stages characterising the idea generation session, and p_j represents the weight assigned to the jth design stage. Indeed, SVS observed that different attributes or functions can differently impact the overall novelty. Similarly, the same scholars also observed that the contribution to novelty can be affected by the considered design stage [e.g., conceptual design, embodiment design (Pahl *et al.* 2007)]. The parameter S_{ij} represents the 'unusualness' or the 'unexpectedness' of the specific solution used by the analysed idea to implement the ith attribute at the jth design stage.

From Eq. (1), it is possible to infer that the SVS novelty assessment procedure underpins the concept of functions or key attributes that can be identified within the set of generated ideas. In other words, the novelty of an idea 'I' in the SVS approach is relative to a specific universe of ideas{U}. Each idea 'I' is considered a composition of the solutions that implement each function (or attribute) used to represent the idea (one solution for each function/attribute). However, according to SVS, the identification of functions and attributes is case sensitive.

The most important parameter of Eq. (1) is S_{ij}, and two different approaches have been proposed by SVS to obtain the related value, that is, the 'a posteriori' and the 'a priori' approaches.

In the a priori approach, the S_{ij} value is 'assigned' by judges that compare the idea (decomposed in terms of attributes and related solutions) against a reference set of existing products. More precisely, SVS reports, '…*a universe of ideas for comparison is subjectively defined for each function or attribute, and at each stage. A novelty score S_1* [the value "1″ identifies the novelty metric in the SVS set of metrics] *is assigned at each idea in this universe*'. Therefore, the 'a priori' approach is based on subjective evaluations made by referring to subjective universes of ideas. This kind of approach then underpins the personal knowledge of the judges, similar to what occurs with other well-acknowledged novelty assessment approaches used in the context of design studies (e.g., Hennessey, Amabile & Mueller 2011; Sarkar & Chakrabarti 2011; Jagtap 2019).

In contrast, in the a posteriori approach, the S_{ij} for each attribute is calculated by Eq. (2):

$$S_{ij} = \frac{T_{ij} - C_{ij}}{T_{ij}} \times 10 \qquad (2)$$

where T_{ij} is the total number of solutions (or ideas) conceived for the ith attribute at the jth design stage and C_{ij} is the count of the current solution for the ith attribute at the jth design stage. Therefore, in this case, the reference universe of ideas is the same set of generated ideas. Indeed, the evaluator (it is preferable not to use the term 'judge' to avoid confusion with the 'a priori' rating approach) is asked to count the number of times a specific solution for a specific attribute (or function) appears within the set of generated ideas (for each design stage). Then, such a value C_{ij} is compared with the total number of solutions generated for the specific attribute in the specific design stage (T_{ij}), obtaining a value of the 'infrequency' of that solution. Accordingly, the a posteriori approach is heavily affected by the specific set of analysed ideas, and therefore, the novelty value is relative to that specific set of ideas.

2.2. What do we know about SVS novelty assessment approaches?

In the last decade, perhaps due to their widespread success and dissemination through the scientific community, the SVS assessment procedures have been deeply investigated and discussed. For example, Brown (2014) reviewed and discussed some novelty assessment approaches. Concerning SVS, Brown highlighted some problems related to the subjective identification of functions or key attributes, the subjective identification of the weights for each attribute and the additional difficulty of separating the ideas according to the design stages (if the user intends to use Eq. (1) in its complete form). Srivathsavai *et al.* (2010) reported that the 'a posteriori' novelty assessment approach proposed by SVS cannot be used to assess ideas in relation to existing ideas (or products). In other words, considering the definitions provided by Boden (2004), the SVS 'a posteriori' novelty assessment approach is not related to historical novelty. However, such a metric can be successfully used to assess psychological novelty (i.e., what is novel

for those who actually generate the idea). In theory, the 'a priori' approach should be capable of assessing historical novelty; however, its actual use in the scientific community appears unclear.

Furthermore, Sluis-Thiescheffer *et al.* (2016) observed that in certain circumstances, the 'a posteriori' approach can lead to misleading novelty scores (i.e., too high), even if similar solutions appear quite often in the examined set. Vargas-Hernandez *et al.* (2012) claimed that the 'a posteriori' approach could be improved to better address changes within the examined sets of ideas and to be more effectively applied to boundary situations.

These and other observations have been made, which we summarised in comprehensive reviews that accurately describe and discuss each of them (e.g., Fiorineschi & Rotini 2019, 2021; Fiorineschi, Frillici & Rotini 2020*b*). Additionally, we discovered and examined a particular issue concerning the 'a posteriori' approach, that is, the problem of 'missing' or 'extra' attributes. We examined the problem in depth (Fiorineschi *et al.* 2020*a*), and we also proposed a comprehensive solution to the problem (Fiorineschi *et al.* 2021).

However, despite the comprehensive set of studies that analyse and/or discuss SVS novelty assessment, there are still many questions to be answered. In particular, this work points to the following evident gaps that should be bridged to better apply the metrics in the future:

Q1) What is the rate of use of the SVS novelty assessment approaches within scientific works?

Q2) What is the rate of use of the 'a priori' and 'a posteriori' versions of the SVS novelty assessment approach?

Q3) What is the level of consciousness of SVS users in terms of the novelty type and concept needed for the specific experiment?

Q4) What is the rate of use of the 'multiple design stages' capability of the SVS novelty assessment approach?

Q5) What is the range of applicability for the SVS novelty assessment approaches?

Q6) How many scholars comprehensively use SVS novelty assessment approaches with multiple evaluators and perform an interrater agreement test?

Q7) How many research works, among those using SVS novelty assessment approaches, comprehensively describe the following assessment rationale?

The following section provides a description of the investigation targets related to each question, together with a comprehensive description of the following research methodology.

3. Materials and methods

3.1. Description and motivation of the key investigation targets

The seven questions reported in Subsection 4 constitute the key investigation targets on which this literature review swivels. Investigation targets are considered here as information categories that are expected to be extracted from the analysis of the literature. Table 1 reports a short description of each of them.

More specifically, according to Q1, the review is expected to clarify the extent to which the work of SVS is actually cited for the application of the related novelty

Table 1. List of the investigation targets related to the questions formulated in Subsection 4

Question	Description of the related investigation target
Q1	The percentage of works that use one or both of the SVS novelty assessment approaches in their original form
Q2	The percentages of the works that use each specific SVS novelty assessment approach (singularly) or both
Q3	The list of novelty definitions referenced by scholars (and the related percentages) when using the SVS novelty assessment approaches
Q4	The percentage of the works that exploit the 'multiple' design stages capability allowed by Eq. (1)
Q5	The list (and the related percentages) of the different application types where the SVS novelty assessment approaches have been used
Q6	The percentage of the works that comprehensively perform an interrater agreement test among multiple evaluators
Q7	The percentage of the works that provide a clear description of the assessment rationale, intended as the description of the methods used to identify the attributes or functions, and the related weights

assessment procedures. Then, through Q2, we aim to clarify the extent to which each of the two assessment approaches ('a priori' and 'a posteriori') is used.

It is also important to understand whether and to what extent the scholars that use SVS approaches are conscious of the actual range of applicability of the SVS novelty assessment approaches. A first indication is given by Q3, which is expected to reveal that most of the references are to the definitions provided by SVS. Accordingly, in addition to the considered novelty concept, we intend to search for any reference to the considered novelty type, that is, psychological novelty or historical novelty.

Q4 has been formulated as, at first glance, we preliminarily observed a lack of use for the multiple stages capability of Eq. (1). It is important to further investigate this issue, since if confirmed, it would be important to investigate the reasons behind this lack.

Q5 is expected to provide a comprehensive view of the current range of use of SVS metrics. Such information, although not sufficient alone to be considered as a guide, is expected to provide a preliminary indication about the types of application where the SVS novelty metrics have been used.

Q6 and Q7 are also two critical questions (and related investigation targets) that aim to investigate the extent to which the assessment is performed with a robust approach (Q6) and whether the provided information is sufficient to understand and/or to repeat the experiments (Q7).

3.2. Methodological approach for the literature review

To perform a valuable literature review, Fink (2014) reported that it is necessary to conduct the analysis systematically. In other words, it is important to adopt a sound

and repeatable method for the identification, evaluation and synthesis of the actual body of knowledge. Purposeful checklists and procedures for supporting comprehensive literature reviews can be found in the literature (e.g., Blessing & Chakrabarti 2009; Okoli & Schabram 2010; Fink 2014), whose main points can be summarised as follows:

1. Clear definition of the review objectives, for example, through the formulation of purposeful research questions.
2. Selection of the literature database to be used as a reference for extracting the documents.
3. Formulation of comprehensive search queries to allow in-depth investigations.
4. Definition of screening criteria to rapidly skim the set of documents from those that do not comply with the research objectives.
5. Use of a repeatable procedure to perform the review.
6. Analysis of documents and extraction of the resulting information according to the research objectives.

Point 1 has been achieved by the questions formulated in Section 2, with the related investigation targets described in Subsection 3.1. According to the second point, we selected the Scopus database as the reference for performing the literature review and extracting the references of the documents to be analysed. The achievement of the third point has been relatively simple in this case since there was no intention to identify the papers through the adoption of complex search queries. Indeed, all documents citing the paper of Shah *et al.* (2003*a*,*b*) were considered (739 in March 2021).

Points 4–6 have been achieved by means of the procedure represented in Figure 1, which is described in the following paragraphs.

Referring to Figure 1, Step 1 was performed by using the Scopus search engine. In particular, the SVS paper (Shah *et al.* 2003*a*) was identified and exploited to access the list of citing documents. Each citing document was downloaded from the publisher, or when this was not possible, a shareable copy was directly sought from the authors. Unfortunately, a nonnegligible number of documents have not been retrieved (a complete list of these documents is provided in Appendix Table A1).

The very first analysis performed on the achieved documents is represented by Step 2 in Figure 1. In other words, each paper was rapidly screened to verify the presence of SVS metrics or any metric somehow related to SVS. To accomplish this, one of the authors rapidly searched for any reference about SVS in the paper's sections that provide information about the research methodology. The approach used for this verification was to perform in-text searches within each article (e.g., for the terms 'novelty', 'creativity', 'uncommonness', etc.) and/or to directly search for the SVS citation with a subsequent analysis of 'why' it was cited. Although the number of processed documents was high, this analysis was relatively simple and allowed us to perform the screening with a rate of from 10–20 papers per day.

The subset of papers obtained by Step 2 was further processed to clearly identify the documents using SVS metrics in their original form (Step 3). This activity was time-consuming, as it required a clear understanding of the rationale behind the adopted novelty assessment approach. Fortunately, as shown in Section 4, the number of papers that passed Step 2 was quite limited. The outcomes of Step 3 were then expected to answer Q1 and Q2 and thus to accomplish the first two investigation targets listed in Table 1. Consequently, the papers using the original form

of the novelty assessment procedures were further processed to find the information related to the investigation targets from 3 to 7, as listed in Table 1 (Step 4 in Figure 1).

Similar to Step 2, to retrieve information about the novelty concept (Q3), each document among those that complied with Substep 3.1 (Figure 1) was processed by in-text searches for the words 'novelty', 'originality', 'newness', 'uncommonness', 'unusualness' and 'unexpectedness'. In this way, it was possible to rapidly identify the parts of the documents that discuss novelty concepts and to understand which of them (if any) were considered in the analysed work. In addition, the terms 'psychological' and 'historical' (as well any citation to the works of Boden) were searched throughout the text to verify the presence of any description of the type of novelty (i.e., psychological novelty or historical novelty).

To retrieve the information relevant to Q4, it was necessary to deeply analyse the methodological approach used in the reviewed papers. Indeed, it was important to clearly understand the design phases that were actually considered in the experiments.

The extraction of the information related to Q5 required the identification of the motivations and the research context underpinning each analysed document. Often, it was necessary to search in the paper for information about the application type. This was accomplished by focusing on the introduction, the methodology description and the discussion of each revised article. The extracted application types were grouped into a set of categories that we formulated by following a subjective interpretation (there was no intention to provide a universally shared set of definitions about the application contexts of the metrics). The set was created on the basis of the differences that we deemed useful to provide a wide overview of the current application range of the SVS approaches for novelty assessment.

To retrieve the information related to Q6, it was necessary to analyse the sections that describe the results and the methodological approach followed in the considered papers. The purpose of this specific analysis was to search for any trace of interrater agreement tests. In the first phase, we verified whether the assessment was performed by more than one evaluator. Then, for the papers presenting more than one evaluator, the analysis focused on the presence of any type of interrater agreement test.

Finally, for Q7, we checked each paper to understand whether and to what extent there was any description of the rationale used to perform the assessment. More specifically, the searched set of information is as follows:

- Availability of the complete set of ideas.
- Description of the method used to identify the attributes (or functions) and the related weights.
- Description of the rationale used to include or exclude ideas with missing or extra attributes.
- Description of the process used to assess each idea in relation to the identified attributes.

Substep 3.2 (Figure 1) was added after the analysis of a first chunk of retrieved documents, which allowed us to highlight that a nonnegligible number of the documents that passed Step 2 did not use the original version of the SVS approaches. The purpose of this step was to collect these modified versions of the metrics and to
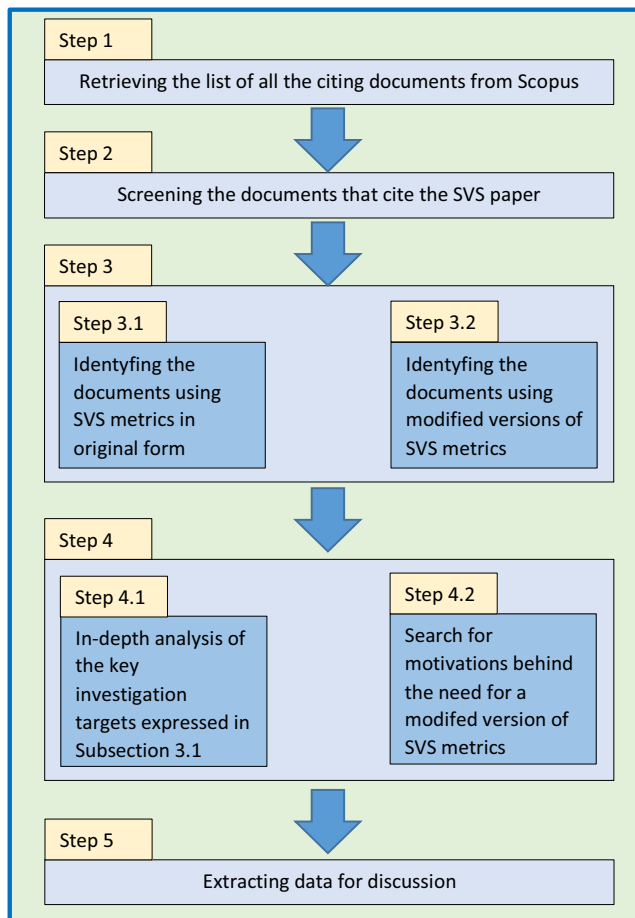
Figure 1. Procedure used to perform the literature review described in this paper.

extract the available information (if any) about the reasons that led the authors to not use the original version.

4. Results

4.1. Results from the investigation target related to Q1

The analysis revealed that only a very small part of the documents that cited the work of Shah *et al.* (2003*a*,*b*) actually used the related metrics for novelty assessments, as shown in Figure 2 for the papers from 2003 to 2020 (the year 2021 was not considered since the data are updated only to March). The figure also shows that many papers did not use an original version of the SVS approaches. More precisely, excluding the 53 papers for which it was impossible to retrieve the document (see Appendix Table A1), the examined set comprises 686 papers. Among them, 61 papers used the original version of the SVS metrics, while 72 used a modified version (see Table 2 for the complete list of references). Therefore, the original versions of the SVS novelty assessment were used in approximately 9% of papers belonging to the examined set.

9/45
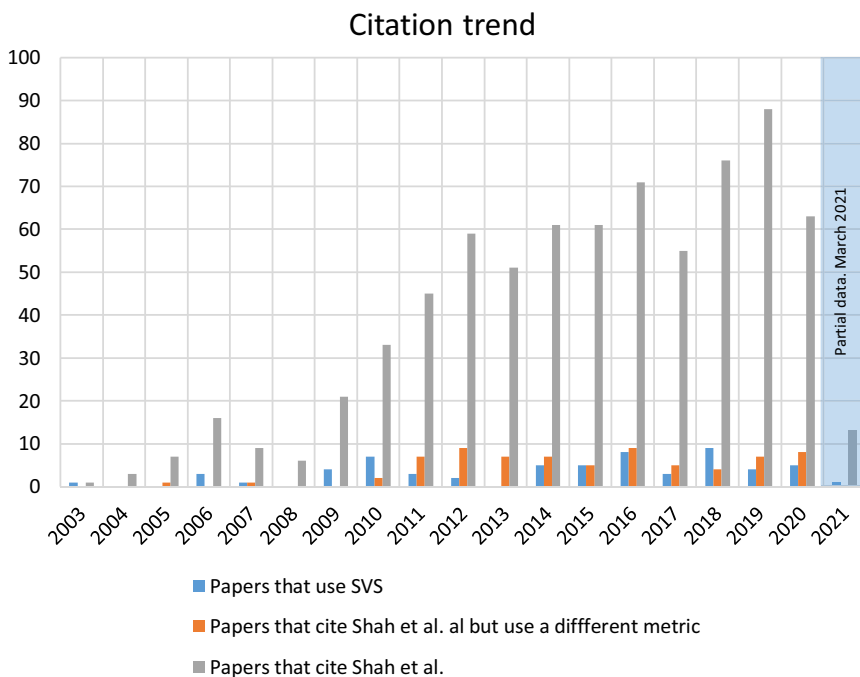
Figure 2. Citation trend for the work of Shah, Vargas-Hernandez & Smith (2003*a*,*b*). The figure also reports the portion of those citations from papers actually using an original version of the SVS approach or a modified version.

To better show the results and to link the contents to the complete set of related references, we used an alphanumeric code (e.g., S10 or A21). The letter indicates whether the document uses an original SVS approach (letter "S") or an alternative approach (letter "A"). The number identifies the article, according to the order shown in Table 2.

It is not within the scope of this paper to comprehensively analyse the 72 papers that used a modified version. However, a complete list of metrics is reported in Table 3, together with the indication of the papers that used them.

Unfortunately, the authors of the papers that are listed in Table 3 often failed to provide comprehensive motivations behind the need to use a metric different from the original SVS. A motivation was provided by Moore, Sauder & Jin (2014), paper A38 in Table 2. The authors stated that they used a different metric because they were focused on the novelty of each design entity and not on the total novelty of the entire process.

Another case is that of Filippi & Barattin (2016), paper A19 in Table 2, who simply report that their metric resembles SVS but actually measures something different from novelty.

4.2. Results from the investigation target related to Q2

Figure 3 graphically reports the results obtained for Q2, according to Substep 4.1 in Figure 1. In particular, the results show that among the 61 papers that use the

Table 2. List of documents identified according to Substeps 3.1 and 3.2 in Figure 1

Papers that use SVS in its original form		Papers that cite SVS but use other approaches	
Code	References	Code	References
S01	Abid, Shi & Toh (2018)	A01	Atilola, Tomko & Linsey (2015)
S02	Ahmed et al. (2018)	A02	Barclift et al. (2017)
S03	Bao, Faas & Yang (2018)	A03	Berthelsdorf & Stone (2017)
S04	Bao, Faas & Yang (2016)	A04	Borgianni et al. (2020)
S05	Boedhoe & Badke-Schaub (2017)	A05	Camburn et al. (2019)
S06	Chulvi et al. (2020)	A06	Cascini, Fiorineschi & Rotini (2020)
S07	Chusilp & Jin (2006)	A07	Cascini, Fiorineschi & Rotini (2018)
S08	Coelho & Vieira (2018)	A08	Chan et al. (2011a)
S09	Deitrick, O'Connell & Shapiro (2014)	A09	Chan et al. (2011b)
S10	Dinar et al. (2015)	A10	Choo et al. (2014)
S11	Doboli & Umbarkar (2014)	A11	Cuellar et al. (2020)
S12	Faas et al. (2014)	A12	Curtis et al. (2013)
S13	Faas & Gong (2016)	A13	Curtis et al. (2012)
S14	Ferent & Doboli (2011)	A14	Deo & Holtta-Otto (2018)
S15	Fillingim et al. (2021)	A15	Duflou & Verhaegen (2011)
S16	Fiorineschi et al. (2018°)	A16	Dumas, Schmidt & Alexander (2016)
S17	Fiorineschi, Frillici & Rotini (2018b)	A17	Dunnigan, Dunford & Bringardner (2020)
S18	Fiorineschi et al. (2020a)	A18	Durand et al. (2015)
S19	Fiorineschi et al. (2020b)	A19	Filippi & Barattin (2016)
S20	Fiorineschi et al. (2018)	A20	Fiorineschi, Frillici & Rotini (2019a)
S21	Fu et al. (2014)	A21	Fu, Kotovsky & Chan (2012)
S22	Genco, Hölttä-Otto & Seepersad (2010)	A22	Glier et al. (2011)
S23	Gosnell & Miller (2015)	A23	Hay, Duffy & Grealy (2019)
S24	Gyory, Cagan & Kotovsky (2019)	A24	Henderson et al. (2020)
S25	Gyory, Cagan & Kotovsky (2018)	A25	Hernandez et al. (2010)
S26	Han et al. (2018)	A26	Vargas-Hernandez, Schmidt & Okudan (2012)
S27	Han, Shi & Childs (2016)	A27	Vargas-Hernandez et al. (2012)
S28	Vargas-Hernandez, Shah & Smith (2010)	A28	Vargas-Hernandez, Schmidt & Okudan (2013)
S29	Hua et al. (2019)	A29	Schmidt, Hernandez & Ruocco (2012)
S30	Hwang et al. (2020)	A30	Jia et al. (2020)
S31	Jagtap et al. (2012)	A31	Kim, McAdams & Linsey (2015)
S32	Johnson et al. (2016)	A32	Kim & Zimmerman (2019)
S33	Kershaw et al. (2019)	A33	Levy et al. (2017)
S34	Kulhanek et al. (2017)	A34	Linsey et al. (2011)

Table 2. Continued

Papers that use SVS in its original form		Papers that cite SVS but use other approaches	
Code	References	Code	References
S35	Kurtoglu, Campbell & Linsey (2009)	A35	Liu & Lu (2013)
S36	Liu & Lu (2016)	A36	Luo, Bian & Hu (2022)
S37	Liu & Lu (2014)	A37	Miller *et al.* (2020)
S38	Milojevic *et al.* (2016)	A38	Moore, Sauder & Jin (2014)
S39	Nelson, Wilson & Yen (2009)	A39	Moreno *et al.* (2016)
S40	Nelson *et al.* (2009)	A40	Moreno *et al.* (2014)
S41	Okudan *et al.* (2010)	A41	Okudan *et al.* (2012)
S42	Okudan, Ogot & Shirwaiker (2006)	A42	Oman, Tumer & Stone (2014)
S43	Oman & Tumer (2009)	A43	Pace *et al.* (2011)
S44	Oman & Tumer (2010)	A44	Perez *et al.* (2019)
S45	Ranjan & Chakrabarti (2015)	A45	Perttula & Sipilä (2007)
S46	Restrepo *et al.* (2018)	A46	Pucha *et al.* (2017)
S47	Rizzuti & De Napoli (2020)	A47	Raviselvam, Hölttä-Otto & Wood (2016)
S48	Jagtap *et al.* (2015)	A48	Raviselvam *et al.* (2017)
S49	Sarkar & Chakrabarti (2011)	A49	Sauder, Lian & Yan (2013)
S50	Sarkar & Chakrabarti (2007)	A50	Schmidt, Hernandez & Ruocco (2012)
S51	Schmidt & Hernandez (2010)	A51	Sluis-Thiescheffer *et al.* (2016)
S52	Shah, Smith & Vargas-Hernandez (2006)	A52	Starkey, Toh & Miller (2016)
S53	Shah, Vargas-Hernandez & Smith (2003*b*)	A53	Starkey, Gosnell & Miller (2015)
S54	Shireen *et al.* (2011)	A54	Sun, Yao & Carretero (2014)
S55	Sinha *et al.* (2017)	A55	Sun, Yao & Carretero (2015)
S56	Sonalkar *et al.* (2016)	A56	Tan, Hölttä-Otto & Anariba (2019)
S57	Genco, Hölttä-Otto & Seepersad (2010)	A57	Toh & Miller (2015)
S58	Sun & Yao (2012)	A58	Toh & Miller (2014)
S59	Sun *et al.* (2014)	A59	Toh & Miller (2016*a*)
S60	Vandevenne, Pieters & Duflou (2016)	A60	Toh & Miller (2016*b*)
S61	Wilson *et al.* (2010)	A61	Toh & Miller (2013*a*)
		A62	Toh & Miller (2013*b*)
		A63	Toh, Miller & Kremer (2014)
		A64	Toh, Miller & Kremer (2012)
		A65	Tsenn, McAdams & Linsey (2013)
		A66	Verhaegen *et al.* (2011)
		A67	Viswanathan & Linsey (2013)
		A68	Viswanathan & Linsey (2010)

Table 2. Continued

Papers that use SVS in its original form		Papers that cite SVS but use other approaches	
Code	References	Code	References
		A69	Weaver, Bennetts & Caldwell (2018)
		A70	Weaver, Caldwell & Sheafer (2019)
		A71	Weir *et al.* (2005)
		A72	Zheng, Ritter & Miller (2018)

original version of the SVS, 63.9% use the 'a posteriori' approach, and only 8.2% use the 'a priori' version. To these percentages, it is also necessary to add the papers that use both approaches (3.3%). However, it is important to observe that a nonnegligible percentage of the examined documents (24.6%) does not provide sufficient information to understand which of the two approaches was used.

The latter information is critical. Indeed, while the use of one approach in place of the other (or both) can be a consequence of the experimental requirements (assuming that the authors correctly selected the most suited one), it is unacceptable for a scientific paper to fail to provide the information to understand which assessment procedure was used.

4.3. Results from the investigation target related to Q3

Concerning the level of consciousness that SVS users have in terms of novelty concepts, we found that the terms 'unusualness' and 'unexpectedness' are used very often. This result was expected since these terms are used in the original SVS work. However, as shown in Figure 4, other terms or a 'mix of terms' were also used among the reviewed works. More importantly, Figure 4 also shows that a non-negligible part (24.6%) of the examined articles (among the 61 that use the original SVS metrics) does not provide any information about the considered novelty concept.

While it is often acceptable to use a specific term in place of others (e.g., due to the absence of a shared definition of novelty), it is unacceptable that some scientific works completely fail to provide any reference about the novelty concept. Indeed, the reader needs to understand what the authors intended when referring to novelty and/or when defining the investigation objectives. Independent of the correctness of the provided definitions, this is crucial information that cannot be neglected. Missing any reference to the considered concept necessarily implies that the authors failed to collect sufficient information about the plethora of different ways that actually exist for defining and assessing novelty.

Concerning the novelty type, we observed that almost all the examined papers (among the 61 that use the original SVS metrics) do not provide any specification about the actual need to assess psychological novelty or historical novelty. Only in three cases was the specification correctly included (Gosnell & Miller 2015; Fiorineschi, Frillici & Rotini 2020*a*,*b*). This result is also critical. Indeed, the

Table 3. List of metrics used in the works that refer to SVS but use different approaches

Metric	Description	Paper the metric was used in
Unclear	The actual metric used by the authors is unclear because they refer to both SVS and A54	A55
SVS for a single phase, with a different set of ideas	The considered set of items to be assessed contains the total number of ideas generated, including those that have been dismissed at the end of the process	A54
$Span = \sum_{i=1}^{n} (1 - R_i)$	Span is a proxy of novelty and is considered the sum of distances of each entity in the concept to the central named entity, as measured by minimum spanning path within the knowledge graph. R_i is referred as the 'relevance' of the idea	A05
$Novelty = 1 - \frac{Ns}{Tc}$	Tc is the total number of concepts, and Ns is the number of very similar concepts. The metric was originally proposed by Jansson & Smith (1991)	A01, A04, A14, A18, A22, A23, A31, A33, A34, A39, A40, A43, A44, A46, A65, A67, A68
$N_i = \frac{T_i - C_i}{T_i}$	T_i is the total number of solutions generated for the ith subfunction, and C_i is the total number of solution tokens of the current solution type in the first phase of ideation. The final novelty score for each solution concept is the average of its subfunction novelty scores	A08, A09, A10, A21, A25
$O = \frac{T - C}{T} \times 10$	O is the originality of the assessed idea, T is the total number of generated and C is the number of ideas belonging to a specific type	A16
$S_i = \frac{T_i - C_i}{T_i} \times 10$	S is the novelty of each idea belonging to a specific category. C is the count of ideas in a specific category, and T is the total number of ideas across all the categories (Raviselvam et al. 2017)	A03, A 47, A48, A71
$S_k = \frac{(T_k - C_k + 1)}{T_k} \times 10$	S is the novelty score; T is the total number of ideas. C is the count of current solutions (ideas) for key attributes	A56
$Nf_i = \frac{\sum_{i}^{k_f} \left(\frac{T - C_{if}}{T} \right)}{k_f}$	C_{if} is the total number of designs that addressed functional feature i_f, and T is the total number of designs produced by all participants; k_f is the total number of functional features	A57, A58

Table 3. Continued

Metric	Description	Paper the metric was used in
$D_{j,k} = \frac{\sum(f_i \times E_{i,j,k})}{\sum E_{i,j,k}}$	$D_{j,k}$ is the design novelty for the jth idea in team k, while f_i is the novelty of the ith idea, calculated as: $f_i = \frac{T-C_i}{T}$ where T is the total number of ideas generated by all participants and C_i is the number of ideas generated for feature i $E_{i,j,k} = 1$ if feature i is addressed by the team k, 0 otherwise	A52
$D_j = \frac{\sum f_k}{\sum f_i}$	D_j is the design novelty, and f_k is the feature novelty of a feature that was different from the original design. The sum of f_i is the novelty of all the features that were addressed in the generated idea, where: $f_i = \frac{T-C_i}{T}$ T is the total number of concepts generated for each category (brush head, body design), and C_i is the total number of concepts (for a specific feature) that were rated 3 or 4 by the raters (i.e., different from original design)	A32, A37, A53, A59, A61, A62, A63
$D_j = \frac{\sum f_i}{\sum i}$	D_j is the idea novelty, f_i is the novelty of the ith idea, calculated as: $f_i = \frac{T-C_i}{T}$ where T is the total number of ideas generated by all participants and C_i is the number of ideas generated for feature i $\sum$ is the number of features addressed by the design	A60, A72, A64
$N = S \times \frac{Concept\,Rep_{max}}{Concept\,occurrences}$	N is defined as the total novelty of a concept, S is the weighting factor for each level of the hierarchy, $Concept\,Rep_{max}$ is the maximum number of times a concept can be repeated and $Concept\,occurrences$ is the number of times the concept appears in the considered set	A49
$N = \frac{\#Teams - \#DE}{\#Teams} \times 10 \times p$	N is defined as the total novelty of a design entity and is measured by comparing the maximum number of times a design entity can be repeated (or the number of teams) to the number of times it was invented by	A38

Table 3. Continued

| Metric	Description	Paper the metric was used in
	each team. p is the weighting factor for each level of the hierarchy	
No equation provided	'The novelty calculation was based on the total number of characteristics and calculating the novelty weight of each characteristic which was inversely proportional to the number of times it appeared'.	A17
No equation provided	The score range is different from that used in the original SVS work. The maximum novelty score in this case is 30	A11
$M = \frac{\sum_{j=1}^{j=m}\sum_{k=1}^{k=n}\left(\frac{T-C_{jk}}{T}\right)\cdot 10\cdot p_{jk}}{m}$	M is the novelty score for a subject who produced m solutions, and n is the number of elements used in the solutions. T is the total number of element parts, while C_{jk} is the count of current parts of the kth element used in the solution. Then, p_{jk} is the weight of this combination	A36
$N = \sum_{i=1}^{m} f_i \sum_{j=1}^{o} S_{ij} w_{ij}$	f_i is the normalised weight of function i, m is the number of functions, o is the number of GT items and w_{ij} is the normalised weight assigned to the item j, related to the function i. S_{ij} is still calculated according to SVS	A06, A07, A15, A20, A66
$N = \frac{1}{C_{wp}m}$	C_{wp} is the count of occurrences in specific WP branches of the GT (i.e., the number of nodes at the embodiment level, under the same WP node), and m is the number of nodes at the WP level	A26, A27, A28, A29, A41
SVS with genealogy tree	No equation provided. Used genealogy tree levels in place of attributes	A35, A50
$M = \sum_{j=1}^{m} \frac{(1-P_j)s_j}{2}$	M is the novelty score, and m is the hierarchical level in the genealogy tree. P_j is the count of responses at the genealogy tree level j divided by the count of responses of its parent. Metric originally proposed by Johnson *et al.* (2016)	A02, A69, A70
SaPPhiRE-based novelty scale	Novelty score: 1 – low novelty; 3 – medium; 6 – high; 10 – very high. See Sarkar & Chakrabarti (2011) for SaPPhiRE	A30

	Table 3. Continued	
Metric	Description	Paper the metric was used in
No equation provided	The rarity of a concept at each level (intended as Physical Principles, Working Principles and Embodiment Principles) was calculated as the ratio of the number of concepts grouped at that level to the total number of concepts in the dataset. The lower the ratio, the rarer the idea	A24
$LDI = \frac{\sum f_j A_j}{N}$	LDI is the 'Link Density Index' and is used to measure the degree to which generated ideas are linked to the provided examples. f_j is the weight assigned for type j link, A_j is the number of type j links and N is the total number of concepts	A45
$N = \begin{cases} 1 \; for \; C_i \leq P \\ 0 \; for \; C_i > P \end{cases}$	Novelty is assessed with a binary metric (novel or not novel), and a threshold (in the form of a percentile) is considered. C_i is the number of occurrences of the idea for the attribute i, and P is the percentile that can be chosen between 0.5 and 1	A51
$M_n = \frac{\|\Omega\| - \|\Omega^{(0)}\|}{\|\Omega^{(0)}\|}$	'Ω is the diagonal of the hypercube containing the entire formulation objective space, $\Omega^{(0)}$ is the diagonal of the hypercube containing the original design objective space, and in general $\Omega^{(i)}$ is the diagonal of the hypercube containing the i-th space' (Curtis et al. 2013)	A12, A13
$ID(F,P) = \sum_{j=1}^{m} ID(f_i, P)$	The authors use specific equations to assess the interaction distance (ID) of a product P that implements the set F of m. However, this variable is different from novelty	A19
$M_n = \sum_{j=1}^{n} f_j \left(\frac{T_j - R_j}{T_j} \right)$	T_j is the number of total ideas produced for criterion j, R_j is the number of similar solutions in T_j to criterion j and f_j is the weight of importance of criterion j	A42

Note: See Table 2 for reference codes.

selection of the most suited novelty assessment procedure (and the related metric) should be performed on the basis of 'what is actually needed' and not on the basis of naïve motivations such as whether a procedure 'is the most cited' or 'is often used by scholars'. In the specific case of SVS metrics, the authors
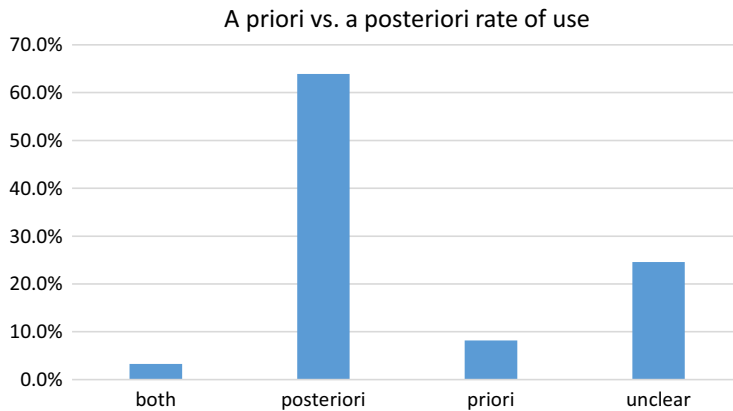
Figure 3. Percentages of the papers using the two different novelty assessment approaches originally proposed by SVS.

infrequency		3,3%
innovativeness		1,6%
newness,unusualness		1,6%
rarity		3,3%
rarity, unusualness		1,6%
similarity		1,6%
uncommonness		1,6%
unexpectedness		3,3%
unique or unusual		1,6%
uniqueness		3,3%
uniqueness, originality		1,6%
unsualness, unconventionalness		1,6%
unusualness		14,8%
unusualness, originality		1,6%
unusualness, uncommonness		6,6%
unusualness, unexpectedness		26,2%
none		24,6%

Figure 4. Terms used by the different authors to identify the novelty concept underpinning the assessment performed through the SVS metrics.

should always be aware that when using the a posteriori approach, they are actually measuring a psychological novelty, which cannot be interchangeably used with the historical novelty.

4.4. Results from the investigation target related to Q4

The possibility of applying Equation 1 to multiple design stages was not exploited by the 61 papers collected with Substep 3.1 in Figure 1.

Unfortunately, no explanation for the reasons behind this lack of use was found in the reviewed documents. However, it is possible to infer that the reason for this lack lies in the nature of the SVS metrics. Indeed, the SVS metrics were formulated to assess the effectiveness of idea generation, and it is widely acknowledged that the

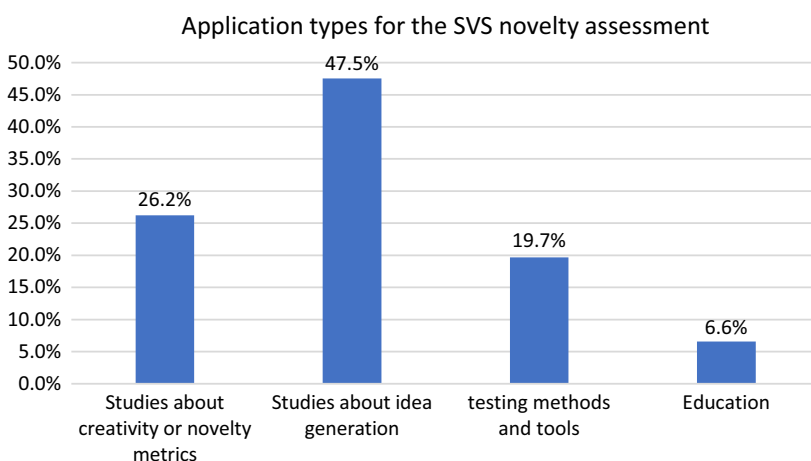**Table 4.** Application types identified for the SVS novelty metrics

Group	Description	References according to Table 2
Studies about creativity or novelty metrics	Articles about proposals, analysis, comparisons or discussions about creativity metrics, novelty metrics or innovation metrics	S16, S17, S18, S19, S23, S31, S32, S33, S34, S40, S43, S44, S45, S49, S50, S57
Studies about idea generation	Articles involving tests or experiments aimed at extracting information about idea generation mechanisms	S01, S02, S03, S06, S07, S08, S09, S10, S11, S12, S13, S14, S15, S21, S22, S24, S25, S28, S29, S35, S38, S42, S48, S52, S53, S54, S56, S58, S61
Testing methods and tools	Articles focused on testing the effects of design methods and/or tools, in terms of creativity	S04, S20, S26, S27, S30, S36, S41, S46, S51, S55, S59, S60
Education	Articles aimed at discussing different educational aspects concerning creativity	S05, S37, S39, S47

most creative part of the design process is the conceptual design phase. According to what was observed in the reviewed papers, we can assume that the studies using the SVS metrics are almost totally related to conceptual design activities.

4.5. Results from the investigation target related to Q5

Concerning the types of applications where the SVS metrics were applied, the performed analysis (as described in Section 3) led to four different groups (see Figure 5). A short description of each group is reported in Table 4, together with the related list of coded references.

As shown in Figure 5, a majority of works were about idea generation, followed by studies about creativity, innovation or novelty metrics.

Figure 5. Types of application identified for the SVS novelty metrics.
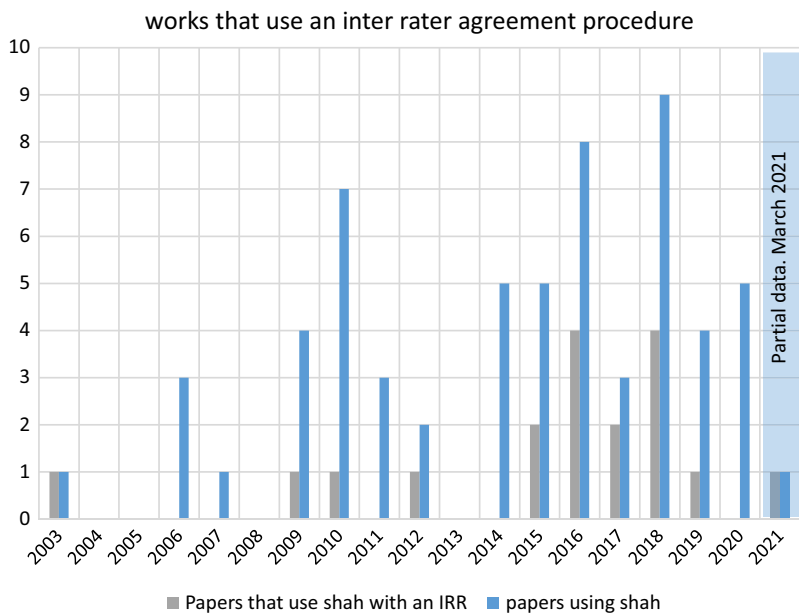
Figure 6. Papers that use SVS novelty metrics assessment and apply interrater agreement tests.

All of the reviewed contributions are related to academia. Indeed, even if industry was indirectly mentioned or involved, the application of novelty metrics was always performed by academic staff for academia-related purposes. Therefore, there is no evidence of the use of SVS in industry.

4.6. Results from the investigation target related to Q6

Figure 6 reveals that only a portion of the reviewed works used an Inter Rater Agreement (IRR) test to validate the novelty assessment. At first glance, the application rate of the IRR is quite irregular, without any evident trend. There appeared to be an increasing trend at least from 2009 to 2018, but the use of the IRR rapidly decreased thereafter.

Surprisingly, in some specific years, the IRR was never applied to novelty assessment results (i.e., 2006, 2007, 2011, 2014, 2020 in Figure 6). In particular, only 18 contributions (among the 61 that use the original SVS novelty assessment approach) mentioned an IRR test (e.g., Shah, Vargas-Hernandez & Smith 2003*b*; Kurtoglu, Campbell & Linsey 2009; Johnson *et al.* 2016; Vandevenne, Pieters & Duflou 2016; Bao, Faas & Yang 2018).

4.7. Results from the investigation target related to Q7

It emerged that a large part of the reviewed documents did not provide any information to allow a comprehensive understanding and repeatability of the assessment. We are conscious that due to ethical and/or professional agreements, it is often impossible to share whole sets of ideas (e.g., images, sketches or CAD files). This constraint could be the main reason behind the absence of documents
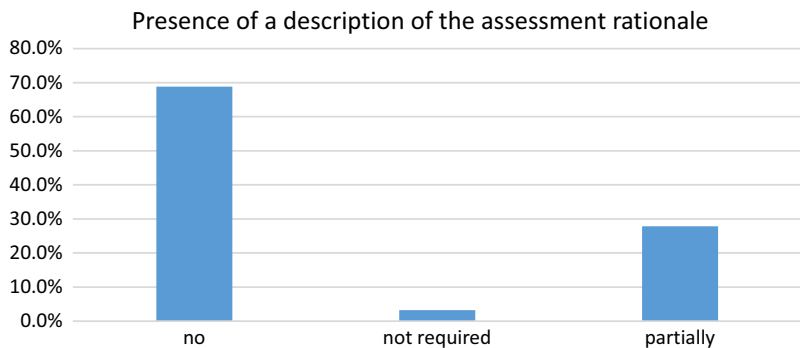
Figure 7. Percentages of articles that describe rationale for using the original SVS novelty assessment approaches. In particular, the graph shows how many documents do not report, partially report or are not required to report information about the assessment rationale. None of the reviewed papers completely reported the information required to ensure the repeatability of the experiment.

that allow a complete replication of the experiment. Indeed, without the original set of ideas, it is not possible to repeat the same assessment. However, as shown in Figure 7, a nonnegligible number of the reviewed documents report 'partial' but important information about the assessment procedure (e.g., description of the procedure used to identify the attributes and the related weights, list of attributes, set of assessed ideas codified in terms of functions and attributes, etc.).

Only in two cases (among the 61 articles that used the original SVS assessment procedure) was the description of the rationale not needed. Indeed, in these cases, the authors do not consider the assessment from a real experiment or design session but use ad hoc data to explain their proposal (Nelson *et al.* 2009) or to explain potential SVS issues in border cases (Fiorineschi *et al.* 2018*a*).

5. Discussion

5.1. Findings

According to the seven research targets reported in Table 1 and then according to the related research questions formulated in Section 2, the outcomes from this review work can be summarised as shown in Table 5.

SVS novelty metrics are used by less than 10% of the citing contributions (and almost all the contributions use the 'a posteriori' version), notwithstanding the high number of citations received by the work of Shah *et al.* (2003*a*). Indeed, many of the reviewed contributions consider other contents of the paper by Shah *et al.* (2003*a*). For example, Dym *et al.* (2005) refer to the SVS concept of variety, while Chandrasegaran *et al.* (2013) cite Shah *et al.* (2003*a*) when discussing creativity-related aspects. In general, the work of Shah *et al.* (2003*a*,*b*) is often mentioned when discussing creativity and idea generation concepts and definitions (e.g., Charyton & Merrill 2009; Linsey *et al.* 2010; Crismond & Adams 2012; Gonçalves, Cardoso & Badke-Schaub 2014).

The categories of applications are congruent with the original intent of the SVS work, that is., to support design creativity research with a systematic and practical approach to perform repeatable assessments. However, the observed (partial or

total) lack of information about the assessment rationale implies that the experiments described in the reviewed papers cannot be repeated (or comprehensively checked) by scholars. Indeed, as highlighted by Brown (2014) and confirmed by our recent works (Fiorineschi *et al.* 2020*a,b*), the identification of the functions and/or attributes of the assessed ideas and the definition of the related weights are highly subjective.

Furthermore, it was a disappointing surprise to see that interrater agreement tests are often not performed or even mentioned at all. Due to the previously mentioned issue of subjectivity (which characterises any creativity assessment approach), it is always necessary to involve multiple evaluators (at least 2) and then to carefully check the robustness of the obtained scores. Fortunately, comprehensive interrater agreement approaches (e.g., Cronbach 1951; Cohen 1960; Hayes & Krippendorff 2007) were used in some of the reviewed works (e.g., Shah *et al.* 2003*b*; Kurtoglu *et al.* 2009).

Another important flaw detected in the reviewed documents that use the original SVS approaches is the lack of comprehensive descriptions about the actual type of novelty that the investigation is expected to assess. In our recent review of novelty metrics, we identified a map to orient among the variety of different metrics (Fiorineschi & Rotini 2021), and one of the most important parameters is the type of novelty, intended as historical novelty or psychological novelty. The two SVS novelty assessment approaches belong to two distinct types of novelty but implement the same concept of novelty (uncommonness or unexpectedness). Any comprehensive work using the SVS metrics should demonstrate that their use is actually compatible with the expected measures.

5.2. Implications

The present work provides a clear picture of the actual usage of the SVS novelty assessment approaches, making it possible to understand the main flaws that characterise most of the published works. Implications from the observations extracted for each research question (see Table 5) are summarised in Table 6.

The implications expressed in Table 6 can be reformulated by better focusing on both readers and external agents. In the bullet list reported below, we try to do so by referring to scholars, teachers, reviewers, PhD supervisors and industrial practitioners:

- Implications for researchers who use the metrics and for paper reviewers:

  The implication derived from the findings related to Q6 deserves particular attention. Indeed, these findings imply that most of the reviewed works actually do not follow a robust assessment procedure. It is acknowledged that novelty assessment is necessarily performed by means of subjective interpretations of the assessed design or idea, and this also applies to the SVS metrics. Therefore, any assessment that fails to perform an IRR test among the evaluators cannot be considered scientifically valid.

  Additional implications can be extracted from the findings pertaining to Q7. Indeed, here, the evidence emerges of a substantial impossibility (for most of the research works) of providing the information required to allow the repetition of the assessment with the same data. To increase the ability to perform comparable experiments, it is necessary to allow the reader to understand any detail about how the experiment has been conducted. First, the assigned design or idea generation task should be

Table 5. Findings from each of the seven research questions introduced in Section 2

Question	Findings from this literature review
Q1	Only a limited number of the reviewed works actually use a novelty assessment approach related to SVS, and among those that do, less than half use the original version of the metrics
Q2	The a posteriori novelty metric is the most used approach among the contributions that use the original versions of the SVS assessment procedure. However, a nonnegligible number of the reviewed documents do not provide sufficient information to understand which metric is adopted
Q3	As expected, the majority of the reviewed documents directly refers to the definitions provided in the SVS work. However, it emerged that a nonnegligible number of the reviewed documents do not provide such information. Additionally, almost all the documents that use the original SVS metrics do not sufficiently clarify which novelty type (historical versus psychological) was required for the investigation
Q4	None of the papers that use the original SVS novelty assessment approaches mentions the use of the multiple design stages
Q5	We identified four categories of SVS applications, where the cluster related to studies about idea generation mechanisms is the most populated. The least frequently applied is about education, while studies related to creativity metrics and design methods or tools appear quite often. The applications refer to the academic field, while their use in industry does not appear
Q6	We detected a low use of interrater agreement tests. In addition, there is no evident application trend across the years
Q7	Most of the papers that use the original version of the SVS novelty assessment approaches do not provide sufficient descriptions of the assessment rationale followed. Some studies provide partial but important information

carefully described, as should the method used to administer it to the sample (or samples) of participants. In addition, it is important to carefully describe the considered sample of participants in terms of knowledge background, design experience, and, of course, gender, ethnographic and age distributions. Additionally, it is essential to carefully provide in-depth information about the experimental procedure. More specifically, it is crucial to indicate the time chosen to introduce the task, the time allotted to perform it and (if any) the presence of possible pauses (e.g., to enable incubation). Finally, it is necessary to provide indications about how participants worked, for example, whether they worked alone or in groups, whether they worked in a single design session or in subsequent design sessions, whether they worked on a single task on multiple tasks, etc.

It is also important to provide detailed information about the postprocessing activity (i.e., the novelty assessment for the scope of this work). More specifically, it is crucial to provide information about the evaluators, their expertise and the related background. The assessment procedure also needs to be carefully described in detail. In particular, it is important to mention and describe prealignment sessions among raters, as well as the procedure that each of them followed to identify the attributes from the ideas to be assessed.

Without the information described above, any research work where designs or ideas are assessed in terms of novelty (as is the case for any creativity-related assessment) cannot be considered as a reference.

Table 6. Implications of the results presented in Table 5

Question	Implications of the review results
Q1	When referring to the SVS metrics as 'some of the most cited ones', it is important to consider that this statement is partially incorrect. Indeed, while it is true that 61 papers actually used them, this is less than the 10% of the number of citations received by the article by Shah, Vargas-Hernandez & Smith (2003a,b) The majority of the citations received by the SVS paper reference other aspects of the paper or simply mention the metrics
Q2	When referring to SVS, it is important to be aware that two possible assessment procedures exist, each of them implementing a different novelty type (as defined by Fiorineschi & Rotini (2021). It is therefore of fundamental importance to clarify which is the assessment procedure actually used in the paper and to clearly describe the motivation for its use according to the experimental objectives
Q3	Failing to clearly specify the types and concepts of novelty the experiment is expected to deal with is a critical flaw for any research work about creativity research. Without such information, it is impossible to understand the motivation for the use of the SVS metrics
Q4	Notwithstanding the theoretical possibility of applying the SVS metrics to multiple design stages, this extension of the metrics has never been tested in practice. Therefore, when referring to the SVS metrics as 'applicable to any design stage', it is important to clarify that this is true only from a theoretical point of view, while practical proof of the metrics' actual applicability in other settings is still missing
Q5	The absence of research works where the SVS metrics have been used by or within industry suggests the distance between academic interests and industrial needs. Design research is of course a discipline that aims at supporting industry; therefore, it is important to ask ourselves why, after more than 20 years, one of the most acknowledged academic assessment procedures is almost unknown by industry
Q6	The presence of articles not using an IRR is alarming. In design science, it is essential to promote studies that comprehensively apply robust scientific approaches. To this end, both authors and reviewers should be aware of the importance of this issue when dealing with novelty assessments, which are tasks notoriously affected by subjectivity
Q7	Papers that claim to assess novelty but fail to provide comprehensive information about the experiment and the assessment procedure should not be considered scientifically sound. Unfortunately, except for few cases, the majority of the reviewed papers fail to provide such information. This shortcoming implies that most of the current literature that applies the SVS metrics cannot provide any valid proof of the correct application of the metrics

Generally, these considerations can be extended to each of the acknowledged novelty assessment approaches.

- Implications for teachers:

  What emerged in this paper is the need for a better understanding of the available concepts and types of novelty. Teaching creativity in design contexts should not neglect how to measure it. In this sense, due to the plethora of different metrics and assessment procedures, it is important that future designers or scholars start their professional lives with a sound understanding of 'what can be measured'. Indeed, a clear understanding of the novelty concepts and types to be measured will surely help in selecting the most suitable way to assess novelty and then to assess creativity.

24/45

- Implications for PhD supervisors:

  The need for more comprehensive descriptions expressed in the previous points should constitute a reference for PhD supervisors. Indeed, PhD students are often expected to perform experimental activities and then to apply (when needed) novelty metrics. First, it is necessary to identify 'what' is intended to be assessed. As demonstrated by the flaws highlighted in this paper, this is not a trivial task, and the aim is to clarify both the novelty type and the novelty concept (Fiorineschi & Rotini 2021). Then, before starting any experimental activity, it is important to plan it by considering the parameters to be considered in the assessment procedure (depending on the specific metric). Eventually, each experimental step must be opportunely archived and described to allow a comprehensive description of the adopted procedure. It is fundamental to allow reviewers to evaluate the robustness and the correctness of the experiment, as well as to allow scholars to repeat it in comparable boundary conditions.

- Implications for future development of novelty metrics:

  A particular criticality observed among the reviewed works concerns the presence of papers that cite SVS but use specifically developed metrics. The criticism is based on the observed absence of sound motivations or justifications about the actual need to use or to propose an alternative metric. As already highlighted in this paper, it is not our intention to denigrate any work, but it is important to provide a clear message for future works. More specifically, it is necessary to stem the trend of creating 'our own' metrics to be used in place of already published ones without providing any reasonable motivations and, more importantly, without any proof about the actual improvement provided in relation to existing metrics. Indeed, the field of novelty metrics is already very populated by different alternatives, and it is already quite difficult to navigate them. We are aware of this challenge because we personally tried to review novelty metrics to support our selection (Fiorineschi *et al.* 2019b; Fiorineschi & Rotini 2020, 2021). This does not mean that new metrics proposals or improvements should be avoided. This would be a hypocritical suggestion from us, since we have also proposed new metrics (Fiorineschi, Frillici & Rotini 2019a, 2021). What is important for future works that deal with novelty assessment is to use metrics that have been tested (in precedent works or in the same work) and to comprehensively describe the motivation for the choice. In particular, it is necessary to ensure that the selected metric is compatible with novelty type and concept type, which are expected to be measured according to the experimental objectives.

- Implications for design practice:

  Indirectly, this work could also help in design practice. Indeed, the major understanding of metrics that this paper provides is intended to support both better novelty measurements and more efficient method selection. More precisely, the future possibility of improving the selection and arrangement of ideation methods will ultimately help develop better products.

5.3. Limitations and research developments

The work suffers from two main limitations, which have been partially highlighted in the previous sections. First, the analysis is limited to the citations to the work of Shah *et al.* (2003a) as of March 2021, and second, we were unable to retrieve a nonnegligible number of documents (see Appendix Table A1). Indeed, our institution did not provide access to all contributions, and we tried to retrieve as many

of these as possible by directly asking for a free copy from the authors. Nevertheless, scholars could take inspiration from this work to perform similar analyses on other well-known assessment approaches (e.g., Hennessey *et al.* 2011; Sarkar & Chakrabarti 2011). With additional works such as this one, it may be possible to generate a clear map of the actual usage of the creativity assessment approaches used in the field of design creativity research.

Concerning the considered research questions, as mentioned above, we have identified the seven questions introduced in Section 2, which arise from our experience with in-depth (theoretical and practical) studies on novelty. We are therefore conscious that this work may not encompass all the doubts and questions about the argument.

An important limitation also concerns the missing analysis of the alternative metrics used in place of the SVS approaches. We believe that this kind of analysis can be considered feasible for future research, for which the list of documents reported in Table 3 could pave the way. The expected outcome from this possible extension of the work is a complete list and analysis of the whole set of metrics somehow inspired by or based on the SVS metrics. For that purpose, the list of metrics summarised in Table 3 could be integrated with other contributions (identified by following a different approach) that were already reviewed in our previous works (*Fiorineschi et al. 2019b*; Fiorineschi & Rotini 2019).

A further limitation of this work concerns the absence of any comprehensive analysis or discussion about the works that, even if not using the metrics, provide important considerations about the pros and cons of the SVS approach. However, we intentionally avoided this kind of analysis to avoid overlap with our recently published works that are focused on this kind of investigation (Fiorineschi *et al.* 2018*a*, 2020*a*,*b*, 2021), where the reader can find an updated set of related information.

5.4. Expected impact

The main impact expected from this work is upon academic research on design creativity and can be summarised as follows:

- Help scholars understand the application field of the SVS novelty assessment approach.
- Promote comprehensive assessments through the correct application of the metrics by at least two evaluators, whose scores should always be checked by an IRR test.
- Invite scholars to provide sufficient information about the assessment rationale that has been followed for the application of the selected novelty metric.
- Describe the need for clear indications about the considered novelty type that the selected metric intends to measure (i.e., historical novelty or psychological novelty).

Generally, it is expected that this work could shed further light in the field of design creativity research by focusing on the novelty assessment of generated ideas. In particular, the criticalities highlighted in this work are expected to push scholars towards a more responsive use of metrics and to follow robust assessment procedures. This is fundamental to improving the scientific value of studies focused on novelty-related works about design and design methods and tools.

Unfortunately, it is not possible to formulate any 'short-term' expectation from the industrial point of view. Indeed, this work highlights that the use of the metrics is limited to academic fields (at least according to what is claimed in the analysed contributions). Therefore, a question may arise: 'Are novelty metrics from academia useful for the industrial field?'

However, to answer this question, at least two other issues should be considered:

- 'Are industrial practitioners sufficiently aware of the presence of novelty assessment procedures'?
- 'Are industrial practitioners conscious of the potential information that can be extracted by the application of novelty and other creativity-related metrics?'

Therefore, even if a direct impact cannot be expected for industry, this work can push scholars to bridge the gap that currently exists between academia and industry in relation to the topic.

6. Conclusions

The main focus of this work is to shed light on the actual use of the two novelty assessment procedures presented by Shah *et al.* (2003*a*,*b*) For that purpose, we formulated seven research questions whose answers have been generated through the analysis of the literature contributions that cite the work of Shah *et al.* (2003*a*,*b*). We found that even if scholars actually use the SVS novelty assessment approaches, the citations to the work of Shah *et al.* (2003*a*,*b*) often do not refer to novelty assessment. In addition, scholars frequently use a different version of the SVS metrics without providing explicit motivations behind this need. However, the most important issue highlighted in this work is the almost total lack of any reference to the type of novelty (historical or psychological) that scholars intend to assess when they use SVS metrics. This kind of information is fundamental and allows the reader to understand whether the selected metrics are suitable to obtain the expected results. Furthermore, the results highlight that, except for a few cases, the information provided in the reviewed works is not sufficient to repeat the experiments and/or the assessments in comparable conditions. Indeed, it emerged that only a few works provide a comprehensive description of the assessment rationale and apply interrater agreement evaluations. This is a critical aspect that should be considered by scholars for improving future literature contributions where novelty assessments are involved. As a further result, the methodology applied in this work can be reused by scholars to perform similar analyses on other metrics, not only limited to the field of creativity assessment. Indeed, several metrics exist in the literature (e.g., the quality of a design, modularity level of a system, sustainability of products and processes, etc.), and similar to what occurs in creativity assessment, comprehensive selection guidelines are still missing. Indeed, the expected impact of this work is to help scholars perform novelty assessments with improved scientific value. Eventually, studies such as this can contribute to the discussion about how to use metrics in different branches of engineering design and research.

Acknowledgments

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Appendix

A.1. List of the articles for which it was impossible to retrieve the document in this literature review

Table A1. Not retrieved articles

Title	Authors	Year	Source title	DOI
Mitigating Design Fixation: A Visualization Tool for Enhancing Situation Awareness	Hwang D., Choi B., Bae S., Park W.	2021	Journal of Mechanical Design, Transactions of the ASME	10.1115/1.4048814
Out in the Field Versus Inside in the Lab: A Comparison of Design Professionals' Concept Screening Practices (DETC2019–97564)	Zheng X., Miller S.R.	2021	Journal of Mechanical Design, Transactions of the ASME	10.1115/1.4047904
Adaptive inspirational design stimuli: Using design output to computationally search for stimuli that impact concept generation	Goucher-Lambert K., Gyory J.T., Kotovsky K., Cagan J.	2020	Journal of Mechanical Design, Transactions of the ASME	10.1115/1.4046077
Mirroring neurostimulation outcomes through behavioral interventions to improve creative performance	Sahar A., Farb N.A.S., Shu L.H.	2020	Proceedings of the ASME Design Engineering Technical Conference	
Properties of design representations: An interdisciplinary exploration of their functional role [Propiedades de las representaciones en diseño: Una exploración interdisciplinaria de su rol funcional]	Maya J., Mazo E.P.	2020	Kepes	10.17151/kepes.2020.17.21.2
Integration of weekly reflections in an introductory design class to assess experiential learning outcomes	Morimoto T.K., Delson N., Sandoval C.L.	2020	ASEE Annual Conference and Exposition, Conference Proceedings	

Table A1. Continued

Title	Authors	Year	Source title	DOI
Revitalization Wayang in present context through creative learning; brainstorming, and mind mapping	Setiawan K., Zahar I., Lihardja N., Yunithree M.	2020	Journal of Advanced Research in Dynamical and Control Systems	10.5373/JARDCS/V12I2/S20201286
Impact of TRIZ learning on performance in biologically inspired design	Liu W., Tan R., Peng Q., Li H., Li Z., Yang B.	2020	International Journal of Engineering Education	
Exploration of the timing of introduction of design heuristic cards to early design brainstorming sessions by interdisciplinary student teams	Rivera A.M., Lugo J.E.	2020	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2020-22477
From information to ideas: How designers structure information to support idea generation	Damen N.B., Toh C.A.	2020	Proceedings of the ASME Design Engineering Technical Conference	
How engineering design students' psychological safety impacts team concept generation and screening practices	Cole C., Marhefka J., Jablokow K., Mohammed S., Ritter S., Miller S.	2020	Proceedings of the ASME Design Engineering Technical Conference	
Does it translate? A case study of conceptual design outcomes with U.S. and Moroccan students	Peng A., Menold J., Miller S.R.	2020	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2020-22623
Can process metrics predict product success?: A pilot study of student design teams	Bracken J., Glavin F.X., Henderson D., Jablokow K., Sonalkar N., Erdman A.M.	2019	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2019-97704
Should it stay or should it go?: A case study of concept screening in engineering design industry	Zheng X., Miller S.R.	2019	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2019-97564
Toward a functional failure analysis method of identifying and	van Bossuyt D.L., Arlitt R.M.	2019	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2019-98255

Table A1. Continued

Title	Authors	Year	Source title	DOI
mitigating spurious system emissions in a system of systems				
Requirement generation: Lecture intervention impact on variety and novelty	Elena M.V., Summers J.D.	2019	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2019-97528
Design for additive manufacturing: Effectiveness of unit cell design guidelines as ideation tools	Boyd I., Fazelpour M.	2019	ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE)	10.1115/IMECE2019-11539
IISC DBox: A game for children to learn design thinking	Bhatt A.N., Bhaumik R., Chandran K.M., Chakrabarti A.	2019	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2019-98066
Learning experiences that facilitate innovation and workforce preparation: Exploring the impact of in-class and extracurricular activities	Amelink C.T., Davis K.A., Watford B.	2019	International Journal of Engineering Education	
Effect of team size on problem-solving and solution quality: An empirical study	Jacobs S., Pfarr M., Fazelpour M., Koroma A., Mesfin T.	2019	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2019-97719
Evaluating idea quantity and variety when using digital collaboration tools to support brainstorming in non-collocated teams	Kaweesa D.V., McComb C., Menold J., Ritter S., Meisel N.A.	2019	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2019-98203
Exploring the relationship between idea quality and satisfaction on new ideas for smart products	Rhiu I., Yun M.H.	2019	Industrial Engineering and Management Systems	10.7232/iems.2019.18.2.163
Uncovering ownership bias: The influence of idea goodness and creativity on design professionals' concept selection practices	Zheng X., Miller S.R.	2018	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2018-85964

Table A1. Continued

Title	Authors	Year	Source title	DOI
Let's generate ideas - A review of web-based crowd sourcing tools for the basis of entrepreneurship	Fellnhofer K., Pree W.	2018	Journal for International Business and Entrepreneurship Development	10.1504/JIBED.2018.10012206
Confidently exploring the solution space: The within-subject effects of product dissection on design variety and creative self-efficacy	Starkey E.M., Alzayed M.A., Hunter S.T., Miller S.R.	2018	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2018-85875
Helping teams expand the breadth of their solution space through product dissection: A simulation based investigation	Alzayed M.A., McComb C., Hunter S.T., Miller S.R.	2018	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2018-85832
Team idea generation in the wild: A view from four timescales	Shroyer K., Turns J., Lovins T., Cardella M., Atman C.J.	2017	Analysing Design Thinking: Studies of Cross-Cultural Co-Creation	10.1201/9781315208169
Gamifying evaluation of creativity in early stages of conceptual design	Dinar M., Shah J.J.	2016	4th International Conference on Design Creativity, ICDC 2016	
Study of the effectiveness in design communication: Comparing 3D printing pen Vs. sketching	Vargas Hernandez N., Acevedo S., Chowdhury R.	2016	4th International Conference on Design Creativity, ICDC 2016	
The relationship between team gender diversity, idea variety, and potential for design innovation	Fila N.D., Purzer Ş.	2014	International Journal of Engineering Education	
The role of individual risk attitudes on the selection of creative concepts in engineering design	Toh C.A., Miller S.R.	2014	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC201435106
GC-MAS – a multiagent system for building creative groups used in computer supported collaborative learning	Moise G., Vladoiu M., Constantinescu Z.	2014	Advances in Intelligent Systems and Computing	10.1007/978-3-319-07650-8_31
Introduction to two new conceptual design methods: Extraordinary	Liu A., Lu S.Y.	2014		

Table A1. Continued

Title	Authors	Year	Source title	DOI
breakthrough thinking and innovative design thinking			ASEE Annual Conference and Exposition, Conference Proceedings	
A method to select best nuggets from eco-innovation sessions	Vallet F., Tyl B., Millet D., Eynard B.	2013	Green Design, Materials and Manufacturing Processes - Proceedings of the 2nd International Conference on Sustainable Intelligent Manufacturing, SIM 2013	10.1201/b15002-125
Impacts of team composition of distance and on-campus students on the conceptual design performance	Liu A., Lu S.C.-Y.	2013	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2013-12631
Towards a comprehensive test of qualitative reasoning skill in design	Khorshidi M., Woodward J., Shah J.J.	2012	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2012-70657
A tablet based application for teaching function and exploring concept alternatives during early design	Bohm M.R., Nagel R.L., Shirley M.L.	2012	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2012-71118
Engineering design: Representation and reasoning, second edition	Dym C.L., Brown D.C.	2012	Engineering Design: Representation and Reasoning, Second Edition	10.1017/CBO9781139031813
Evaluation of design work and the achievement of learning outcomes in senior Capstone courses	Sorensen C.D., Todd R.H., Halverson T.	2012	ASEE Annual Conference and Exposition, Conference Proceedings	
An approach toward developing metrics to predict performance and creativity of final products in project-based design class	Takai S., Midha A., Esterman M.	2012	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2012-70415

Table A1. Continued

Title	Authors	Year	Source title	DOI
Pre-post assessment of creativity methods in an experimental course	Takai S.	2011	International Journal of Engineering Education	
Impacts of team characteristics and design activities on design outcomes	Takai S.	2011	Proceedings of the ASME Design Engineering Technical Conference	10.1115/DETC2011-47498
Tacit knowledge acquisition method for the process of concept design	Liu Z., Lu N., Sun L.	2011	Jixie Gongcheng Xuebao/Journal of Mechanical Engineering	10.3901/JME.2011.14.184
The Development and Evaluation of Tools for Creativity	Smith S.M., Kerne A., Koh E., Shah J.	2009	Tools for Innovation	10.1093/acprof:oso/ 9780195381634.003.0007
Self-organised semantic feature evolution for axiomatic design	Hao H., Feng Y., Tan J., Xue Y.	2008	Chinese Journal of Mechanical Engineering (English Edition)	10.3901/CJME.2008.02.108
Innovative technology education using a virtual reality learning environment	Thorsteinsson G., Pages T.	2008	Pedagogika	
Creative design based on knowledge management in engineering design	Liang J., Jiang Z., Zhen L., Su H., Wang K.	2007	Chinese Journal of Mechanical Engineering (English Edition)	10.3901/cjme.2007.05.101
Innovative technology education	Gisli T., Page T.	2007	Technical Paper - Society of Manufacturing Engineers	
Contextual cueing and verbal stimuli in design idea generation	Liikkanen L., Perttula M.K.	2006	Design Computing and Cognition '06	10.1007/978-1-4020-5131-9_32
Generating creative ideas through patents	Wen G., Jiang L., Wen J., Shadbolt N.R.	2006	Lecture Notes in Computer Science (including subseries Lecture Notes	10.1007/11801603_72

Table A1. Continued

Title	Authors	Year	Source title	DOI
			in Artificial Intelligence and Lecture Notes in Bioinformatics)	
Evaluating relative instructional effectiveness and efficiencies of design activities for Product Platform Planning	Sahin A., Terpenny J., Shooter S.B., Stone R.B., Simpson T.W.	2006	Proceedings of the ASME Design Engineering Technical Conference	10.1115/detc2006-99517
Empirical studies of creative cognition in idea generation	Smith S.M., Gerkens D.R., Shah J.J., Vargas-Hernandez N.	2005	Creativity and Innovation in Organizational Teams	10.4324/9781410615732
Cognitive modeling of iteration in conceptual design	Chusllp P., Jin V.	2004	Proceedings of the ASME Design Engineering Technical Conference	