Automatic assessment of creativity in heuristic problem-solving based on query diversity

Evaluación automática de la creatividad frente a la resolución de problemas heurísticos basada en la diversidad de consultas

Cristian Olivares-Rodríguez[1,2], Mariluz Guenaga[2] and Pablo Garaizar[2]

[1] Universidad Andres Bello. Faculty of Engineering. Engineering Sciences Department. Antonio Varas, 880 - Santiago (Chile)
[2] University of Deusto. Faculty of Engineering. Avda. Universidades, 24 - 48007 Bilbao (Spain)

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ABSTRACT

Research, development and innovation are the pillars on which companies rely to offer new products and services capable of attracting consumer demand. This is why creative problem-solving emerges as one of the most relevant skills of the 21st century. Fortunately, there are many creativity training programs that have proven effective. However, many of these programs and methods base on a previous measurement of creativity and require experienced reviewers, they consume time for being manual, and they are far from everyday activities.

In this study, we propose a model to estimate the creative quality of users' solutions dealing with heuristic problems, based on the automatic analysis of query patterns issued during the information search to solve the problem. This model has been able to predict the creative quality of solutions produced by 226 users, reaching a sensitivity of 78.43%. Likewise, the level of agreement among reviewers in relation to the creative characteristics is evaluated through two rubrics, and thereby, observing the difficulties of the manual evaluation: subjectivity and effort.

The proposed model could be used to foster prompt detection of non-creative solutions and it could be implemented in diverse industrial processes that can range from the recruitment of talent to the evaluation of performance in R&D&I processes.

Keywords: innovation, information search, query pattern, complex problem solving, machine learning.

RESUMEN

Investigación, desarrollo e innovación son los grandes pilares sobre los que las empresas se apoyan para ofrecer nuevos productos y servicios capaces de atraer la demanda del consumidor. Por este motivo, la resolución creativa de problemas emerge como una de las competencias más importantes del siglo XXI. Afortunadamente, son abundantes los programas de entrenamiento de la creatividad que han demostrado su eficacia. Sin embargo, muchos de estos programas y métodos se basan en una medición previa de la creatividad y requieren experiencia por parte de los revisores, consumen tiempo debido a que son manuales y se encuentran alejados de las actividades cotidianas.

En este artículo se propone un modelo para estimar la calidad creativa de las soluciones elaboradas por los usuarios frente a problemas heurísticos, que se sustenta en el análisis automático del patrón de consultas emitidas durante la búsqueda de información para resolver el problema. Este modelo ha sido utilizado para predecir la calidad creativa de la solución de 226 usuarios, alcanzando una fiabilidad del 78.43%. Asimismo, se evalúa el grado de acuerdo existente entre los revisores en relación a las características creativas, evaluadas por medio de dos rúbricas, y constatando las dificultades de la evaluación manual: subjetividad y esfuerzo.

El modelo propuesto puede emplearse para la detección temprana de resultados poco creativos e implantarse en procesos industriales diversos que pueden ir desde la captación de talento a la evaluación del desempeño en procesos de I+D+i.

Palabras clave: Innovación, búsqueda de información, patrón de consultas, resolución de problemas complejos, aprendizaje automático.

1. INTRODUCTION

Research, development and innovation (R&D&I) processes are fundamental in the evolution of highly competitive industrial organizations, but they require strategies to reduce the risks inherent in the knowledge exploration [1]. Innovation is conceived as the medium through which the organization changes, either as a reaction to its environment or proactively from within the organization. Therefore, innovation is the systematic search for improvement in products, services or procedures through the generation of new knowledge [2], this is, it is the process that starts from the creation of ideas and ends with the implementation of the solution [3].

Human capital is the main resource that provides sustainability to the organization and, therefore, both specific technical skills and transversal skills contribute to the innovation process [4]. In particular, creativity is a crucial skill in the generation of novel and useful ideas that lead to innovation. Professionals from industry must explore knowledge to propose alternative solution to solve problems, especially by heuristics. At present, this is one of the most demanded transversal skills by employers when hiring professionals in general and, particularly, engineers, because they face complex problems in competitive environments on a daily basis. Thus, creative problem-solving has become a crucial skill of the 21st century [5]. It has been proved that participants with good performance in mathematics, language or science do not necessarily have good results when

solving unknown problems [6]. This skill demands an active process of searching for alternatives, i.e. information, to develop novel and useful solutions. Similarly, concept-association skills have proven essential for the generation of creative ideas, since the greater the amount, diversity, originality and elaboration of associations, the better the opportunity for creative ideas to emerge [7]-[9]. In this line, several authors have proposed the inclusion of strategies that promote creative thinking during the resolution of complex problems in the training of engineers [10], such as: analogical thinking, which seeks the deconstruction of elements to produce new ideas [11]; the brainstorming, which seeks to generate and relate a large number of ideas [12]; the checklist, which promotes the analysis of various points of view of the problem; mental maps, which allows the structuring of ideas [13]; the morphological analysis [14]; or the theory of inventive problem solving (TRIZ), which is an algorithmic approach to the innovation process [15].

Unfortunately, measuring creativity requires long procedures in which experts on creativity have to evaluate it manually. Otherwise, there could be low agreement among reviewers, and consequently, low reliability. It has been evidenced that manual measurement tools [16][17] have high reliability but their application and review are time and effort consuming. On the other hand, other manual tools to evaluate associative skills, such as «uncommon uses» [4] or word associations [18] have a low application time but they have a low inter-reviewer reliability, especially when reviewers are not experts on creativity. In particular, there are instruments that measure creativity of engineers who need to produce original ideas within their job and have been used in professional selection processes: Purdue Creativity Test, PCT [19] and Creative Engineering Design Assessment, CEDA [20]. Those procedures often involve activities that have to be explicitly and directly evaluated, so they suffer from the problems already mentioned: long and tedious procedures with low agreement among reviewers.

The challenge addressed in this study is to reduce the time and effort to automatically estimate the creative quality of participants' solutions using data from their interaction with a Web search system during the information search to solve a problem. We propose a user model that based on the diversity in the search behavior, allows to automatically discriminate users' query issuing pattern of those who elaborate more creative solutions during a problem-based intervention, which could be applied in engineering educational and professional contexts. With this purpose, a dataset was experimentally obtained which contains participants' actions during the creative problem resolution. This dataset was used to evaluate the quality of the proposed model regarding the prediction of the creative quality of the solution.

The information search process is an interactive experience in which the selection of pieces of information aims at extending user's knowledge [21]. This process was recently validated [22] and is influenced by different components: the User, the Search Task, the Search System, the Environment and the Outcome. Each of these components impacts directly on the search behavior. The user's search behavior is defined by all the actions that he or she performs during the interaction with a search engine in order to retrieve relevant or useful information, this is, entered queries, used terms, retrieved documents, time spent, etc. Previous studies on the search behavior have focused on evaluating the influence of different components in the process, such as the domain knowledge [23][24], cognitive styles [25][26], the type of tasks to solve [27][28], search system functionality [29][30], training sessions [31][32], etc. In this work a supervised learning model is trained with creative and non-creative participants' queries entering pattern, since it evidences users' association skill, and as mentioned, it is a relevant characteristic in the creative process [7]-[9].

Previous studies designed user models based on search behavior to predict the characteristics of the search process, such as participants' actions [33], their role [34], task difficulty [35], knowledge of the domain [36] or creative quality [37]. User models derived from behavioral data emerge in order to describe which search strategies are followed by users. First, Cen et al. aimed to explain user behavior through reinforcement learning models, which are trained with a behavioral dataset [33]. Second, Eickhoff et al. implemented a user model to predict search success and user role based on a dataset of the search behavior. Users' behavior was manually classified in two types of categories: role and success. Data collected were used to learn user models, and they achieved high precision: 76% for role and 77% for success [34]. Third, Arguello trained a model to predict task difficulty based on a high number of search sessions, which defined a behavioral dataset. Both cognitive and physical data were extracted from the sessions, and a prediction was made according to the first search attempt and with the complete session, but the latter showed better results [35]. Fourth, Jingjing Liu proposed a model to predict user knowledge about a topic through their search behavior. A predictive model based on behavioral dataset showed a sufficient performance in the initial stage (65.37%), similar to the middle and final stages of the process (65.15%) [36]. Finally, Olivares-Rodríguez and Guenaga defined an unsupervised model to analyze the creative solutions in terms of the query issuing pattern. A clustering method was used to discover a set of point of views from a dataset of queries. These data were used to train user models and to detect the creative quality of solutions [37]. To the best of our knowledge, only this last study aimed at predicting the creative quality of solutions [37]. However, it depends on both a huge number of queries and on the user's ability to formulate queries [38]. On the contrary, the model in this study proposes that the prediction of creative quality or creative class of solutions depends on the inherent diversity of queries, which can be achieved using a semantic analysis.

Taking the above into consideration, the hypotheses of this work are the following:

- H1: *There is a moderate agreement among reviewers who manually evaluate the associative skill linked to creativity through «uncommon uses» developed by users*. This would support the difficulty of evaluating the creative quality of participants by means of general rubrics.
- H2: *The semantic diversity when users enter queries during the Web information search (as a means to creatively solve a challenge/problem), can automatically and implicitly predict the creative quality of the solution*. This would provide the opportunity to build automatic and implicit tools to estimate the creative quality of information search engine users when solving complex problems in educational and professional contexts.

The next section presents the process to construct the proposed model for the estimation of the creative quality. Section 3 provides the results of the study, while in section 4 a brief discussion of the results is made to finally present the conclusions and future work.

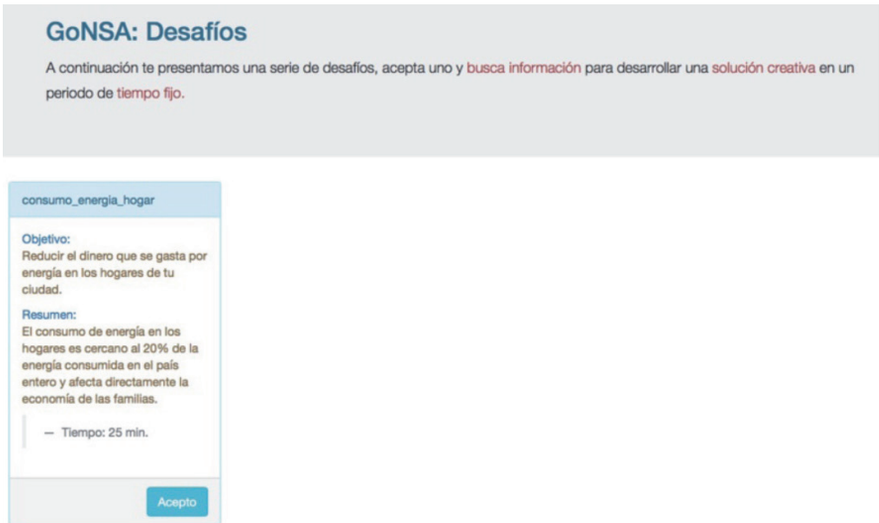

Figure 1: GoNSA: the challenge interface: «Reduce the money spent on energy in your city's homes»

Figure 2: GoNSA: the information search interface: challenge (left) and results of query (right)

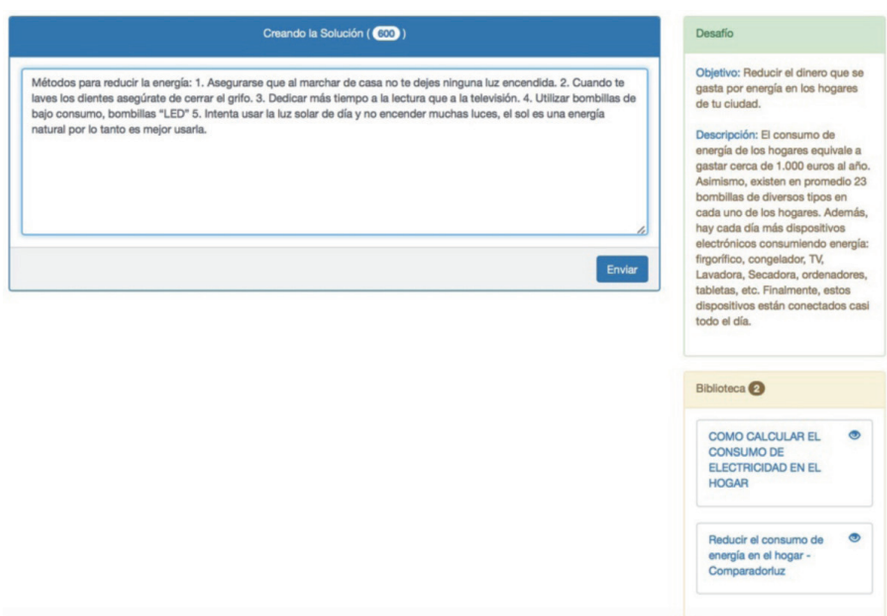

Figure 3: GoNSA: the solution interface: participant's solution (left), challenge (up-right) and library (down-right)

2. AUTOMATIC ASSESMENT OF CREATIVITY

The proposed models aim at implicitly and automatically estimate the creative quality of solutions developed by users during the resolution of heuristic problems, similar to real cases in the industry. In order to construct the estimation model it is necessary to have a dataset with the information search behavior and the evaluation of the creative quality of elaborated solutions. This generates the necessary evidence to later carry out the training and validation of a computational model capable of providing estimates of creativity, implicitly and automatically. Therefore, during the intervention based on heuristic problems, it was performed: 1) manual evaluation of creativity to the participants, 2) manual evaluation of the creativity to the solutions developed by participants, 3) extraction of the dataset of the Web search behavior of all participants and 4) construction and validation of the proposed model for the estimation of the creative quality of the solutions. The process of obtaining the dataset and the characteristics of the creative model is described below.

2.1. PROBLEM-BASED INFORMATION SEARCH

As explained before, to build and validate the model proposed in this work it is necessary to obtain a dataset with users' Web information search actions. For this purpose, a problem-based intervention was conducted with a group of participants, who solved a heuristic problem through a Web search using a technological platform developed especially for this research, named GoNSA. The participants' search behavior registered by this platform was then manually assessed by a solution assessment process in order to train the computational model.

Problem-based intervention was conducted in Spain and Chile. There were a total of 256 participants, 52.4% male and 47.6% female, with similar age (M: 12.08 SD: 0.75), knowledge base and skills, all of whom gave their consent. However, none of the materials used in this procedure can be considered sensitive or offensive. Rooms equipped with personal computers were used for the experiment. Participants used web browsers to connect to GoNSA, which registers actions (queries, pages, clicks, etc.) performed by participants during the information search process to solve a problem. Fig. 1 shows the interface that presents the challenge to be solved; Fig. 2 presents the information search interface where you can find a library to store relevant documents and the complete challenge description; finally, in Fig. 3 the solution interface is shown, where users write the so-

lution to the challenge and they can consult the library they have built during the search phase. Thanks to the GoNSA platform we obtain queries issued by participants and evaluate them through the proposed model.

We chose the design of heuristic challenges, as proposed in [39], because the aim of this study is to promote intensive associations during the information search process and to simulate a realistic problem-based context. The challenge is in Spanish, the mother tongue of participants. It is open -there is a wide variety of solutions-, general -within their daily scope-, realistic -similar to real life problems in professional contexts-, and requires creativity, since it is necessary to integrate elements in order to elaborate the solution.

In order to manually measure creativity, two rubrics were used: the first evaluates the general association ability of participants, while the second, specific to the problem, evaluates the creative quality of the solutions:

- Association Assessment (κu). In order to validate the first hypothesis, Spanish users' creativity was evaluated through the «uncommon uses» procedure, using the procedure defined by Benedek et al. [9], where participants have to write uncommon uses of an object. Their answers are evaluated using a Likert scale regarding Fluency, Flexibility and Originality. Even if this evaluation is quite easy, it involves a high degree of subjectivity.
- Solution Assessment (κs). The solutions' creativity was evaluated to estimate the creativity level of each participant by solving heuristic problems, this will be used as a label to train the proposed supervised model. The rubric used to evaluate the solutions is defined through four dimensions: Novelty, Specificity, Workability, and Relevance. This evaluation process requires a lot of effort for each solution [17].

The experiment was conducted by the main researcher of this study through a face-to-face session in Spain and a virtual session in Chile.

- The association assessment (uncommon uses) was made with the Spanish group and lasted five minutes.
- The solution assessment was made by a heuristic problem-based approach. Participants from Spain and Chile had 35 minutes to solve the challenge of «Reducing the money spent on energy in your city's homes». During this time, users search for information entering queries using the GoNSA platform; they review the results and save those results or documents they consider useful; and they elaborate a creative solution. Studies on user's behavior have found that search sessions do not last more than 15 minutes.
- Three external reviewers with different professions, unknown to each other, took part in the evaluation of the uncommon uses and the quality of the solutions. The review was anonymous and it was made randomly using the GoNSA platform. Reviewers were provided with the evaluation context description, instructions, participants' artifacts (uncommon uses and solutions) and rubrics.

Fig. 4 shows the solution evaluation interface, where the rubric and its criteria is partially shown. Solutions' evaluations made by reviewers are averaged to obtain the final mark for each user, if it passes a minimum threshold a the solution is classified as creative.

Finally, after the problem-based intervention we obtain a dataset with each user's search session (query pattern) and the corresponding creative or non-creative classification, depending on the creativity level assigned by the reviewers by solution assessment. Our interest is to publish the dataset to contribute to the development and validation of new user models, as well as to ensure the replicability of experiments.

2.2. CREATIVITY MODEL

Considering that creative people are those who explore new conceptual spaces, the proposed model is based on the diversity of associations in information search behavior. It is computed using the dataset obtained from the experiment with users and the solution assessment carried out by reviewers.

Equation 1: The aim of this function is to capture the diversity of associations inherent to the pattern of queries, to estimate automatically and implicitly the creative quality of solutions elaborated for the challenge *d*.

$$\phi(Q_d^u) \sim \sum_{q}^{|Q_d^u|} dist(q_j^u, d) \quad (1)$$

Where *dist* is a measure of the diversity of a query for the challenge *d*, which is automatically computed. Meanwhile, f is a vector

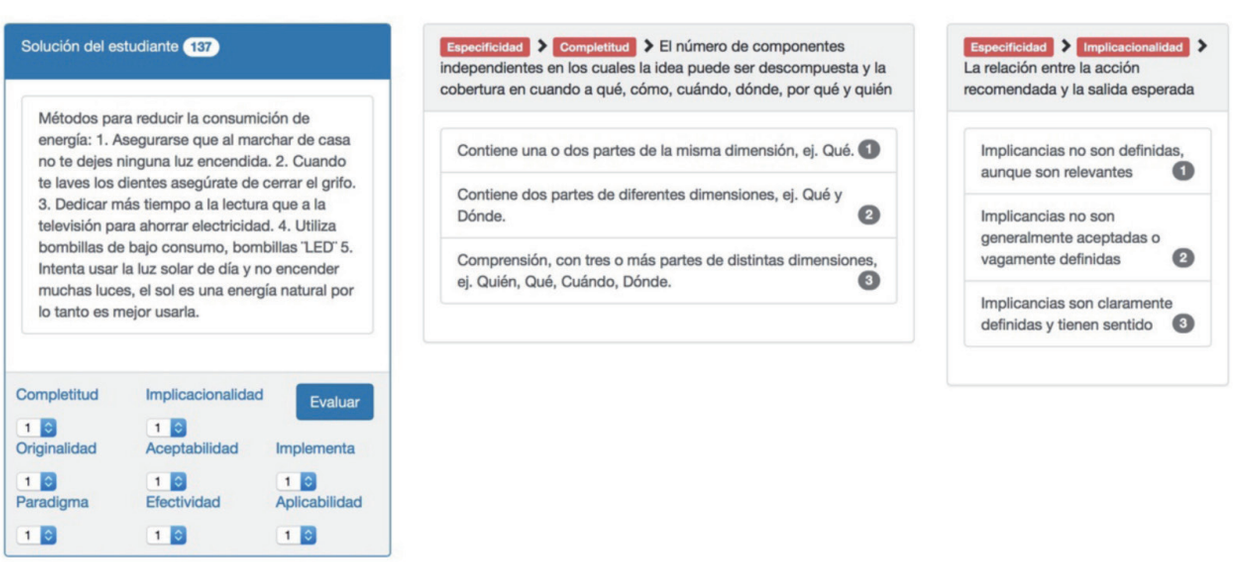

Figure 4: GoNSA: part of the evaluation interface, in particular, participant's solution and part of the rubric

of similarities among the queries and c-concepts most relevant to the challenge *d* based on Explicit Semantic Analysis [40].

In order to compute the query diversity function Wikipedia is considered as the explicit knowledge source. However, due to the great number of articles on Wikipedia, only those with 400 words or more in the description have been extracted and used during the function computation. In order to obtain the diversity between the queries Qdu and the challenge *d*, we estimated the semantic similarity of each user-issued query to the *k* most relevant concepts for the challenge. For this purpose, we calculated the similarity of all concepts obtained from Wikipedia (*T*) with respect to the terms used in the challenge *d*, and they were ordered in a decreasing list to retain the part associated to the first *k* concepts in the list Cdk. Finally, from this list Cdk we obtained the rows associated with each of the *w* words of each query qju, and we obtained an average vector that represents the semantic distance to the challenge (eq. 2). Fig. 5 shows the query diversity computation.

$$dist(q_j^u, d) = \frac{\sum C_d^k(Wt_j^u)}{|W_j^u|} \quad (2)$$

Where Wju are the words used by the user *u* in the query *j*.

Finally, after transforming the initial dataset in function of the proposed queries' diversity model, a dataset is obtained represented by the diversity vectors ϕ and the corresponding creativity or non-creativity labels of each participant.

3. RESULTS

Below, we show the results organized according to the hypotheses of this study.

H1: *There is a moderate agreement among reviewers who manually evaluate creativity through «uncommon uses» developed by users.* Table 1 shows the results disaggregated by each dimension of the rubric and integrated in the weighted global evaluation, using Cohen's weighted Kappa coefficient. Fluency (0.56) achieves a moderate level of agreement among the three reviewers, while Flexibility (0.36) and Originality (0.38) reach a sufficient level of agreement among reviewers, using Fleiss's Kappa coefficient. The inter-class correlation coefficient with continuous values was used to evaluate the inter-reviewer reliability in the weighted global evaluation.

In conclusion, the global agreement was higher than the one proposed in H1, reaching a substantial level. However, sufficient and moderate levels of agreement are seen when disaggregating by dimension. This shows the high subjectivity and low inter-reviewer reliability of this rubric to evaluate users' creativity.

Criteria	R1-R2	R1-R3	R2-R3	R1-R2-R3
Fluency	0.65	0.46	0.56	0.56
Flexibility	0.52	**0.28**	**0.28**	**0.36**
Originality	0.41	**0.35**	**0.38**	**0.38**
Evaluation	0.74	0.68	0.52	**0.64**

Table 1: Inter-reviewer reliability over association assessment (κu) by dimension and global evaluation

H2: *The semantic diversity when users enter queries during the Web information search (as a means to creatively solve a challenge/problem), can automatically predict the creative quality of the solution.* The diversity query model, ϕ*d*, was used to train and test classifiers based on random trees, because it is a bagging model and reduces the overfitting. Results were compared with a model,

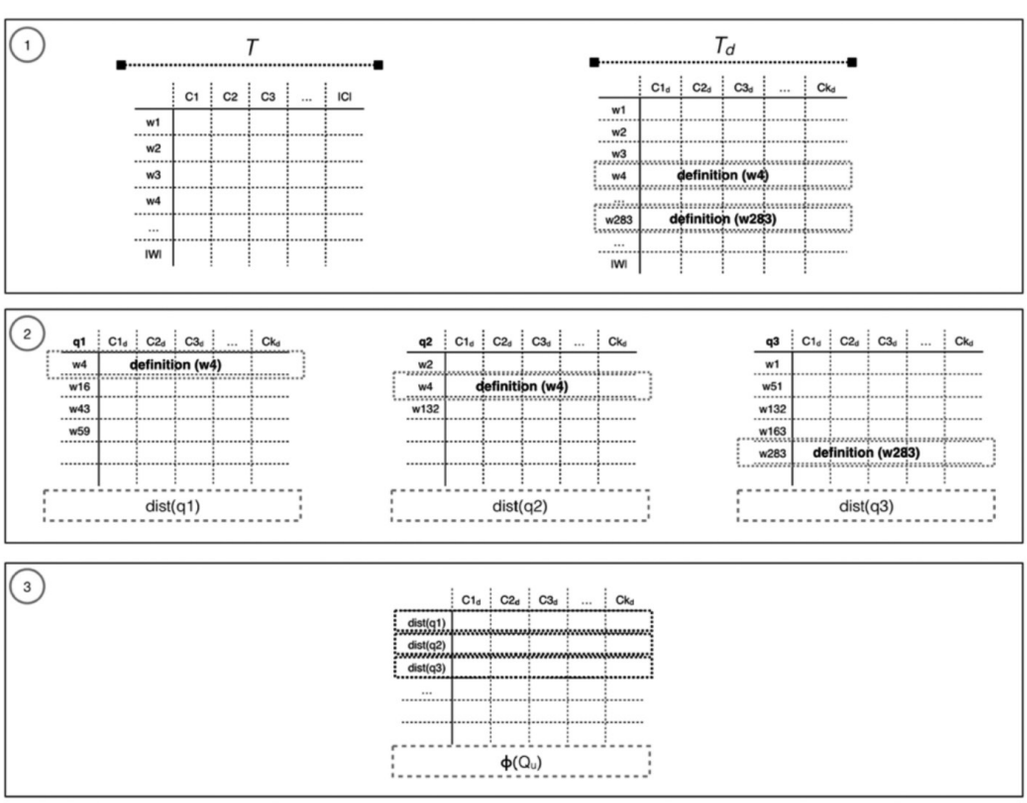

Figure 5: Calculating the diversity of queries: (1) obtaining the K more relevant concepts to the challenge from Wikipedia (2) calculating the distance of each query and (3) calculating the diversity of queries

ϕv, that depends on *k* points of view, which are both similar to c-concepts in our model and obtained by computing a clustering method over a query dataset [37]. Several values for *k* were used with the aim of analyzing the impact of the number of concepts and points of view on the classifiers' performance. Models were trained and evaluated using the diversity dataset. A leave-one-out cross-validation schema was used in the quality evaluation of models, and the sensitivity, specificity and space under the curve (ROC) were used as metrics for the performance of the model.

k	ϕv			ϕd		
	ROC	Sens	Spec	ROC	Sens	Spec
3	52.04%	53.31%	46.15%	61.86%	65.34%	57.37%
5	58.28%	55.73%	52.77%	55.47%	52.77%	51.87%
7	58.71%	55.92%	48.12%	58.69%	54.39%	52.87%
9	66.09%	67.32%	55.66%	**66.04%**	**64.68%**	**60.27%**
15	65.29%	65.68%	52.65%	62.68%	66.94%	57.93%

Table 2: performance of evaluated users' models for different values of k and a α 55%

Table 2 shows the results obtained using a creative threshold α of 55%. A better balance is obtained between creative and non-creative solutions, while the model based on semantic analysis offers a better balance between the correct classification of positive and negative solutions, which is evidenced in the level of sensitivity (creative) and specificity (non-creative) achieved by this model.

k	ϕv			ϕd		
	ROC	Sens	Spec	ROC	Sens	Spec
3	58.73%	71.52%	25.20%	63.25%	**78.43%**	41.21%
5	62.95%	71.97%	27.50%	59.04%	80.33%	20.54%
7	62.35%	78.92%	24.10%	58.73%	76.86%	24.10%
9	63.43%	76.85%	22.89%	60.28%	83.94%	27.14%
15	63.99%	81.02%	21.06%	60.99%	80.88%	24.10%

Table 3: performance of evaluated users' models for different values of k and a α 60%

Table 3 shows the results obtained for a creative requirement α of 60%. A trend is observed to correctly classify creative solutions, due to the imbalance in the number of samples. However, a sensitivity of 78.43% is reached in the Wikipedia-based model, this is, the model is able to efficiently estimate creative solutions compared to the model based on the points of view.

4. DISCUSSION

There is a wide variety of tools to evaluate creativity and solutions' creativity, but they often require experience from those who apply and evaluate them. So, if reviewers have little experience, there could be a low level of agreement. Results obtained from the first hypothesis show a substantial level of agreement in the global evaluation of creativity, but the level is just sufficient or moderated in the disaggregation by dimension. Therefore, such general rubric is not suitable to regularly evaluate participant creativity, because there are evidences about high subjectivity and low reliability in such evaluation procedures.

The model proposed in this study contributes to reduce the time and effort needed to detect the creative quality of solutions elaborated by users. Contrary to the manual evaluation procedures [16]-[18], the assessment proposed is computed both implicitly and automatically during a problem solving task based on query diversity. Consequently, it enables the development of activities and procedures based on Web information search tasks to implicitly assess creativity in both educational and professional contexts. Results are in line with the second hypothesis. The proposed model obtains high levels of sensitivity (78.43%) to the detriment of specificity, and it also achieved satisfactory results that balance sensitivity (64.68%) and specificity (60.27%). Additionally, our user model based on query diversity has a better performance than a previous model based on points of view, which strongly depends on a huge set of queries to discover such views [37]. Therefore, we think this approach opens the possibility of generating solutions that contribute to improve creative quality of users and to implicit and automatically evaluate professional creativity similarly to manual procedures such as PCT and CEDA.

In spite of the good results obtained, it is possible to go into more depth in similar studies in the future. First, we could use a higher number of users' actions (queries, clicks, browsing, information selection, etc.). Second, the inclusion of more concepts could give the model more expressiveness. Third, demographic variables such as gender, age or location could be integrated into the model.

5. CONCLUSIONS

Innovation is a crucial process for competitive companies and it is based both on the high technical capacities of human capital and on the highly demanded transversal skills in the labor market. We live in a knowledge society where huge amounts of information are generated daily. Such context generates threats and opportunities to solve information problems through efficient search processes. In this context, the availability of a tool capable of automatically and implicitly evaluating these processes contributes to the generation of new problem solving scenarios in order to automatically estimate the creative potential of professionals. Thanks to such tools, technologically improved platforms would be able to detect extreme cases and develop an early and effective intervention plan of industrial process, that can go from the capture of talent to the performance evaluation of R&D&I processes. Assessing not only creative solutions, but heuristic problem solving processes, would be also possible using this kind of tools in order to better understand how we manage information during innovation processes.

Finally, the time and effort to evaluate the creative quality of solutions were reduced in contrast to manual procedures. Therefore, systems based on the model presented here could be used to automatically assess millions of search patterns and obtain a better understanding of the knowledge acquisition and information management of engineers doing innovation. Also, the proposed model outperforms previous works based on a clustering method, which depends on a huge set of queries. Further research is needed in this area, but this study presents an effort towards the improved assessment of users' creative quality through automatic and implicit technological tools, which could be applied to both educational and professional contexts in order to promote

creative search, recommend creative associations and enhance innovation strategies.

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