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Information-Seeking in Education for Creative Solving of Design and Engineering Problems

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Abstract: The paper aims to highlight the significance and place of information-seeking in finding improved solutions in the design of innovative products. The observation method was used to identify a way to increase the efficiency of searching for information needed when pursuing a creative solution to a design problem. The study was based on the experience gained in professional activities in higher education for industrial engineering and in the classes held for two academic subjects, when students' creativity was stimulated, including in the search for information. One conclusion is that an experienced designer or researcher should make sketches and notes immediately after formulating the design objective. In this way, the possible inhibitory influence exerted by the results of a deep search for information could be avoided. In the case of a novice designer, it may be necessary to have a minimum collection of general information in the design topic field to familiarize the designer more with the problem addressed. The novice designer could thus develop a few sketches and notes and then go through a deeper stage of information-seeking. Another conclusion was that a certain minimum amount of scientific and technical knowledge is necessary to use technical creativity effectively.

Keywords: information-seeking; characteristics; place of the information-seeking; creative solving

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1. Introduction

In machine manufacturing, it is accepted that design refers to a plan or only a sketch of an object, a piece of equipment, or a process that will be materialized later.

In a broader sense, the design could be considered a component of scientific research and innovation activities. As a result, the design might involve taking on a design problem defined by others or recognizing and formulating a problem, formulating hypotheses, collecting data using observation and experiments, and testing the initially formulated hypotheses.

The consultation of the specialized literature on design and technological innovation highlighted that many authors of works in this field were teachers involved in educating pupils and students to develop innovative activities. They considered that one of the first stages in innovation is information seeking, and the pupils or students must have ample knowledge of this subject.

Thus, it is known that an important criterion in evaluating the results of innovation is the originality of results. The designer and the student involved in innovation have to prove originality. On the other hand, originality could be connected with the human characteristic called creativity. Opinions differ as to the definition of creativity. American psychologist Gordon Allport proposed one of the first definitions of creativity. He considered creativity as an integrative modality according to which human beings should be able to succeed not only in understanding, reproducing, and solving the countless issues of life, work, and the environment they are confronted with but also in generating new and original solutions [1].

Some stages must be completed, from formulating the theme of innovation or research to achieving the desired results. Over time, specialists considered various numbers of such stages specific generally to research or innovative design. As mentioned above, as a rule, innovative design or scientific research could include [2]:

1. Defining an innovation topic;
2. Seeking specific information;
3. Formulating hypotheses;
4. Performing experiments and collecting data;
5. Analyzing the data;
6. Interpreting the data and formulating conclusions that could be used to develop new hypotheses;
7. Publishing the results;
8. Possible retesting and validation of results by other designers.

Even the simplest structures proposed for innovation include at least one information-seeking stage. In innovation activity, information-seeking or documentary research could be considered an operation carried out deliberately to seek, identify, and process technical and scientific data, using them efficiently in the near or distant future, developing, testing, and applying innovative hypotheses.

Within this paper, information-seeking refers to the systematic seeking, storing, and processing of scientific and technical knowledge.

Generally, it could place the information-seeking process immediately after identifying the innovation or research topic. Information seeking may precede the so-called operational stage. The efforts are generally directed toward solving the research topic/problem and identifying a solution incorporating original elements.

Thus, in a book published in 1923, Santiago Ramon y Cajal wondered whether it was necessary to consult the available bibliography before starting research. He notes that the general opinion of that period was that no research might start before knowing all the preceding works in the approached field. He considered that consulting all the available literature was a more prudent approach [3].

Beveridge noted that the designer or scientific researcher usually could be accustomed to thoroughly studying the bibliography concerning the research subject. However, specialists in that epoch considered that such an approach would limit thinking. The specialists appreciated that this would generate difficulties in finding a new and fruitful point of view [4].

Garrett showed that in science education, a distinction must be made between the concept of the puzzle when there is, or it is supposed to be a solution and the concept of the problem for which it is not possible to have a solution [5]. He believed identifying a problem could be more important than finding a solution.

In the former Soviet Union, studying the literature was seen as a second stage, which could be approached after formulating the research topic [6,7]. The literature examination must provide an image concerning the level the previously developed innovation reached and the latest results obtained in the field of interest [7]. The seeking, accumulating, and processing of information could thus be considered a science.

To highlight the importance of information seeking, in a chapter called "Searching the literature", E. Bright Wilson, Jr. states that six hours in the library may save six months in the laboratory [8].

Mandanshetty [9] noticed that the novices and non-specialists succeeded in offering interesting and useful solutions during the brainstorming meetings. It can be formulated as the lack of much-consolidated information sometimes facilitates access to new or improved solutions for design problems.

A widely accepted opinion by designers considers axiomatic design a handy tool for developing creative solutions to various problems [10–13]. Using axiomatic design principles involves decomposing the functional requirements to be met by the system to be designed. This decomposition is based on the previous existence or intentional accumulation of sufficiently clear and consistent information about that system.

Each innovative project must be based on the results of previous projects in the same field, against which it must differentiate itself. Information-seeking could be considered a technique and art, and sometimes it is similar to the activity of a detective or a prospector. It is important to know about the existence of previous knowledge, how it may be accessed, and how to process it [14].

Wilson [15] believed that a problem-solving model includes four possible stages: problem identification, problem definition, problem resolution, and solution statement. Between every two stages, uncertainty resolution and information-seeking are required.

The issue of information-seeking is considered a major worry and a barrier for relatively inexperienced researchers [16]. Solving some of the problems specific to information-seeking (how to read, what to read, how to make sense of the reading) may help the designer understand what other designers or researchers have done in that specific research area.

Jenkins' model for the research and innovation process considers library research as the second stage, after the development of the idea, followed by the formulation of the topic, research strategy and experiment design, data capture, data analysis, and publishing results [17].

A problem for the young designer or researcher is the time allotted to information-seeking activities. It is important to limit this duration, especially in the current circumstances, when many documents are published in various fields. Almost three centuries ago, in 1613, the English writer Barnaby Riche stated: "One of the diseases of this age is the multiplicity of books". The duration of information-seeking has to be rationally evaluated and established, considering the complexity of the topics to be researched. Hans Selye showed that the information-seeking activity that extends too much in time could generate a serious obstacle in the way of ingenuity [18].

The information retrieval may be and has to be a process allowing creativity. Ford showed that technological developments must accompany the effort to help the users develop information-seeking skills to maximize the benefit [19]. He concluded that when searching for new directions and developing new approaches, a rich diversity of information could facilitate the identification of creative ideas. Thus, a compensation of the inherent limits of the retrieval information system is possible, and a useful tool, in this case, could be the method for stimulating creativity.

Brissaud et al. highlighted the significance of reusing previous design knowledge inclusively in the case of the development of new products. They proposed a system to capture design process rationale and make it available for reuse in future projects [20].

In papers published in 2006 and 2007 [21,22], researchers from the Nanyang Technological University of Singapore highlighted the advantages of creative information-seeking. They identified six stages in creative information-seeking and developed two studies examining the subjects' creative information-seeking behavior. Their model for creative information-seeking took into consideration the unique characteristics of a directed and open-ended information-seeking task, respectively. The analysis of the findings showed that more iterative, non-sequential progression may be needed to accomplish more complex tasks.

Eaglestone et al. [23] studied the issue of understanding the requirements of information systems to assist the specialists involved in creative intellectual processes. Their field is concerned with electro-acoustic music composition. They noticed that information systems do not always contribute genuinely to the stimulation of creativity.

In a paper concerning the possibility of obtaining a unified framework for understanding the concept of information in three distinct domains (physical, biological, and human), D. Bawden notes that there has been considerable debate on the nature of the information science subject [24]. The author expressed his conviction that human information, together with consciousness and intelligence, may have an unforeseeable contribution to the development of the universe in the future.

Hyman placed the background information about the research topic in a first stage, which he called "problem definition", followed by a second stage, dedicated to research design [25].

Aurisicchio et al. proposed the introduction of a distinction between requests to acquire information and to process information; they considered that while the first type of request refers to access to design and domain information, the second type of request is used in defining designs, in developing new solutions [26].

Klucevsek et al. considered that for students to acquire scientific skills, specific training is needed on what it means and how to carry out the scientific information-seeking activity [27]. They found that addressing this issue with a science librarian could lead to effective results in how they interact with scientific texts.

Yang et al. undertook a quasi-experimental design that aimed at the efficiency of using strategies to stimulate students' creativity [28]. They found that some supportive teaching strategies can be used to develop creative thinking, such as facilitating associative thinking, sharing impressive ideas, formulating evidence-based conclusions, etc.

Kwon et al. considered that enterprise creativity could be used efficiently when approached for applying design thinking [29]. They appreciated that in large organizations, the exploration of many new ideas could be expensive, and design thinking is applied in a limited context.

In research on the interior design of an academic library, Abouelela started from the fact that such a library must be characterized by creativity and innovation [30]. In this way, it is possible to ensure a research environment that meets the demands of students and faculty members.

The possibility of identifying useful information resulting from a sequence of interactions between applicants and an information system was called conversational information-seeking. Some researchers have pursued the characteristics and increasing the efficiency of information transfer in the conversational information-seeking process [31–33].

The difficulties of an information-seeking activity within different economic or academic fields and different ways of overcoming them have also been an object of researchers' attention [34–40].

The study of specialized literature sometimes highlights different opinions regarding the role and position of information-seeking in the context of a design or research activity. The authors of this paper took into account the experience gained through teaching in their capacity as teachers involved in stimulating the technical-scientific creativity of students in engineering design. They found that accumulating extensive knowledge through information-seeking activity immediately after formulating the innovation theme could generate a psychological obstacle in identifying innovative solutions. This fact happens especially when starting from the premise that the quantum of knowledge specific to the domain of the innovation theme is a closed system that can no longer be developed or whose further development is difficult. A psychological obstacle effect is also generated when the information-seeking is not carried out from the beginning in a critical spirit by self-formulating a requirement to identify a better solution than those found in the accessed documentation. The previous considerations do not deny the importance of deep information-seeking. Still, it can be argued that this activity must take place after elaborating some initial sketches and texts related to a possible innovative solution. Thus, it is possible to reduce the inhibition effect generated by the identification, through the activity of deep information-seeking, for high-performance solutions, and for solutions promoted by prestigious personalities or companies. The authors propose distinct solutions for postponing the deep information-seeking stage in the case of an experienced designer and, respectively, in that of a novice designer.

This paper aimed primarily to identify those characteristics of information-seeking that are essential to such an activity and need to be known by students, designers, or researchers. A second purpose was to highlight the place of information-seeking during the innovative design process developed by the authors or resulted from the coordination of research/design groups consisting of professors, researchers, and students, and to showcase the teaching of creative information-seeking in higher education at the "Gheorghe Asachi" Technical University of Iaşi, Romania.

2. Materials and Methods

2.1. Research Objective

The objective of the research whose results have been presented in this paper was to structure some observations gradually and notice some characteristics of innovative engineering education in the case of students from a bachelor's degree program and a master's degree program, respectively. Two academic subjects from the two study programs were taken into account, namely:

1. "Fundamentals of the technical creativity" from the "Manufacturing engineering" degree study program;
2. "Fundamental of the scientific research" from the master studies programs "Management of the industrial production" and "Advanced manufacturing technology", respectively. In the case of both academic master studies programs, the teaching activities are in the form of lectures (2 h per week) and seminars or projects (2 h or 1 h per week).

In the case of the first academic subject, the aim was to complete the teaching activities by identifying and innovatively solving engineering design problems. In the case of the second academic subject, the objective was to familiarize the master's students with the requirements and how to conduct research in innovative engineering problems solving.

Both engineering innovation and scientific research involve systematically going through specific steps, but this paper has prioritized detailing information-seeking issues. Even in the involvement of students, the lecture and applicative activities allowed the gradual identification and structuring of observations and working principles whose use allowed a successive improvement of the results obtained through the activities aimed at achieving the objectives mentioned above.

When the students resort to a deep information search immediately after formulating the design theme, they can appreciate that they cannot identify innovative solutions when comparing their solutions with those identified by deep information-seeking. Under such conditions, it was appreciated that a research problem was identified and that the observation method could be used to formulate possible improvement solutions to avoid the psychological inhibition effect.

The observation method is a fundamental method of accumulating empirical data, used primarily in the social and human sciences field. It presupposes a planned action carried out to certain objectives and assumptions. In the case of the research whose results are presented in this paper, the formulated objective was to identify a modality to avoid the inhibitory psychological effect generated as a result of identifying some solutions to the engineering design problem formulated by experienced specialists, or by prestigious personalities or companies. It was hypothesized that a postponement of deep information-seeking could be particularly beneficial to designers with experience in the innovation problem. In the case of novice designers, it was hypothesized that less extensive information-seeking would be necessary first to familiarize them with the aspects of the innovative design problem assumed. Later, after formulating the first sketches and texts to solve the design problem, experienced and novice designers could develop a deep information-seeking activity. Thus, they could compare their first solutions (elaborated without feeling the inhibitory psychological effect) with those others proposed. This could facilitate the improvement of the initially identified solutions.

There are different opinions regarding the stages of applying the observation method [41–45]. In principle, it is thus appreciated that the main stages of the application of the observation method are the following:

1. Behavior observation;
2. Recording the observed behavior;

3. Analysis and interpretation of behavior;
4. Generalization of findings.

Observing how the position of the information-seeking stage exerted influence on the ability to creatively solve some engineering design problems was carried out during the didactic activities developed in engineering design university matters, as well as in the university matters intended to stimulate technical creativity.

Concretely, within the applicative didactic activities to the university subjects mentioned in the paper, it was found that when the students were obliged to develop principal solutions for the design tasks received, possibly after a brief clarification of what was wanted by solving the design problems, students were able to relatively quickly devise alternative solutions to the problem. It is worth noting that the group discussions of alternatives for solving design problems also seemed to have stimulated the manifestation of students' creativity. When deep information-seeking was performed after receiving the research themes, but before starting to identify possible solutions for the design themes, students appeared timid and more reticent about their possibilities of creatively solving the design problems they faced. It was appreciated that this effect could be attributed to a type of inhibition of creativity generated by the identification of solutions previously promoted by personalities and companies that proved real capabilities to identify and finalize some sometimes complex solutions for the design themes attributed to the students.

It was also found that students with deeper professional knowledge were confident enough in their creative abilities to formulate innovative solutions for the given design themes more quickly.

The authors of this paper also obtained positive results in solving some engineering design problems. There were confirmed possibilities of the fuller manifestation of creativity when postponing the stage of deep information-seeking after the first elaboration of some sketches or texts if sufficient scientific and technical information about the design topic existed.

The applicative activities of the previously mentioned university matters involved the participation of groups of 10–25 students, each being assigned a specific design theme which, as far as possible, had to be solved creatively. Under similar conditions, it was found that when a student first resorted to deep information-seeking, the previously highlighted sense of inhibition appeared. The students appreciated that, having relatively little scientific and technical information, they could not identify innovative solutions for the creative solution of design theme. It was found that if in the first stage of preliminary information the students were more familiar with the design topics, and there was an encouraging attitude on the part of the teachers who coordinate the applied didactic activity, the students became more confident in their own strengths and identification situations appeared of truly creative solutions to design problems. Afterwards, the student resorted to deep information-seeking. Now, they could compare their solutions with those presented in scientific papers, patents, or handbooks. Following comparison with the solutions identified in the previously published documents, some students found that the solutions they identified were inferior to those found in the process of deep information-seeking. Still, they appreciated that they could be creative in seeking and identifying innovative solutions. A lower number of students found that, somewhat to their surprise, the solutions they identified had interesting elements of originality. Other students identified possibilities to improve the previously identified solutions. Higher-level innovative solutions were identified quite quickly by some students who had deep and advanced practical knowledge. Such students had previously graduated from vocational schools or were self-involved in practical activities in the field of mechanics. Some of the students' innovative achievements will be mentioned later in Section 3.4 of this paper.

In carrying out the research presented in the paper, other methods could have been used apart from the observation method. Such a method could have been the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) method. However, the PRISMA method's application would have required more information regarding that method's content, characteristics, and application stages from the beginning. For this reason and due to the simpler structure of the observation method, the application of the last mentioned method was preferred, but the use of the PRISMA method could be considered in the future.

2.2. Research Questions

The research questions that were sought to be answered through the content of this paper were the following:

1. What are the characteristics of the information-seeking activity that the students should know to make this activity more efficient?
2. When the information-seeking activity must be carried out within the stages of innovative engineering innovation and scientific research;
3. What quantum of technical knowledge do students need to effectively solve innovative engineering and scientific research problems?
4. What factors can affect the efficiency of the information-seeking activity and the identification of innovative solutions for the innovation and research problem addressed?

3. Results and Discussion

3.1. Main Characteristics of the Creative Information-Seeking Process

Some aspects concerning the significance and the characteristics of an efficient information-seeking process are considered below:

(a) The process of information collection has to allow the accumulation of useful knowledge, offering a general image concerning the theoretical and practical knowledge of the addressed topic. The information-seeking process facilitates understanding what other specialists have done in the interest area since direct personal experience can never be enough [16]. From this point of view, the process of information-seeking has to be quite thorough;

(b) The information obtained may extend the scope of the proposed topic and better place the designer's work in the existing context;

(c) An efficient process of information-seeking has to provide the conditions for avoiding an investment of time, financial or material resources, and of psychical energy in investigating a topic that has already been researched in-depth or about which significant practical or scientific results have already been obtained;

(d) Following the abovementioned aspect, the information-seeking process could decrease the duration of applying new knowledge in practice. Throughout history, the time interval between the discovery of new phenomena or processes and their application for solving practical problems has decreased constantly;

(e) The process of information seeking must lead to the formulation of useful suggestions or the generation of new ideas, both for the development of future innovative solutions and for the identification of innovation directions;

(f) The information-seeking process should start by approaching the closest resources, consulting/interviewing the specialists who accept to provide information concerning the topic of interest, and examining the documents that may exist in one's own company or institution archives. Thus, it is possible to see if any studies were previously developed in the field of interest or fields close to a particular field of interest or in fields that could offer suggestions or technical and scientific instruments for developing their efforts;

(g) Even when aiming for a certain innovative solution for the addressed problem, it is very unlikely that it can be found through a process of information-seeking alone; the sources of information can, however, provide useful suggestions for the innovative design or research process;

(h) The process of seeking information does not restrict the thought process. It must not generate the feeling that all aspects of scientific or technical interest have already been investigated and the best solutions have been found. Such a risk appears especially when the information found is developed by significant personalities or by well-equipped organizations from a technical point of view. The content of the documents, the competence, and the authors' prestige could induce anxiety and cause the innovative person to doubt their capability. The creative engineer must consider that the authors of the consulted documents are also human beings, working to the extent of their possibilities and knowledge. Nothing the engineer finds in accessed documents can be definitively established and impossible to develop. History sometimes proved that valuable results were obtained or valuable studies were initiated in less well-equipped laboratories in terms of technology and information resources. The engineer should be aware of and convinced that his experience, abilities, and passion, as well as the new instruments used, could help him in identifying interesting and original solutions for the innovative topic;

(i) The information-seeking process has to be developed so that, as much as possible, to further ensure a convenient retrieval of relevant knowledge for solving a certain problem. The question is how to find and apply a way to store the information identified during information-seeking and make it searchable, including for issues not of current interest. As a rule, every specialist finds and adopts/develops his way of storing relevant information;

(j) Both experienced and novice innovators/designers should approach information-seeking in a so-called "aggressive" way, not only following up on what the documents' authors meant to show, but also highlighting the aspects that were not approached or insufficiently developed. They could also consider any contradictions, any elements that differ from generally accepted views. Moreover, the innovators should ask themselves permanently if what they read, hear, examine, or have presented to them, could be achieved in a better or more effective way;

(k) The process of information-seeking has to allow, in the end, the comparison of the designer's results with the results of the activities of other innovative designers;

(l) Information-seeking could clarify the innovator's research objectives and open new topics in fields where problems have not been solved or have only been partially solved. The information-seeking process could also allow innovative designers to establish the critical aspects concerning the state-of-the-art of technique in their field of interest.

(m) The increasingly intense use of computers and especially of the Internet, including for improving the efficiency of information collection, has been visible in recent decades, becoming a real characteristic of the information-seeking process [46].

Many of the previously mentioned problems can be more easily solved nowadays by using digital means [47]. Thus, using keywords and recommendations for utilizing various search engines, the identification of potentially useful works is greatly facilitated without the need to consult the physical synthesis documents generated by the documentation offices, which are usually found in large libraries. In the last decade, in the course of deep information-seeking, the use of patent information was possible, for example, by accessing the web pages https://worldwide.espacenet.com/ (accessed on 12 November 2022), https://patents.google.com/ (accessed on 15 November 2022), http://www.patentinspiration.com/ (accessed on 20 November 2022), etc.

3.2. The Process of Creative Information-Seeking as a Stage of the Engineering Activity

Generally, it may be considered that there are two ways to approach the design:

(1) Routine design, when the time for problem-solving is too short for trying to find and develop an original solution. Despite the time being too short, this does not mean that sometimes an original solution could not be found; the innovator's intuition and experience could help them identify an original and, if possible, a more convenient (superior) solution in comparison with the known ones;

(2) Creative design is used when there is enough time for investigating and finding an original solution, or at least trying to find an original one. In this case, the process of information-seeking has a significant role.

It might consider the possible psychological inhibition generated by the solutions found in accessed documents by a possible "obscuration" of the way towards finding new and possibly superior solutions. The statement could be valid, for example, in the case of the solutions found, accepted, and promoted a long time before, or promoted by personalities who are important authorities in a certain field. Such situations require a more detailed analysis. For example, the invention of the wheel has sometimes been considered an obstacle to finding new locomotion means. Similarly, statements formulated by high scientific authorities may have negatively influenced the evolution of science and technology. For example, the French Academy of Science's statement that heavier-than-air bodies would be unable to leave the ground by their means may initially have negatively influenced researchers, designers, and inventors in the field of aeronautics.

A commonly-accepted idea says that when an inventor tries to find a new solution to a problem, he must "forget" to a certain extent about any previous solutions, precisely to ignore the limits introduced by the apparent impossibility of solving the problem.

Thus, if it takes into consideration the innovator's available experience, two situations could be identified (Figure 1):

(a) The first situation involves experienced innovators. This innovator is aware and accepts that each structure (material or theoretical) is susceptible to improvement. This designer could take the direct approach to problem-solving, followed by or carried out simultaneously with information-seeking. Even in this case, it is recommended that the innovative designers start the in-depth process of information-seeking only after outlining their own possible solution for the problem under consideration;
(b) The second situation is characteristic of the novice designer, which could be the innovative student situation. There is the possibility that this student may be inhibited by the information found during the information-seeking activity.

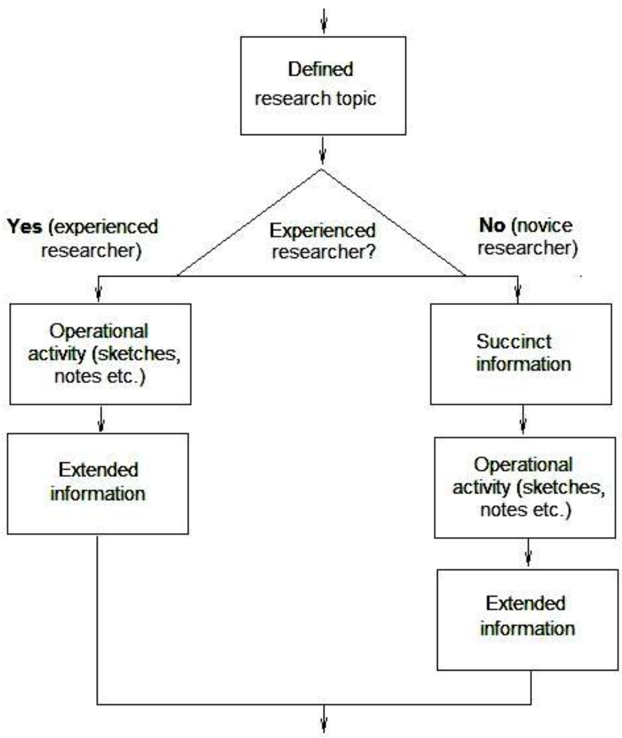

Figure 1. Place of information-seeking in case of experienced designers and novice designers.

It is necessary to mention that the innovative student/engineer must try to outline his/her solution in both situations, possibly even before accumulating too much knowledge about the problem to be solved. From the beginning, the innovative person should elaborate sketches, notes, and structures for the proposed papers/reports/design, etc., to avoid any possible inhibitive influence from the other specialists' results. After a preliminary development of their solutions, the innovative person may expand the consultation of accessible scientific or technical information sources. Thus, other achievements will not negatively influence the innovative specialist's considerations. There will be a higher probability of identifying a new, possibly original, and superior solution for the topic of interest.

Thus, the innovative designer has two options:

- An experienced designer may try to develop their solution based on the available knowledge. Later on, or simultaneously, the experienced designer may carry out a systematic and effective process of information-seeking;
- A novice designer with insufficient knowledge of the design topic will consult only general documents, such as handbooks, encyclopedias, etc. Only after the designer may develop his solution could he continue the process of information-seeking to compare and verify their results with the results of other designers.

One of the authors recalls when, as a novice designer searching for documents in a large national library, he felt discouraged by a large amount of information on the subject and the material conditions available to other designers in the field of the problem addressed.

The abovementioned considerations are not a plea for diminishing the significance of the information-seeking process. This process must finally verify the originality of the proposed model proposed by the designer, comparing the designer's results with any previously obtained by him or other designers.

Nowadays, many tools for information-seeking exist, if only considering the solutions proposed by standard or virtual libraries [48–50]. There is a high probability that new solutions for increasing the efficiency of information-seeking processes will appear.

3.3. Factors That Influence a Creative Process of Information-Seeking

Creativity may be stimulated, including at the stage of information-seeking. It is of great interest to carry out information-seeking creatively.

The factors that may influence creativity have been classified into several groups.

Some factors stimulate, others hinder the creative information-seeking, and some do both. If it tries to analyze the factors that may, as a rule, influence creativity or the capacity of innovation, the following main groups [2,51] may be distinguished:

1. Factors of a biological nature: genetic potential, the capacity of memorizing, age, sex, state of health, etc.;
2. Factors of a predominantly psychological nature: imaginative qualities, abilities, temperament features, volitional qualities, motivation, curiosity, level of commitment, etc.;
3. Factors of a cognitive–intellectual nature: specialized intellectual qualities, specialized intellectual training, gnoseology factors, time management skills, the spirit of observation, discernment, etc.;
4. Factors of a socio-economical nature: school, family, material status, socio-professional background, socio-economical demands, social climate, etc.;
5. Chance.

It is important to recognize the factors that may influence creativity to increase the efficiency of the factors that may stimulate it and diminish the influence of those factors that may negatively affect it. Secondly, it should take into consideration the possible interrelation of various factors. This means that some factors are potentially more significant only when other factors simultaneously act similarly. Thirdly, some factors may act as stimulating or inhibiting factors for creativity. Knowing the circumstances in which these influence factors act in the direction of interest or the opposite direction is necessary.

In the authors' opinion, information-seeking could be affected particularly by some of the factors included in the cognitive-intellectual nature group.

Thus, specialized training must diminish the possible negative influence of some factors such as: psychological inertia (the tendency of the human intellect to follow essentially the known ways); functional rigidity (the tendency to attribute a unique use to a certain object); low fluency (incapacity to go rapidly from one idea to another, to make associations, analogies, etc.); difficulties when using the sequential–divergent approach in problem solving (difficult problems can be divided and approached in successive steps); approaching simultaneously both the creative stage and the critical stage (this obstacle is usually removed in a specific way, for instance by using the brainstorming method); the possible inhibitive influence exerted by the personalities who work in a certain field or merely by some known outstanding achievements in the field (considering that the quantum of knowledge accessible at a certain moment as a closed volume of knowledge, that cannot be developed); and a low level of knowledge in the field of interest, etc.

Some gnoseology factors that may influence creativity could be:

- A low level of education, a lack of knowledge concerning the stages of the innovation process;
- A lack of knowledge concerning the intuitive and logical techniques and methods that may stimulate engineering creativity;
- The lack of a minimum level of knowledge in the field of interest;
- The overspecialization or the accumulation of a significant volume of knowledge in a narrow field;
- A lack of collateral knowledge for the field of interest, etc.

As can be noticed, both the lack of knowledge and too high a level of knowledge in the field of interest could sometimes be considered factors that may negatively influence creativity (Figure 2).

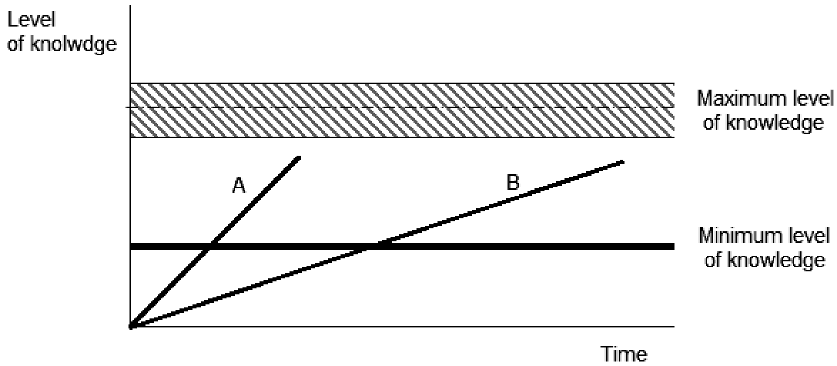

Figure 2. Importance of the level of professional knowledge for obtaining creative results A, B- persons; person A can accumulate professional knowledge faster compared to a person B.

Of course, a low level of specialized knowledge impedes increasing creativity efficiency. Generally, it is difficult to approach a certain issue without having enough general knowledge.

The claim that a high level of knowledge could also be an obstacle to the effective use of engineering creativity may come as a surprise. This statement is valid only when the designer considers that the available volume of knowledge is closed and cannot be developed any further. Both of these aspects (a lack of knowledge and a rich quantum of knowledge) connect with the information-seeking process. A particular aspect could be the speed and how professional knowledge is accumulated. For example, person A could accumulate more professional knowledge faster than person B (Figure 2).

The speed with which the students could accumulate professional knowledge and the methods applied to stimulate engineering creativity are important. The authors believe it could be adequately addressed and sometimes developed during high school and university studies.

3.4. Teaching Creative Information-Seeking in Higher Education at the "Gheorghe Asachi" Technical University of Iaşi, Romania

At the "Gheorghe Asachi" Technical University of Iaşi (Romania), there are some academic subjects that teach the students how to:

(a) Develop originality of their design projects;
(b) Conduct scientific or technical research on design-imposed themes or self-identified design topics. Here, the methods of stimulating engineering creativity are applied to a larger extent;
(c) Write papers with a high content of engineering originality as much as possible.

For example, as previously mentioned, two courses on such academic subjects are "Fundamentals of technical creativity", and "Fundamentals of scientific research".

The academic subject "Fundamentals of technical creativity" is included in the curricula of some study programs in industrial engineering. The main objective of this academic subject is to initiate the students in applying several methods for stimulating engineering creativity, identifying new technical solutions, and elaborating documents specific to a patent application. Reaching these objectives supposes an activity of technical and sometimes scientific information-seeking concerning at least the engineering or scientific solutions close to the design topic that needs to be solved by the students. The proposal to include the academic subject "Fundamental of technical creativity" in the academic curricula was formulated about four decades ago by Professor Vitalie Belous, a significant promoter of inventics in Romania [52].

The authors of this paper found that when the scope of the information-seeking stage was wide, and the student had succeeded in examining a large number of existing solutions which may have been complex and modern, a certain feeling of inhibition appeared. Being confronted with a diversity of solutions and possibly with the impressive achievements of important personalities or prestigious organizations (companies, universities, research institutions, etc.), the student seemed less confident in their ability to generate new solutions through their efforts.

On the contrary, when the student had a certain quantum of knowledge (not too large!) in the field of the design topic to be solved, but he/she approached the identification of his/her solution before or during the initiation of the process of information-seeking, sometimes he/she found innovative engineering solutions. Some such solutions were patented; for example, such solutions were: a—Ciulică M. et al. Device for measuring cutting energy. Patent no. 65424/1975, Romania (Figure 3a); b—Cioban G. et al. Device for manufacturing cutting tools for machining teeth in a circular arc. Patent no. 71849/1979, Romania (Figure 3b); c—Colceriu E. et al. Chuck with elastic collet. Patent no. 86708/1983, România (Figure 3c); d—Ilade C. Transformable footwear. Patent no. 110293/1994, Romania (Figure 3d); e—Calin M. Device for obtaining braided dough cords. Patent no. 109420/1994, Romania (Figure 3e); f—Rezmireș D. Automated relaxation generator. Patent no. 115608, România; g—Gherman L. et al. Device for machinability study by drilling with constant advance force. Patent no. 128618/2011, Romania (Figure 3g).

Before he became a student in 1979 and before high school, M. Ciulică had attended vocational school. Therefore, he had a quantum of practical knowledge equivalent to that of a cutting machine tools operator. Having improved access to technical information (as a student), and his open approach to new developments in engineering, helped him identify an improved solution for a device meant to measure cutting energy (Figure 3a).

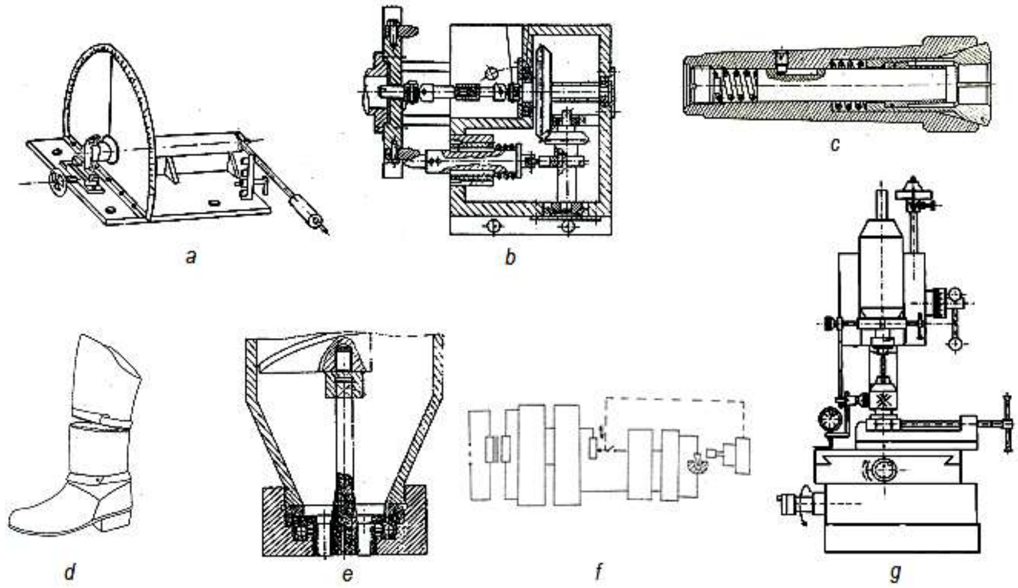

Figure 3. Design solutions patented by students as a first or a single author: (**a**)—Ciulică M. et al. Device for measuring cutting energy. Patent no. 65424/1975, Romania; (**b**)—Cioban G. et al. Device for manufacturing cutting tools for machining teeth in a circular arc. Patent no. 71849/1979, Romania; (**c**)—Colceriu E. et al. Chuck with elastic collet. Patent no. 86708/1983, România; (**d**)—Ilade C. Transformable footwear. Patent no. 110293/1994, Romania; (**e**)—Calin M. Device for obtaining braided dough cords. Patent no. 109420/1994, Romania; (**f**)—Rezmireș D. Automated relaxation generator. Patent no. 115608 România; (**g**)—Gherman L. et al. Device for machinability study by drilling with constant advance force. Patent no. 128618/2011.

G. Cioban was a student (in 1979) interested in the theoretical aspects of mechanical devices and an attentive observer of mechanical devices used during the applicative activities for academic subjects in industrial engineering. At the same time, the student showed a strong interest in consulting and understanding the technical solutions described in the accessible literature (monographs, handbooks, patents, etc.).

In the case of many patented inventions, the students had major contributions to the definition of innovative solutions. For this reason, they were mentioned as the main author or as the single author of the invention.

As previously mentioned, applied activities in university subjects aimed at stimulating the creativity of future engineers were carried out in groups of 10–25 students. The students had different levels of theoretical and practical training, men, and women, aged between 22 and 35. This means that groups or subgroups with several students were involved simultaneously in the design activities, according to the administrative division and regulations in the university plans. If before the application of the postponement of deep information-seeking, only 2–3 students submitted patent applications to the Romanian invention office, after the application of the postponement of the deep information-seeking, a percentage of up to 30% of the students believed that they had identified original solutions and they went through the specific stages of preparing and submitting patent applications.

It can be noted that by using the results obtained during the applicative activities of the academic subject “Fundamentals of technical creativity”, a percentage of 10–30% of the students developed patent applications and sent the adequate documents to the national specialized office (the Romanian State Office for Inventions and Trademarks). Finally, after patent office experts analyzed patent applications, some students obtained patents for their innovative ideas.

During the applicative activities for the academic subject “Fundamentals of technical creativity”, the main accent is placed on stimulating the students’ creativity and, to a lower extent, on economic aspects (costs, efficiency, etc.). More careful consideration of economic aspects in promoting the improved solutions proposed by the students is a current concern of the professors involved in coordinating the abovementioned activities.

Stimulating and encouraging the students to promote the solutions to the problems proposed by the professors, or by themselves, determined a significant increase in the number of patent applications whose main authors were students. Thus, when the patenting fees were lower, or the university partially paid the patenting fees, there were situations when the number of patent applications from the "Gheorghe Asachi" Technical University in Iași represented 5–10% of the total annual number of patent applications received by the Romanian patent office.

The academic subject "Fundamentals of the scientific research" was included in the curricula of some master studies programs about 15 years ago. The main objective of the academic subject was to inform the students about how to identify an innovation topic and solve the problems according to the stages specific to approaching and developing an innovative design. In this case, good results were sometimes obtained by the students who, immediately after clarifying the innovation objectives or simultaneously with the information-seeking process, tried to formulate hypotheses, to design theoretical models or solutions for the equipment necessary for the possible experimental research. Such preliminary solutions were materialized by developing structures for papers, sketches, mathematical models, etc., forming the foundation for the subsequent elaboration of innovative design solutions.

The abovementioned arguments highlight that, at least in certain situations, the attempt at originally solving an innovation design topic could start before or during the process of scientific or/and technical information-seeking. In these situations, a possible ample quantum of existing knowledge or prestigious achievements in the field of the subject of interest for the student does not seem to constitute a psychological obstacle capable of inducing a lack of confidence in their capacities.

The previous is not a plea for the exclusion of deep information-seeking activity. A finding of the authors of this paper concerns only the possibility of postponing the development of an extensive information-seeking activity until after the development by the experienced designer and by the novice designer of some first sketches and texts referring to the sought solution. In this way, it would be possible to avoid or at least reduce the inhibitory psychological obstacle/effect exerted by the solutions proposed for the same problem or similar problems by specialists, prestigious personalities, or companies. After developing some first sketches and texts related to the sought solution, one will develop deep information-seeking activity to better characterize or improve one's own solution by comparing it with the solutions identified by others. For the novice designer who does not know enough about the given design theme, a preliminary information-seeking sub-step that is less extensive but can familiarize him with what is required by the design theme may be useful. It would follow that the novice designer would then try to develop some first solutions and then continue with extensive information-seeking on the topic to develop or refine the initially identified possible solution.

4. Conclusions

The analysis of the information-seeking stage specific to innovative design has highlighted some characteristics of interest for designers. When examining the accessible information sources, designers should ask themselves whether other ways to resolve the approached issues could be found in addition to those presented in the accessed documents. A certain psychological inhibition may appear during the information-seeking activity due to the prestige and scientific authority of the authors of some results previously obtained by other designers/researchers in the field of interest. To diminish and restrict the potential inhibitory influence generated by examining the accessed information sources, an experienced designer can directly approach the elaboration of sketches, and notes, before or simultaneously with the information-seeking stage. For the novice designer, it has been observed that the information-seeking stage should only aim at accumulating general information to become familiar with the problem addressed. Only after developing the first sketches and own written notes can one proceed to the approach of extensive information-seeking. As can be seen, such situations may require some postponement of the deeper information-seeking stage. Another conclusion, however, confirms that a certain minimum amount of scientific and technical knowledge is needed for a clearer expression of technical creativity.

At the "Gheorghe Asachi" Technical University of Iaşi, Romania, the university curricula of some study programs currently include academic subjects that aim to contribute to the stimulation of students' engineering creativity (e.g., "Fundamentals of technical creativity") or of the students' scientific and technical creativity (e.g., "Fundamentals of scientific research").

In the future, there is an intention to address in more detail the issue of the size of the scientific or technical information fund capable of not generating psychological obstacles, and to allow a more pronounced manifestation of engineering creativity.

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