Brain activity of problem solving process: a systematic literature review

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Abstract. Comprehending the problem-solving process is an effort that is no less important than teaching problem-solving skills at school. By understanding the problem-solving process, it will be easier to teach at school. Several neurological studies discuss activities in solving problems, but the scope of the discussion is narrow and in-depth. On the other hand, it requires complete information about how the problem-solving process is a complex cognitive process. This research is a systematic literature review using the PRISMA approach. The result shows that the problem-solving skills were developing based on ages of development. The effectiveness of problem-solving skills is characterized by minimal brain activity but produces the right solution. In addition, the result of the review shows that semantic ability and mathematical logic ability play an important role in a problem solving process. Getting complete problem solving process needs many parts of the brain. DLPFC and IFG are the dominant parts of the brain in the process of solving problems.

1. Introduction
The world entered the era of the industrial revolution 4.0 where human is facilitated by a network system that is connected to the internet. Distance and time are no longer a problem for someone to interact. The industrial revolution 4.0 was first introduced by a group of German businessmen in 2011 who trying to improve industrial competitiveness through the integration of cyber-physical systems into production systems [1].

One of the characteristics of industrial revolution 4.0 is high ambiguity [2,3,4]. This causes the human face complex issues in the 21st century. This is according to the World Economic Forum [5], which explained that the top ability of the 10 capabilities most needed in 2020 is the ability to solve complex problems (Complex Problem Solving).
Nowadays and future, complex problem-solving skills have a role in one's success in the work environment, community environment, and family environment. Complex problem solving is also needed by a person to be able to actively participate in social life in the present and future [6]. Globalization and digitalization as a result of the industrial revolution 4.0 caused people to have increasingly complex environments and demanded many problems to be solved in personal life and at work [7].

Based on the description above, it can be concluded that the ability to solve problems is important to be taught to students at school. However, the problem-solving process is a complex process that requires a lot of cognitive operations, including understanding, reasoning, calculation, pre-conception, as well as manipulating new information from the given problem [8]. Thus, comprehending how brain activity works when someone is solving problems is no less important than teaching the ability to solve problems in class. By understanding the brain activity when someone resolves a problem, it can be designed to train the work of the brain maximally when solving the problem.

This article aims to find out how brain activity works when someone resolves a problem. In addition, this article aims to find out which parts of the brain play a role when someone resolves a problem. This article tries to answer the research question by reviewing research articles from reputable journals that examine brain activity when solving various types and types of problem-solving.

2. Methods
The type of research used in this study is systematic literature review research. This review study uses the type of systematic literature review research because this type of research uses strict criteria for selecting the articles to be reviewed so that the researchers' subjectivity can be avoided. This research tries to reveal how brain activity works in various types of problem-solving processes. The literature review research was conducted to provide an overview of the reviewed themes related to existing research [9]. The systematic literature review research method in this study uses the PRISMA principles, which stages include: Identification, Screening, Eligibility, and Included [10]. This stage of the study adapted the principles of PRISMA.

2.1 Defining eligibility criteria and Resources
In this stage, the criteria of journal articles will be determined as data sources. To get valid data, it uses reputable journal articles. The criteria used consisted of two main criteria, namely inclusion criteria and exclusion criteria.

The inclusion criteria used to constrain the search area of what will be done. The inclusion criteria used in this study are as follows:
1. The article used is an article from a Scopus indexed journal. It ensures that the data source obtained has a high level of validity.
2. The article is derived from a journal published by reputable publishers: Elsevier, Springer, Taylor & Francis, John Wiley & Sons, and Sage. It ensures data reliability.
3. The articles used were published in the period 2010-present. This is to ensure the novelty factor.

Exclusion criteria are used to limit what data sources should not be used. The exclusion criteria used in this study are as follows:
1. The article used is not a review article. This is to ensure that the data presented is primary data, so the data used is secondary data.
2. The articles used are in English. This is to avoid mistakes in understanding the contents of journal articles.
3. The journal articles used do not book review articles.
2.2 Search Strategy
To facilitate the search for the data source, it is necessary to do a search strategy. The search uses the keyword "Brain Activity + Problem Solving" and is limited to the type of article "research article". Searching for articles is also limited to publication year, which is the longest published in 2010. This is to ensure that the article analyzed still has a novelty factor.

2.3 Literature Selection
At this stage, the selection of articles will be used as a data source. Articles are selected based on the article title and/or abstract that contains the word "Brain Activity + Problem Solving". After that, the articles are downloaded and screened to see the relevance to the data needed. The number of articles reviewed is 33 journal articles. The flow chart of the searching article adapted from PRISMA is presented in Figure 1.

![Figure 1. The Flow Chart of Article Selection](image)

2.4 Collecting Data
A total of 33 journal articles are reviewed by noticing the background, problems, objectives, research methods, results, and novelty. Furthermore, the data is tabulated into a table. To ensure the validity of the results of the review article, an examination of the results of the review by an English linguist to avoid misinterpretation.

2.5 Analyzing Data
Data analysis was conducted by adopting the constant comparative method [11]. The step of analysis with the method of fixed comparison is organizing data, data reduction, categorization, synthesis, compiling "working hypotheses". The analysis steps carried out in this study are as follows:
1. We are organizing data by sorting and grouping articles by the year of publication to see research trends.
2. Tabulating data from the review results.
3. We categorize articles based on two criteria, namely 1) brain activity based on the type of problem-solving process and 2) the part of the brain responsible for a problem-solving process.

4. We present journal article data based on 1) brain activity based on the type of problem-solving process and 2) the part of the brain responsible for a problem-solving process.

5. We are looking for general patterns of problem-solving activities and the part of the brain used for problem-solving activities.

3. Results and Discussion

3.1 Brain Activities during the Problem Solving Process

The process of problem-solving is a mental activity that involves many parts of the brain. In education, the ability to solve is considered complex and involves many thinking abilities. Ghaderi, Nazari, & Darooneh stated that complex networks might be involved in solving real-life problems [12]. All this time, the process of problem-solving is only assessed from the results of problem-solving products, while how the process of problem-solving in the brain is very little discussed. This section will be presented how the brain processes a form of problem-solving.

The problem-solving process begins with understanding the problem. This stage is characterized by increased brain activity in the motoric and visual areas [13]. The next step in solving the problem is the process of finding a solution. During the search for solutions, activity increases in the prefrontal and parietal regions [13].

As a part of cognition, one's problem-solving skills continue to grow, especially in childhood and adolescence. This is indicated by the research results of Rosenberg-Lee et al., which shows a significant difference in brain activities in arithmetic problem solving between elementary school students in grade 2 and grade 3 [14]. The changes in brain activities in problem-solving that only occur in a range a year proves that childhood is a golden period in the development of cognition.

In a problem-solving process, the regularity of EEG waves is formed when someone focuses on solving a cognitive problem even though the background of the problem is not structured [15]. This shows that the process of solving a problem is an organized mental activity. This possibility is caused by the concentration of all brain resources to try to solve the problem being faced. The concentration of the whole mind is characterized by the appearance of theta waves. This theta wave is also reported to occur when someone completes a chess game with a high level of difficulty [16].

The mobilization of all brain resources to solve a problem occurs in solving a problem, followed by anxiety. This is supported by the results of Dandan et al. research, which states that someone who has anxiety when solving arithmetic problems uses more resources of attention while anticipating future arithmetic problems [17]. It shows that panic when facing a problem drains more brain energy, so most people who are panicking are unable to think clearly.

The effectiveness of the problem-solving process is characterized by the use of brain resources as little as possible. This is supported by the research results of Jin et al., which shows that experts need less energy in solving problems than laymen [18]. De Visscher et al. also stated that people with low performance need higher brain activity in solving arithmetic problems than people with low performance [19].

The effectiveness of problem-solving can be achieved through joint problem solving or in a group. The decreasing brain activity over time during the process of joint solving problems shows that the effect of forming chemistry in a group, the mental activity works more effectively [20]. This occurs because higher synchronization of nerves during cooperation correlates with higher behavioral reciprocity [21].

Completion of a previously known problem proved using brain activity more effective. Huang et al. stated that one must work harder to operate an unknown solution, especially to resolve competition from
a solution that is already known but is not valid to use [22]. However, repeatedly solving a series of similar problems with the same solution will lead to nerve adaptation and cognitive inflexibility [23]. This causes the ability of one's cognition will not to be developing.

The brain that is accustomed to solving difficult problems will improve its performance. When someone solves a difficult problem, the part of the brain related to metacognition will work actively [24]. This is in accordance with the research of Takeuchi et al., which states that metacognition has an important role in problem-solving insight [25].

The effectiveness of problem-solving is the key to a complex problem-solving process. The ability to solve complex problems is activating all brain resources and is related to which part of the brain must be active and which parts are not active. The purpose is to focus the energy on certain parts of the brain to form the effectiveness of brain performance. Solving complex problems may require activation of the left parietal-prefrontal circuit to retain and manipulate a lot of information but deactivate the temporal [26]. The decreasing parietal-temporal correlation can be related to text processing and emphasis on the reasoning that relies on content to focusing cognitive resources on mathematical reasoning.

Effectiveness in problem-solving is also influenced by the level of age maturity. An adult is more effective in using brain resources compared to children. Privodnova and Volf state that adults experience desynchronization in smaller areas of the anterior brain in the early stages of creative thinking compared to young children [27]. Differences in problem-solving strategies are also evident between a young woman and an adult male [28]. Differences in problem-solving strategies are only apparent if there is a significant age difference. Obersteiner et al. stated there was no difference in brain activity in problem-solving between 4th-grade elementary school students and 8th-grade junior high school students [29].

One of the important things about the effectiveness of the problem-solving process is the ability to understand the problem itself. Part of the failure to get a solution is due to the inability to understand the problem. This is indicated by the results of research by Zhang et al., which show that the occurrence of obstacles to creative problem solving is shown by the appearance of the N400 signal on the EEG [30]. It shows that the obstacles faced by someone when they find an oddity in the problems faced when semantic processing occurs in the brain.

The ability to understand problems is closely related to semantic abilities. The IFG (inferior frontal gyrus) brain area and the middle temporal gyrus are related to semantic control [31]. These brain areas are involved in the process of finding a problem. The part of the brain for this semantics can be trained with visuospatial [32].

The ability to solve problems is affected by the ability of mathematical logic. A person with low mathematical logic has problems in the part of the brain that is working for verbal and numerical [33]. They tend to use numerical activities in solving simple problems, whereas a person who has no problems with mathematical logic uses more parts of the brain that are working for verbal. Verbal problems in a person can occur due to gene mutations. Research by Nair et al. shows the pressure on verbal problem-solving causes changes in the connectivity of medium temporal gyrus in individuals with type S alleles, but not on type L [34].

One of the interesting things in a problem-solving process is the emergence of the solution to a problem suddenly without going through the process of solving a problem that was planned in advance. In neuroscience, it is referred to as insight problem solving and, conversely, problem solutions that arise from a problem-solving plan are called Analytical Problem Solving [35].

Insight problem solving is not influenced by the knowledge possessed [36]. Insight problem-solving arises because someone does not know what to do next [37] and loses focus of attention [38] which results in representational changes in cognition [39]. This representational change will result in a problem restructuring. In the process of insight problem solving, problem restructuring occurs just before a solution is found [31].
The solution to the insight issues is marked by the explosion of gamma wave oscillation activity over the prefrontal cortex around 500 ms before someone claims to have finished with a solution to the problem [40]. This signal is produced in part by the orbitofrontal cortex, an area associated with learning appreciation and pleasant hedonic experiences such as food, positive social experiences, addictive drugs, and orgasms. It explains why most people are interested in solving puzzles, reading murder mysteries, creating inventions, or doing research [40].

Erickson et al. state that a person's potential to solve problems with insight or analytics can be predicted when the brain is at rest [35]. It shows that there are differences in brain activity during the brain at rest that indicates a difference in one's intelligence.

3.2 The Working Brain Parts for Various Types of Problem Solving Activities
The problem-solving process is a complex cognitive process. The process of solving problems involves a complex neural network of the brain [12]. "Which part of the brain is responsible for the problem-solving process?" Of course, this question is not as easy as answering the question "Which part of the brain is responsible for verbal ability?" This is because the process of problem-solving involves a variety of basic cognitive activities such as verbal, visual, spatial abilities, etc. In terms of thinking skills, problem-solving skills involve several thinking skills, such as deductive and inductive reasoning skills, creative thinking skills, critical thinking skills and etc. In this article, various types of problem-solving and related dominant brain parts are presented in Table 1.

| Types of solving problem | The working brain parts |
|--------------------------|-------------------------|
| Arithmetic Problem Solving [41] | fronto-insular |
| Arithmetic Problem Solving [19] | left inferior frontal gyrus |
| Arithmetic Problem Solving [29] | korteks parietal |
| Arithmetic Problem Solving [14] | lower right frontal sulcus and anterior insula, and left intraparietal sulcus (IPS) |
| Chess Problem Solving [16] | C4 (central site) |
| complex-mathematical problem solving [26] | left prefrontal and parietal cortex, and temporal |
| Cooperative Problem Solving [20] | TPJ dan aPFC / DLPFC |
| Cooperative Problem Solving [21] | bilateral prefrontal cortex and temporo-parietal section |
| Creative Problem Solving [27] | fronto Parietal |
| Expert and Novice [18] | inferior frontal gyrus (IFG) |
| Insight and Analytical Problem Solving [35] | Temporal-lobe cerebral hemisphere |
| Insight Problem Solving [31] | insulasi anterior |
| Insight Problem Solving [38] | parieto-oksipital |
| Insight Problem Solving [36] | PO4-PO8 electrode |
| Insight Problem Solving [40] | Above the prefrontal cortex (orbitofrontal cortex) |
| Insight Problem Solving [37] | frontal cortex (P3a) |
| Insight Problem Solving [25] | korteks prefrontal (PFC) |
| Insightful Problem [17] | DLPFC |
| Mathematical Problem Solving [24] | parietal dan prefrontal |
| Mathematical Problem Solving [15] | prefrontal dan parietal |
Numeric and verbal problem solving [33]  
- Verbal: girus frontal kiri inferior dan left middle temporal to superior temporal gyrus  
- Numerical: right superior parietal lobule including intraparietal sulcus

Numeric Problem Solving [42]  
- Left inferior frontal girus and certain areas in the parietal, and temporal cortex

Problem Solving [23]  
- superior parietal lobule (SPL), inferior frontal gyrus (IFG)

Pseudo-Insight Problem Solving [39]  
- precuneus ventral dan thalamus

solve similar problem [22]  
- inferior frontal gyrus (IFG), korteks oksipital tengah (MOG), lobulus parietal superior (SPL) dan korteks cingulate anterior dorsal (dACC)

Verbal Creative Problem Solving [31]  
- IFG

Verbal Problem Solving [34]  
- Medium temporal gyrus

visuospatial simbolic [32]  
- supramarginal bilateral, precuneus, cuneus, parahippocampus, and the left middle temporal section

Table 1 shows that DLPFC and IFG play an important role in the process of solving problems. DLPFC has a role in solving technical problems [17]. DLPFC also has a role in determining the appropriate response to the tasks assigned [43]. DLPFC will be active during the problem-solving process related to social interaction [20]. Thus, working in teams will activate parts of the brain that have a role in problem-solving.

IFG plays a role in the effectiveness of problem-solving. Jin states that the differences in IFG activities determine someone classified as an expert or a layman in the problem-solving process [18]. This is because IFG plays a role in the process of finding solutions [31]. Activities in IFG are related to semantic responses that make sense and demand large tasks, especially when people have to overcome disturbances [22].

Table 1 shows that several parts of the brain besides DLPFC and IFG play a role in the problem-solving process. However, DLPFC and IFG are the parts of the brain that are most involved in all kinds of problem-solving processes.

4. Conclusion
The ability to solve problems develops according to age development. Problem-solving ability thrived on the age of the children. The effectiveness of problem-solving skills is characterized by minimal brain activity but produces the right solution. In solving complex problems, brain activity is focused on certain parts of the brain to achieve an effective thought process. Semantic abilities and mathematical logic abilities consisting of verbal and numerical abilities play an important role in a problem-solving process. Semantic ability is useful in identifying problems, while the ability of mathematical logic plays a role in finding solutions. The occurring complete problem-solving process involves many parts of the brain. It indicates that the problem-solving process is a complex brain activity.

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