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EDITED BY
Douglas F. Kauffman,
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Kazuhisa Miwa,
Nagoya University, Japan

*CORRESPONDENCE
Shijun Wang
✉ shijun-wang@g.ecc.u-tokyo.ac.jp

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How to effectively overcome fixation: a systematic review of fixation and defixation studies on the basis of fixation source and problem type

Shijun Wang[1]*, Takeshi Okada[1] and Kikuko Takagi[2]

[1]Graduate School of Education, The University of Tokyo, Tokyo, Japan, [2]Graduate School of Arts and Sciences, and Art Center, The University of Tokyo, Tokyo, Japan

As a cognitive state that impedes idea generation, fixation has been well studied across various domains in relation to the cultivation of creativity. With the aim of contributing to the development of an effective approach to overcoming fixation in order to enhance creativity, a systematic review is conducted of 53 experimental studies concerning the source of fixation and the problem type, which are two critical factors influencing the effectiveness of defixation approaches. Based on the results, it is indicated that an enhancement of the search beyond the frame, constructed by either information that is externally provided or memory that is internally activated by information about the problem, is essential in overcoming fixation. Further, the elimination of fixation leads to an increase in solution rates of closed-ended problems. However, in open-ended problem solving, defixation does not necessarily lead to an improvement in the performance of problem solving, and an advancement can still be achieved by enhancing the search within the constructed frame even when there is no search beyond the frame. Accordingly, an examination of both beyond-frame searches and within-frame searches is essential for an effective defixation approach to enhance creativity in open-ended problem solving.

KEYWORDS

fixation, creativity, overcoming fixation, fixation source, problem type

1. Introduction

Creativity is considered to be a critical factor in the advancement of civilization (Hennessey and Amabile, 2010). Specifically, the term *creative society* has been coined to describe constantly changing modern society, and it is viewed as an expansion of the traditional perspective of the information and knowledge society (Reimeris, 2016). When confronting an unpredictable future in a rapidly changing world, cultivating individuals who are capable of facing these challenges becomes vital, and nurturing creativity is the first step to achieving this goal (Taddei, 2009). Accordingly, creativity is taken to be one of the most important issues in education around the world (Shaheen, 2010), and specialized pedagogy, which takes improving creativity as one of its main purpose, is well established. For instance, in response to escalating global competitiveness and rapid technological advancements, an increased emphasis on science and mathematics became imperative. This led to the inception of STEM education, an acronym representing Science, Technology, Engineering, and Mathematics, which has gained significant popularity since the year 2000 (Breiner et al., 2012). In STEM education, one of the key objectives is to enhance students' capabilities in solving complex real-world problems (Rifandi and Rahmi, 2019). Later, with the recognition of the growing need for creativity in education, the arts were integrated into STEM, giving rise to STEAM (Land, 2013; Henriksen, 2014). In this expanded framework, the cultivation of creativity is expected as a learning outcome (Perignat and Katz-Buonincontro, 2019), and empirical studies further revealed the beneficial influence of STEAM on nurturing creativity (e.g., Conradty et al., 2020; Ozkan and Umdu Topsakal, 2021). In the light of this notion, numerous studies have been committed to developing effective approaches for enhancing creativity (e.g., Torrance, 1972) and to examining the factors that influence creativity, such as motivation (e.g., Collins and Amabile, 1999) and metacognition (e.g., Davidson and Sternberg, 1998). Among these factors, various studies reported that one phenomenon, fixation, significantly impedes creativity.

As early as 1,620, in his book *Novum organum,* Francis Bacon, who established the scientific research method of inductive reasoning, described four idols of the mind that mislead individuals' reasoning and interfere with scientific exploration. Specifically, Bacon (1902) stated that people tend to collect information which is supportive of the idea that they have adopted and overlook contrary information. Later, the tendency of being influenced by information that has been obtained was reported across various domains (e.g., confirmation bias, Wason, 1960; naive concept, Borun et al., 1993) and it was firstly empirically verified in the domain of Gestalt psychology. Specifically, in the study of solving insight problems, a type of non-routine problem that involves insight and one of the cognitive processes contained in creative problem solving (Hélie and Sun, 2010), individuals were found to be constrained by their prior knowledge of using tools and were not able to solve problems that required them to generate novel usage of tools (Maier, 1931; Duncker, 1945). Meanwhile, Luchins (1942) also reported that participants kept using recently learned arithmetic solutions even when such a solution was no longer applicable to solving a new problem. Later, Jansson and Smith (1991) revealed the tendency to keep copying obstacle features of given examples in solving design problems. Though these findings are termed differently, such as the Einstellung effect (Luchins, 1942), mental set (Wiley, 1998), functional fixedness (Duncker, 1945) and design fixation (Jansson and Smith, 1991), as they share a nature which illustrates the tendency of being fixated by certain information in problem solving, a unified name, fixation, is adopted in this paper to refer this phenomenon.

In problem solving, studies on fixation are well established. For instance, studies have been conducted to investigate what would fixate individuals (e.g., Wiley, 1998; Smith et al., 2017) and clarify the mechanism of how fixation influences problem solving (e.g., Ward et al., 2002; Bilalić et al., 2008). Importantly, as fixation is reported as an obstacle that suppresses the performance of solving problems which involve creative processes (e.g., Jansson and Smith, 1991; Wiley, 1998), and reducing fixation indicates an enhancement of creativity (e.g., Lu et al., 2017; Beda and Smith, 2022), the discussion of fixation and defixation is taken to be an important topic in the study of creativity (e.g., Loesche and Ionescu, 2020). Moreover, as individuals are usually unaware of being fixated (e.g., Bilalić et al., 2008), fixation is difficult to diminish. Accordingly, numerous researchers have focused on developing effective approaches to overcoming fixation (e.g., McCaffrey, 2012; Okada and Ishibashi, 2017; Sio et al., 2017). On the basis of these studies, reviews concerning various aspects have been performed from different perspectives. For instance, regarding fixation found in a specific domain, Sio et al. (2015) clarified the influence of a specific variable in terms of the fixation (Sio et al., 2015), and Alipour et al. (2018) identified the variables that induce fixation, and established a framework to illustrate the relationships of these factors. Further, in the context of specific cognitive processes, Beda and Smith (2022) investigated the mechanism of fixation induction and effective defixation approaches. In addition, based on a methodological perspective, Vasconcelos and Crilly (2016) provided an overview of experimental design and settings to suggest possible reasons for the mixed results obtained across different studies. Moreover, Sio and Ormerod (2009) conducted a statistical meta-analytical review of certain defixation approaches, providing empirical evidence to confirm their effectiveness. However, these reviews only focused on a certain defixation approach, a specific cognitive process or fixation found in restricted domains, and none of these studies systematically reviewed fixation or defixation from a holistic viewpoint. Critically, although the effect of the defixation approach is claimed to be different according to the source of fixation (Wiley, 1998) and the problem type (Sio and Ormerod, 2009), no review on fixation in problem solving has been conducted giving consideration to the source of fixation and the type of problem. Accordingly, in this study, on the basis of the axis of source of fixation and problem type, after reviewing the mechanisms of fixation induction that have been investigated in empirical studies, research that experimentally examined how fixation could be overcome is discussed with the aim of contributing to the development of an effective defixation approach for enhancing creativity.

2. Two axes: source of fixation and problem type

The first axis is the source of fixation. Based on previous studies, two sources of fixation are suggested in the present review. One is developed from external stimuli proposed in Vasconcelos and Crilly's (2016) review of variables manipulated in empirical studies of design fixation. In their review, external stimuli were suggested to be example solutions in design idea generation. In a more general setting, introducing external stimuli, such as the misleading cues given in studies involving Remote Associate Test (RAT) problems (e.g., Koppel and Storm, 2014; Sio et al., 2017) and solutions newly learned from the information provided (e.g., Bilalić et al., 2008; Blech et al., 2020), to induce fixation is a common approach to investigating the influence of fixation. Moreover, even though there is no external information, the performance of problem solving is still impeded by fixation that is induced internally. For instance, past experience of using certain tools is found to impair the generation of novel usage (Duncker, 1945). In this case, prior knowledge of tools, which is activated by problems that involve tool functions, becomes the fixation. Further, in studies which reported that experts were bounded by their expertise in certain domain (e.g., Wiley, 1998), domain knowledge that is activated by domain-related information in a given problem is another example of fixation induced by an internal source. In terms of memory activation, it suggested that fixation is induced by the manner in which activated knowledge is utilized (Agogué et al., 2014). Specifically, they claimed that generating a solution based solely on the knowledge that is spontaneously activated by the source without any further alteration is considered to be fixated. Building on this perspective, our current review proposes that the sources of fixation can be categorized into two types. The first type, which we term *misleading information*, refers to fixation that is triggered by memory related to externally provided information, such as examples. The second type, termed *problem information-related memory*, relates to fixation originating from the long-term memory associated with the problem itself, such as prior knowledge.

The present review also distinguishes problems as being closed-ended or open-ended. Traditionally, problems are differentiated as being well-defined and ill-defined according to the condition of the initial state, the operator, and the goal of the problem (e.g., Reitman, 1964; Newell, 1993).

The problem type is critical in cognitive studies, since different cognitive processes are expected in solving different types of problem (Schraw et al., 1995). However, it is argued that this classification of problems is obscure (Simon, 1973). Therefore, instead of this traditional differentiation, studies adopt an alternative classification by distinguishing problems as being closed-ended and open-ended based only on the goal status. Specifically, in terms of goal status, the number of solutions for closed-ended problems is limited, while the number of solutions for open-ended problems can be unlimited. Additionally, the two types of problems are also differentiated by who defines the goal: the goal of a closed-ended problem is set by the problem giver, whereas the goal of an open-ended problem is set by the problem solver. In terms of the search in problem space, problem solvers can only solve closed-ended problems if they conduct their search within the frame which contains the correct solution. In contrast, there is a personal standard for identifying the correct solution in solving open-ended problems; therefore, problem solvers can address open-ended problems by searching within any frame. Importantly, goal status affects the effectiveness of specific defixation approaches (Sio and Ormerod, 2009). Therefore, considering the type of problem in such a categorization is essential for fixation studies. As such, in addition to the source of fixation, the present review also establishes an axis of problem type to clarify whether a problem's goal status—closed or open—influences how fixation is induced and eliminated.

3. Method

3.1. Inclusion criteria

A systematic review of studies on fixation was conducted to examine the mechanism of fixation induction and effective defixation based on the two axes of fixation source and problem type with the aim of contributing to creativity improvement. The following criteria were proposed to select the papers for the present review. First, the study was required to be an empirical one that adopted experiment as the main research approach, as the statistical analysis of experiments provides results that can be generalized. Second, a standardized experiment was generally required. However, as studies have reported that setting a control condition, i.e., the condition without intervention, is challenging for practical reasons (e.g., Viswanathan et al., 2014), the studies included in the current review were required to have a baseline condition, along with Randomized Condition Treatment, to ensure both the validity and reliability of the experiments. Third, although fixation has been well-studied historically across various domains, such as philosophy and sociology, as the current review focuses on the mechanism of fixation induction and fixation mitigation, studies that discussed fixation/defixation within the domain of cognitive science and psychology, particularly those involving problem solving, were selected. Finally, to ensure the quality of the selected papers, they were required to be peer-reviewed articles written in English.

3.2. Approach to search

Literature was collected by the following steps. Firstly, a search of Google Scholar, ScienceDirect, JSTOR, PsycINFO and ERIC was conducted. In the study of fixation, distinct terms are coined for this phenomenon across different domains. For instance, Maier (1931) described the constraint of prior knowledge in using tools as functional fixedness, while Wiley (1998) termed the constraint of prior knowledge in solving RAT problems as mental set. However, the unified terminology adopted in the current study, i.e., fixation, is often employed in general settings and refers to distinctive concepts across various domains. Accordingly, the keywords for the literature search were selected according to previous studies on fixation rather than using the single term *fixation*. Specifically, the keywords: *functional fixedness, mental set, mental ruts, Einstellung effect*, and *design fixation* were used in the search for article titles in the search in Google Scholar and for titles and abstracts in the search in the rest of the databases. Next, to include studies involve this phenomenon in a more comprehensive scope, a backward search (i.e., examining the citations in the selected literature) and a forward search (i.e., examining the citations of the selected literature) were conducted as a further step in the literature search. Further, though studies claimed that fixation might bring advancement (e.g., Youmans and Arciszewski, 2014), as this review focused on the positive effect of overcoming fixation, studies which discussed the advancement of fixation in problem solving were excluded. Finally, studies that discussed similar research questions and attained similar results with similar explanations were carefully examined and basically selected by the date of publication, as later studies were conducted on the basis of older studies.

4. Results

Following these three steps, 53 articles meeting the seven selection criteria are systematically reviewed in present study. Based on the two axes of fixation source and problem type, the reviewed studies are categorized in Table 1 and the critical information in these articles is sorted in Tables 2, 3. Further, as the main purpose of this review is to identify a preferable defixation approach, a perspective for characterizing the expected cognitive process of effective defixation for individuals is constructed in Figure 1. As depicted in the figure, closed-ended and open-ended problems are categorized into two distinct sections based on their different mechanisms for achieving the expected effects on the solution in problem solving. Specifically, fixation in closed-ended problems can be mitigated by conducting a beyond-frame search, resulting in enhanced solution rates. Similarly, conducting a beyond-frame search is also essential for mitigating fixation and consequently enhancing creativity in open-ended problem solving. However, in solving open-ended problems, even when fixation is not mitigated, creativity can still be improved through within-frame searches. To achieve successful defixation, approaches that facilitate beyond-frame searches are effective. Additionally, while there are approaches that can indirectly promote beyond-frame searches, their efficacy depends on the source of fixation. For instance, approaches which provide opportunities for reflection prove effective in mitigating

TABLE 1 Categorization of reviewed studies on the basis of two axes.

	Closed-ended problems	Open-ended problems
Misleading information	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45
Problem information-related memory	14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28	22, 37, 46, 47, 48, 49, 50, 51, 52, 53

The numbers in the matrix are the No's of reviewed studies shown in Tables 2, 3.

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fixation when the fixation is either induced by misleading information or problem information-related memory. Moreover, approaches designed to allow a decay of misleading information are also effective in reducing fixation.

Based on this perspective, first it is discussed how fixation is induced by misleading information and problem information-related memory in closed-ended problems. Next, approaches that are effective in overcoming the fixation induced by these two sources are reviewed. Then the mechanism of fixation induction and the defixation approaches investigated in the studies involving open-ended problems are examined. Finally, limitations of this review are indicated and future studies are suggested.

TABLE 2 Fixation/defixation studies involving closed-ended problems.

No.	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
1	Luchins (1942)	Arithmetic problem	Misleading information	Newly learned arithmetic solution	Makes individual repeatedly use this learned solution and makes it difficult to find another solution when the learned one is not applicable	This effect is not a fundamental feature of human behavior, but the result of intelligent assumptions with consideration of characteristics of the whole situation	N/A	N/A	N/A
2	Dunbar (1993)	Scientific discovery		Newly learned concepts	Individuals keep using goals that are developed on the basis of the newly learned concepts to deal with inconsistent experimental data	N/A	N/A	N/A	N/A
3	Munoz-Rubke et al. (2018)	Insight problem		Newly learned knowledge of tool function	Impedes individual's novel usage of tools in simple problems regardless of learning modality	Recently learned inaccurate experience biases the search process for novel solutions	Failure experience of physical interaction	Functional fixedness disappears after initial failure in physical implementation	Information accessed is changed by current task goal and modified by experience
4	Sheridan and Reingold (2013)	Chess		Suboptimal familiar solution	Biases expert and novice chess players to focus on the area related to a suboptimal familiar solution and impedes problem solving performance	Activated familiar solution directs individual's attention towards information related to the familiar solution and suppresses the discovery of other solutions	Blunder solution	Increases solution rates by making all experts and the majority of novices gradually disengage their attention from the blunders of the familiar solution and avoid choosing them	Blunder solution provides feedback indicating that the familiar solution is not optimal

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TABLE 2 (Continued)

No.	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
							expertise	experts who discover the optimal solution gradually disengage attention from the distracting solution	N/A
5	Bilalić et al. (2008)	Chess		Suboptimal familiar solution	Makes expert chess players subconsciously focus on the relevant area on board and suppresses recognition of the optimal solution	Experts' schema is activated when the situation is recognized as applicable; this schema directs attention to gathering compatible information and drives attention away from irrelevant information, suppressing the discovery of other solutions	N/A	N/A	N/A
6	Blech et al. (2020)	Arithmetic problem		Newly learned arithmetic solution	Makes individuals repeatedly use this learned solution and makes it difficult to find another solution when the learned one is not applicable	The activated memory of inappropriate information drives individuals to pay attention to perceiving elements that are related to the activated inappropriate elements	N/A	N/A	N/A
7	Neroni and Crilly (2021)	Arithmetic problem		Newly learned solution	Makes it difficult for individuals to find an optimal solution when the learned one is suboptimal	N/A	Experience of demonstrating vulnerability	Decreases fixation	Defixation is achieved by the enhancement in the recognition and being alert to fixation, the memory of the experience of being fixated, and the new information provided by feedback
							Instructions on	No effect	N/A

(Continued)

TABLE 2 (Continued)

No.	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
8	Vallée-Tourangeau et al. (2011)	Arithmetic problem		Newly learned solution	Makes it difficult for individuals to find an optimal solution when the learned one is suboptimal	N/A	Solving problem through physical manipulation of real objects	Increases solution rates and decreases usage of newly learned solution	The rich and dynamic perception from the interaction with real objects draws individuals' attention to problem features which contribute to adopting other solutions
9	Storm and Angello (2010)	RAT problem		Misleading cues	The strong association between misleading cues and RAT problem impedes individuals' solution rates	N/A	Retrieval induced forgetting (RIF)	The more RIF exhibited, the more problems solved by those who are misled by cues	Inhibition underlies RIF and inhibition in the accessibility of inappropriate solutions helps individuals to defixate
10	Koppel and Storm (2014)	RAT problem		Misleading cues	The strong association between misleading cues and RAT problem impedes individuals' solution rates	N/A	Retrieval induced forgetting (RIF) + incubation	The effect of RIF in improving solution rates is reduced by incubation; low-RIF individuals solve more problems with incubation whereas high-RIF individuals solve more problems without incubation	Incubation effect can be partially explained by forgetting hypothesis
11	Kohn and Smith (2009)	RAT problem		Misleading cues	The strong association between misleading cues and RAT problem impedes individual's solution rates	N/A	Incubation with the unsolved problem completely put aside	Increases solution rates of individuals who are misled by cues	Individuals work subconsciously during incubation
							Incubation with the presentation of unsolved problem	No effect	

(Continued)

TABLE 2 (Continued)

No.	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
12	Smith and Blankenship (1989)	Rebus problem		Misleading cues	The strong association between misleading cues and the rebus problem impedes individuals' solution rates	N/A	Incubation	Increases solutions rates and decreases the recall of misleading cues	Forgetting inappropriate information helps individuals to defixate
13	Sio et al. (2017)	RAT		Misleading cues	Strong association between misleading cues and RAT problem impedes individuals' solution rates	N/A	Alternating incubation	Increase in solution rates	Alternating between tasks prevents the repetition of recently retrieved items which strengthen fixation and provides time for decay of these retrievals
							Alternating incubation + incubation	Further increases solution rates when massed working with shorter incubation and distributed working provided with longer incubation	Break provides opportunity for problem-related activation to spread through semantic network and enhances the activation of remote associative items
14	Maier (1931)	Insight problem	Problem information	Prior knowledge of tool's function	Impedes individuals from generating new way of using known tools	N/A	N/A	N/A	N/A
15	Duncker (1945)	Insight problem		Prior knowledge of tool's function	Impedes individuals from generating new way of using known tools	N/A	N/A	N/A	N/A
16	Chesney et al. (2013)	Math problem		Prior knowledge of arithmetic strategy	Makes individuals spontaneously use typical arithmetic strategies that were acquired in past education practice and are suboptimal	The activated typical strategy from prior knowledge suppresses the activation of optimal strategy and forms a problem representation that only contains the typical strategy	N/A	N/A	N/A

(Continued)

TABLE 2 (Continued)

No.	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
17	Wiley (1998)	RAT problem		Domain knowledge related to the task	Biases individuals with higher domain knowledge resulting in lower solution rates and longer response times	Domain knowledge defines and narrows the search space	Instruction	No effect on high domain knowledge individuals, and fixates low domain knowledge individuals to increase solution rates	N/A
							incubation	only effective for fixation induced by external misleading cues found in low domain knowledge individuals to increase solution rates	N/A
18	Knoblich et al. (2001)	Insight problem		Prior knowledge of Roman numerals, arithmetic operations, and equals sign	Makes individuals unable to perceive the problem in a new way and constructs inappropriate problem representation, and this representation produces impasses	Initially constructed inappropriate representation biases individuals' attention	Constraint relaxation and chunk decomposition	Individuals who relax inappropriate constraints and decompose unhelpful chunks successfully solve the problem	Relaxing constraints and decomposing chunks helps individuals to achieve representational change
19	Tseng et al. (2014)	Insight problem		Prior knowledge of Roman numerals, arithmetic operations, and equals sign	Makes individuals unable to perceive the problem in a new way	Initially constructed inappropriate representation biases individuals' attention	Providing hints	Increase in solution rates	Directing attention away from the region that fixates i ndividuals to the region that is key for problem solving enhances representational changes

(Continued)

TABLE 2 (Continued)

No.	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
20	Moss et al. (2011)	RAT problem		Prior knowledge related to the task	Produces impasses	The item that is activated is repeatedly retrieved due to its recency and becomes the fixation in individuals' generate-and-test search through memory	Providing hints	Incidental hints are most effective in increased solution rates when provided at the point of reaching an impasse rather than before or delayed	Reaching an impasse makes individuals recognize the need for a new search; repeated retrieval of activated items in generate-and-test searches decreases the likelihood of using hints
21	Segal (2004)	Insight problem		Prior knowledge of shape	Makes individuals unable to perceive the problem in a new way	N/A	Incubation	Increase in solution rates but no difference in effects of incubation with different interval lengths	Incubation only serves as a diversion of the attention from the influence of the failed solution and this diversion enables individuals to apply new assumptions
22	Lu et al. (2017)	RAT problem + insight problem		Prior knowledge	Impedes individuals' problem solving performance	N/A	Alternating incubation	Switching tasks before reaching an impasse improves solution rates	Individual is not sensitive to recognizing impasses, instructing individuals to switch task before reaching an impasse reduces fixation
23	Beeftink et al. (2008)	Insight problem		Prior knowledge related to the task	Makes individuals unable to perceive the problem in a new way	N/A	Alternating incubation	Switching tasks before reaching an impasse increases solution rates more than being instructed to switch after reaching an impasse	Self-initiated switching allows individuals to choose their ending and starting of a task
24	Kiyokawa and Nagayama (2007)	Insight problem		Prior knowledge related to the task	Makes individuals unable to perceive the problem in a new way	N/A	Reflective writing	Increases solution rates	N/A

(Continued)

TABLE 2 (Continued)

No.	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
25	Knoblich et al. (1999)	Insight problem		Prior knowledge of Roman numerals, arithmetic operations, and equals sign	Makes individuals unable to perceive the problem in a new way	Prior knowledge constructs inappropriate representation of problem	Constraint relaxation and chunk decomposition	Individuals who relax inappropriate constraints and decompose unhelpful chunks successfully solve the problem	Relaxing constraints and decomposing chunks are individuals' responses to persistent failure and they help individuals to achieve representational change
26	Weller et al. (2011)	Insight problem		Prior knowledge of Roman numerals, arithmetic operations, and equals sign	Makes individuals unable to perceive the problem in a new way	N/A	Physical interaction	Increases solution rates and is more effective for more difficult problems	Providing opportunity to perceive problem in another way by directing attention to unrecognized aspects of the problem to enhance representational change
27	McCaffrey (2012)	Insight problem		Prior knowledge of tool's function	Makes individuals unable to generate novel use of tools	N/A	Generic-parts technique (chunk decomposition with function free descriptions for each part)	Increases solution rates, listing more target features, and listing key obscure features more often	N/A
28	Patrick and Ahmed (2014)	Insight problem		Prior knowledge related to the task	Makes individuals unable to perceive the problem in a new way	Prior knowledge constructs inappropriate representation of the problem	Training to enhance representational change	Increases solution rates	N/A

4.1. Fixation in closed-ended problems

4.1.1. Mechanism of the fixation induced by misleading information in closed-ended problems

Fixation induced by misleading information was firstly described by Maier (1930) and experimentally verified and named the Einstellung effect in Luchins' experiment with the water jar task (1942). In Luchins' study, participants were required to pour a certain amount of water using three water jars with different volumes. When participants learned a specific way of pouring water from practice problems, they kept using this method in solving new problems even when this method was suboptimal or inapplicable. This phenomenon was found not only in method information about pouring water when solving water jar problems, which is arithmetic problem solving. Individuals are biased by information given in solving different problems, such as in scientific discovery (Dunbar, 1993). Further, the information provided misled problem solvers regardless of the modality of the information. Munoz-Rubke et al. (2018) reported that the conformity to given information was observed regardless of whether the information was presented in text, video, or audio formats. Additionally, Sheridan and Reingold (2013)

TABLE 3 Fixation/defixation studies involving open-ended problems.

No.42	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
29	Jansson and Smith (1991)	Design	Misleading information	Example presented in line-drawing	Makes individuals copy features from example and impedes creativity	N/A	Instruction	No effect	N/A
30	Smith et al. (1993)	Creative idea generation		Example presented in line-drawing	Makes individuals copy the features of example	N/A	Inserting delay between example presentation and idea generation	No effect	N/A
							Instruction	No effect	N/A
31	Perttula and Liikkanen (2006)	Design		Example presented in picture with the instruction not to copy	Makes individuals generate fewer categories of ideas	Sampling probability effect	N/A	N/A	N/A
32	Viswanathan and Linsey (2013a,b)	Design		Example presented in line-drawing	Makes individuals copy features from example	N/A	Instruction with the explanation of flawed features	No effect	N/A
33	Viswanathan et al. (2014)	Design		Example presented as physical object	Makes individuals copy features from the example	N/A	Instruction	No effect	No explanation of why features are negative and sunk-cost effect
							Externalizing ideas	Decreases copying of negative features of example	Instant feedback makes individuals reflect and be aware of negative features
34	Chrysikou and Weisberg (2005)	Design		Example presented in line-drawing	Makes individuals copy features from example	N/A	Instruction	Decreases copying of the features of example	N/A
35	Ezzat et al. (2020)	Design		Example presented with the instruction not to copy by mentioning specific example	Makes individuals generate more fixated idea and decreases the originality of generated idea	Specific example in instruction makes individuals follow the path of least resistance	Instruction not to copy by mentioning example at a category level	Decreases the number of fixated ideas and increases the originality of generated ideas	High level of abstraction of the example forces individuals to reason beyond fixation

(Continued)

TABLE 3 (Continued)

No.42	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
36	Cardoso and Badke-Schaub (2011)	Design		Example presented in line-drawing and photo	Makes individuals copy features from example, decreases the ease of use and photo example decreases originality, whereas both of them increase manufacture	Pictorial examples are easily accessible and individuals tend to follow a solution which is already available	N/A	N/A	N/A
37	Agogué et al. (2014)	Design		Example that is identified to restrain the search range	Makes individuals generate fewer ideas with less originality	The knowledge spontaneously activated by example limits the search range due to its accessibility	Example that is identified to expand the search range	Increases the originality of generated ideas	Provides alternative solution in C-space (the space which involves the development of conceptualization in idea generation)
38	Atilola and Linsey (2015)	Design		Example presented in CAD, photo and sketch	Makes individuals copy features from examples but CAD and photo examples enhance feasibility	CAD and photo examples present the working principle well	N/A	N/A	N/A
39	Wilson et al. (2010)	Design		Superficially dissimilar example presented in line-drawing and text	Increases novelty, and induces higher variety than similar example	Leaving design space open to foster variation by transferring less attributes from example	N/A	N/A	N/A
				Superficially similar example presented in line-drawing and text	Increases novelty but decreases variety	N/A	N/A	N/A	N/A

(Continued)

TABLE 3 (Continued)

No.42	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
40	Cardoso and Badke-Schaub (2009a)	Design		Example presented in line-drawing	Makes individuals copy the features from example	Pictorial examples are easily accessible	N/A	N/A	N/A
				Example presented in text	Does not induce fixation	Examples with more abstractness and lower accessibility for generating design solutions, thereby leave room for more interpretations and active avoidance of copying			
41	Cardoso and Badke-Schaub (2009b)	Design		Example presented in line-drawing with incubation	Makes individuals copy the features from examples but increases the number of generated ideas	Pictorial examples are easily accessible	N/A	N/A	N/A
				Example presented in text with incubation	Makes individuals copy the features from the example	N/A			
42	Atilola et al. (2016)	Design		Example presented in line-drawing	Makes individuals copy the features from the example	N/A	N/A	N/A	N/A
				Example presented in text	Decreases copying from examples compared with line-drawing example and improves the quality of generated ideas	The text written in a function tree presenting the functions that need to be met without introducing the specific features of example			
				Example presented in line-drawing and text	Makes individuals copy the features from the example	N/A			

(Continued)

TABLE 3 (Continued)

No.42	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
43	Cheng et al. (2014)	Design		Example presented with incomplete information	Increases originality and positive self-evaluation	Incomplete information changes the format of the example; thereby influences how the information is processed and breaks away from the path of least resistance	N/A	N/A	N/A
44	Tsenn et al. (2014)	Design		Examples presented in CAD, photo and sketch with incubation	Decreases copying features from example, technical feasibility and contextual relativeness, but increases novelty	N/A	N/A	N/A	N/A
45	Kohn and Smith (2011)	General idea generation		Others' ideas	Makes individuals generate fewer ideas with less variety and narrower range of categories	N/A	Incubation	Makes individuals generate more ideas in more varied categories	Forgetting hypothesis
37	Agogué et al. (2014)	Design	Problem information	Prior knowledge related to task	Makes individuals tend to generate ideas in similar categories	The knowledge spontaneously activated by problem information limits the search range due to its accessibility	N/A	N/A	N/A
46	Ward (1994)	creative idea generation		Prior knowledge of animals on earth	Makes individuals' imaginative thoughts be bounded by prior knowledge	Items retrieved from the basic level exemplars are used as the base for generating novel ideas	N/A	N/A	N/A
47	Ward et al. (2002)	General idea generation		Prior knowledge related to task	Constrains individuals' imaginative idea generation	The retrievability of items predicts the activation of specific memory	N/A	N/A	N/A

(Continued)

TABLE 3 (Continued)

No.42	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
48	Moreno et al. (2016)	Design		Prior knowledge related to task	Makes individuals generate repetitive ideas	N/A	WordTree	Decreases fixation, increases novelty	Enables divergent mindset by designer-driven semantic re-representation
							SCAMPER	No effect in defixation but increases novelty more significantly than WordTree	Enables divergent mindset by proposing active questions to guide individuals, but the rework on developed ideas promotes fixation
49	Smith et al. (2017)	General idea generation		Prior knowledge related to task	Makes individuals generate fewer ideas with less novelty	N/A	Alternating incubation	Enhances the number of generated ideas for flexible categories and the stable, flexible mixed category, and both the number and novelty of generated ideas for flexible categories	Incubation effect is achieved by restructuring
22	Lu et al. (2017)	AUT		Prior knowledge related to task	Makes individuals generate ideas with less flexibility and novelty	N/A	Alternating incubation	Switching task before reaching impasses enhances flexibility, novelty and decreases fixation	Individual is not sensitive to recognizing impasse, and instructing individuals to switch task before reaching impasse reduces fixation
50	Madjar et al. (2019)	General idea generation		Prior knowledge related to task	Impedes creativity	N/A	Alternating incubation	Switching to in-domain task at a later time enhances creativity more	Sufficient immersion in the main task before incubation contributes to the enhancement of creativity

(Continued)

TABLE 3 (Continued)

No.42	Reference	Type of task	Fixation				Defixation		
			Source		Effect on problem solving	Proposed main mechanism	Approach	Effect on problem solving	Proposed main mechanism
51	Wang et al. (2022)	Drawing		Prior knowledge related to task	Makes individuals draw in the same way for specific themes	N/A	Providing an environment that blocks access to prior knowledge with instruction and reflection enhancing session	Increases creativity and enhances the awareness of fixation and the construction of subjective perspective	The inaccessibility of prior knowledge effectively inhibits memory retrieval, and the instruction and reflection prompts critical reflection
52	Bonnardel and Marmèche (2004)	Design		Prior knowledge related to task	Makes individuals only evoke intradomain sources	N/A	Example + expertise	Enhances the evocation of interdomain sources	N/A
53	Okada and Ishibashi (2017)	Drawing		Prior knowledge of realism	Makes individuals draw with realism	N/A	Imitating and appreciating the artwork in unfamiliar style	Increases creativity and enhances the construction of subjective perspective	The interaction with unfamiliar artwork helps individuals to achieve representational change, thereby to construct new perspectives and new patterns of drawing

demonstrated that the influence of the information provided affected not only novice problem solvers but also experts. Importantly, Bilalić et al. (2008) found that individuals were not conscious of such conformity and subjectively believed that they were exploring different solutions.

To clarify how individuals are fixated by information given, in other words, to examine the mechanism of the fixation induced by misleading information, Blech et al. (2020) replicated Luchins' experiment with the requirement of asking participants to think aloud during problem solving. Based on similar results and protocol data, this revealed that memory which was activated by the information given biased individuals to perceive elements that were related to this inappropriate information. Further, attention paid to inappropriate information activated memories related to the perceived elements. That is, fixation was induced in a cycle of misleading information activating related memory and the activated memory driving attention towards information that was related to the memory that had been activated. This interaction of memory, perception and attention was also revealed in chess problem solving from data about eye movements (Bilalić et al., 2008; Sheridan and Reingold, 2013). Additionally, this also showed that searching for an optimal solution was inhibited by a suboptimal solution rather than being completely blocked.

4.1.2. Mechanism of fixation induced by problem information-related memory in closed-ended problems

In Maier's (1931) experiment of solving problems by using tools in a novel way, it was found that participants were bounded by their prior knowledge of using pliers to cut or hold and failed to use the pliers as a pendulum to solve the problem. Later, similar results were reported in Duncker's (1945) candle task. In the task, participants were required to use a box which contained thumbtacks as a candle holder, and to tack it to a wall to solve the problem. As this is related to the phenomenon of being fixated in generating novel usage of tools, it is called functional fixedness. However, the phenomenon of being fixated by prior knowledge relating to a specific problem is not exclusive to tool function, rather it is reported in solving various problems, such as mathematics problems (e.g., Chesney et al., 2013), RAT problems (e.g., Wiley, 1998), and insight problems (e.g., Knoblich et al., 2001). Based on these studies, the memory activated by information related to a given problem is considered to be the fixation that inhibits problem-solving performance.

To clarify the mechanism, studies tracked the eye movement of participants who were solving a matchstick problem. The matchstick problem is a classical insight problem that is represented in an arithmetical form and solved by perceiving Roman numerals,

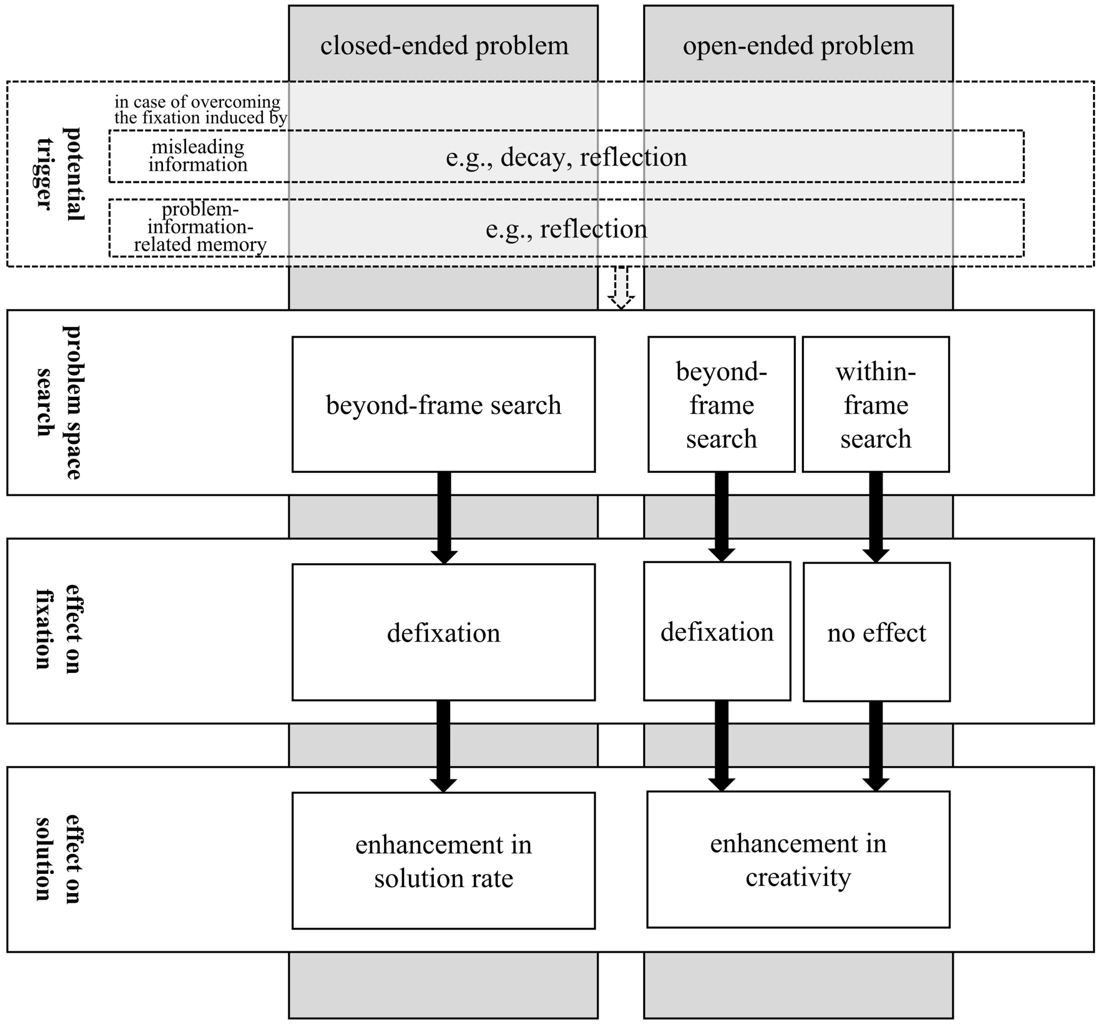

FIGURE 1
Perspective for characterizing the expected cognitive process of effective defixation for individuals.

arithmetic operations, and equals signs that are made up by matchsticks as separate matchsticks and moving these matchsticks to form new mathematical notations. According to the results, it was found that the arithmetical representation of the problem activated arithmetic related prior knowledge. Further, this activated prior knowledge constructed an inappropriate problem representation and caused impasses (Knoblich et al., 2001; Tseng et al., 2014). In the study of solving mathematical problems, similar results were reported by revealing that information about tasks activated the schema of a suboptimal approach, which was acquired from previous educational practice, in addition, the activated prior knowledge suppressed the activation of the schema of optimal solutions (Chesney et al., 2013). Further, in a study involving RAT problems, the protocol data indicated that individuals tended to conduct a generate-and-test search through memory after the initial failure (Moss et al., 2011). Based on the ACT-R model of memory, Moss et al. (2011) proposed that the fixation could be considered to be the construction of the baseline activation developed by recently retrieved items. Further, this baseline activation became the most retrievable due to its recency in generate-and-test searches. According to these findings, it could be concluded that information about the problem activates related memory. Later, if the activated memory is inappropriate, the problem cannot be solved, but this memory is repeatedly retrieved in the process of generate-and-test for problem solving due its retrievability. Finally, this repeated activation of inappropriate memory becomes the fixation that impedes problem solving.

Based on data which indicated the process of problem solving, studies identified the mechanism of fixation induction in closed-ended problems. Specifically, when misleading information is given, the memory of this information is activated when solving problems and the activated memory biases individuals to pay attention and perceive the information that is related to this retrieved memory. Fixation is induced in this interaction between memory activation, perception and attention. In contrast, when there is no misleading information, the information about the task activates the task-related memory depending on its retrievability and if this activated memory is inappropriate, it becomes a fixation due to the recency induced in the repeated retrieval in the generate-and-test search. Further, regardless of whether there is misleading information or not, the activated memory inhibits the activation of other possible solutions.

This inhibitory effect is similar to the interference effect that is claimed in response competition theory (Smith, 1995). Specifically, response competition theory suggests that the likelihood of retrieving a target response diminishes as the strength of competing responses increases, and this strength is determined by the number of competing responses and the association between the stimulus and these competing responses. In accordance with this theory, Smith (1995) believed that the retrieval of an inappropriate solution blocks the retrieval of the target solution, thereby fixation is induced by the block, which is strengthened by the retrieval of an inappropriate approach or inappropriate information.

4.1.3. Defixation approach for fixation induced by misleading information in closed-ended problems

To relax the fixation induced by misleading information, as a direct approach, studies examined the effects of instructing individuals not to utilize the given information. However, little effect is brought about by a mere warning (e.g., Neroni and Crilly, 2021). Moreover, such instruction is even argued to be another fixation (Blech et al., 2020), such as in a study which reported that the instruction of not to think about a white bear functioned as an accelerator of associative thinking about white bears (Wegner, 1989), which hinders problem solving. For this ineffectiveness, an individual's belief of not being susceptible to the negative effect of fixation themselves is proposed as a possible explanation (Neroni and Crilly, 2021). Specifically, Neroni and Crilly (2021) posited that individuals may not perceive themselves to be susceptible to fixation, even if when warned about this potentiality, they acknowledge that such a risk is applicable to people in general. Based on this view, researchers attempted to create a condition where individuals could receive feedback on how they were influenced by fixation, which was information that could not be obtained by being warned to defixate. For instance, a study revealed that providing instruction about fixation on the basis of having experienced failure in solving the water jar problem, rather than just giving instructions to avoid using the information provided, was effective in reducing the negative effect of misleading information and enhancing problem solving performance (Neroni and Crilly, 2021). Importantly, the reflection enhanced by failure-experience-based instruction increased the awareness of fixation and encouraged individuals to modify their behavior in solving problems. This was suggested to be one of the possible explanations for the effectiveness of this intervention. Similarly, providing the opportunity to interact with the physical environment by allowing participants to utilize actual water jars to solve the water jar problem could be seen as an approach which diminishes fixation by providing feedback through the interactive experience with dynamic environmental information (Vallée-Tourangeau et al., 2011). Further, the defixation effect was also indicated by the intervention of offering a second chance after the first failure in solving problems by the physical manipulation of real objects (Munoz-Rubke et al., 2018). Providing a blunder solution is a less straightforward approach to providing feedback for individuals to reflect and realize that the solutions they have tested are not optimal (Sheridan and Reingold, 2013). Based on the results of these studies, providing feedback to enhance reflection is indicated as an effective approach to defixation.

As the fixation discussed in this section is induced by misleading information, inhibiting access to the source of fixation to diminish the negative influence of inappropriate information is considered to be viable. This has been verified, for instance in studies that utilized Retrieval-Induced Forgetting (RIF) (Anderson et al., 1994), a memory phenomenon which indicates a tendency for the retrieval of a target item to suppress the accessibility of a competitive item. On the basis of results showing that the more RIF exhibited, the more RAT problems were solved, forgetting was proposed as a mechanism for the defixation effect (Storm and Angello, 2010; Koppel and Storm, 2014). Actually, forgetting is proposed as a critical mechanism for eliminating fixation (Beda and Smith, 2022). Specifically, forgetting is considered to be one of the possible cognitive processes that could explain how incubation mitigates the influence of fixation.

Incubation, which was originally proposed as one of the four stages of creative process (Wallas, 1926), is shown to be effective in relaxing the fixation induced by misleading information in various studies (e.g., Smith and Blankenship, 1989; Kohn and Smith, 2009; Sio et al., 2017). For the mechanism of the incubation effect, however, studies showed inconsistent results. Two main hypotheses are proposed: one claims that individuals still consciously work on problems even when they are away from problem solving. In contrast, another hypothesis suggests that individuals work subconsciously during a break. Based on results that showed that the incubation was effective when an unsolved problem was put aside and ineffective when the unsolved problem was presented during incubation, Kohn and Smith (2009) confirmed the unconscious hypothesis and rejected the conscious work hypothesis. Further, according to the results of a meta-analytic review of incubation studies, it was not only concluded that little supportive evidence was shown for the conscious work hypothesis, but also pointed out that more studies should be conducted to clarify the specific cognitive processes that account for unconscious hypothesis, as there were three proposals for explaining how incubation work: forgetting, spreading activation, and restructuring (Sio and Ormerod, 2009). The forgetting hypothesis, which is proposed by Smith and Blankenship (1989), claims that incubation is effective by inhibiting the access to the source of fixation and so enhances the possibility of obtaining the correct answer. This hypothesis is strongly supported by their study, which demonstrated that incubation not only improved the solution rates but also decreased the performance of recalling misleading cues. Nevertheless, significant results were not shown in the examination of whether the degree of incubation was affected by modifying the length of the incubation interval. Though there are more studies showing supportive evidence for the forgetting hypothesis (e.g., Wiley, 1998; Koppel and Storm, 2014), there is insufficient evidence indicating that the longer incubation interval, the more the performance of problem solving is enhanced. This is a critical objection for rejecting the forgetting hypothesis. In a study which verified the cognitive process of incubation by investigating how problem solving was influenced by switching between tasks, which is seen as a kind of incubation that provides the same type of experimental task as the incubation task (Smith et al., 2017), Sio et al. (2017) claimed that the spreading activation hypothesis (Yaniv and Meyer, 1987), which suggests that overlooked solution-relevant items are activated during incubation, was the mechanism of incubation, rather than forgetting. Specifically, a study conducted by Sio et al. (2017) reported that the efficacy of incubation in improving the solution rate of distributed work and massed work varied by the length of incubation interval. According to the activation-based processes of memory, a high activation of misleading cues would cause quick decay. Therefore, this result was considered to support acceptance of the spreading activation hypothesis and rejection of the forgetting hypothesis, which assumes that longer incubation would always be more effective regardless of the work condition. However, data of a lexical decision task, which was designed to examine the effect of spreading activation, did not show any further supporting evidence.

From a holistic view, though these studies seemed to show evidence for claiming a different mechanism for incubation, they all demonstrate that fixation induced by misleading cues is eliminated by achieving a decay of its influence. Further, the decay of the influence from a fixated item would enhance the activation of a competitive solution and the performance of problem solving might be improved by this enhancement, since the fixated item is shown to suppress the retrieval of other competitive solutions. Moreover, fixation induced by misleading information could also be effectively diminished by approaches which commit to enhancing reflection by providing information for receiving feedback.

4.1.4. Defixation approach to fixation induced by problem information-related memory in closed-ended problems

In Wiley's (1998) study, which investigated the fixation induced by domain knowledge in solving RAT problems, two proposals were made by examining the effectiveness of two defixation approaches. First, it claimed that such fixation was not a subjective utilization of knowledge by showing the ineffectiveness of instructions to avoid the use of knowledge. Importantly, Wiley (1998) noted that the efficacy of a defixation approach may vary depending on the source of fixation. This conclusion was drawn from results showing that incubation was effective in mitigating fixation induced by misleading information, but not that induced by the domain knowledge activated by problem information. As incubation is a commonly employed defixation approach, subsequent studies have been conducted to further examine its effects and underlying mechanisms in overcoming fixation induced by problem information. For instance, Segal (2004) employed an insight problem, which involves fixation induced by an individual's prior knowledge of a given problem, to verify the mechanism of incubation at the point of reaching an impasse reported by participants. Specifically, the returning-act hypothesis, which suggests that a break does not lead to any cognitive process but only works as a diversion that allows individuals to restructure incorrect attempts, was proposed as the mechanism. The results which indicated that the effectiveness of incubation was independent of the interval length of incubation, and a no-cognitive-load-demanding task, which functioned as a weak diversion, indicated a weaker incubation effect, were claimed to be consistent with the prediction of this hypothesis. Considering the importance of an impasse, which was emphasized in Segal's (2004) experiment by claiming that individuals would spontaneously divert their attention from a given problem when they reached an impasse, this hypothesis is similar to the third main proposal of the cognitive process of incubation, the opportunistic assimilation hypothesis. Specifically, this hypothesis assumes that an individual becomes sensitive to the surroundings after reaching an impasse, and the restructuring or re-encoding of the unsolved problem, which contributes to successful problem solving, is enhanced by encountering environmental hints during incubation (Seifert et al., 1995). According to this hypothesis, the incubation effect reported in Segal's (2004) study could also be seen as the result of the problem restructuring which is prompted by perceiving environmental hints during a break after initial failure. Moreover, a stronger incubation effect found in an incubation task which demanded more cognitive load might be due to an encounter with richer information in the environment. Though further studies on examining whether the incubation is effective by diverting an individual's attention or by providing new information for an individual to encounter, there are two critical issues shared by these two hypotheses. Firstly, both of the hypotheses suggest that defixation is achieved by the restructuring of the initial idea. In other words, a break in the frame constructed by a failed solution of the search in the problem space is essential for overcoming fixation. In the light of this notion, the ineffectiveness of incubation in Wiley's (1998) study could be also explained as an insufficiency in the incubation task in enhancing a search beyond the frame constructed by the activated domain knowledge, whereas such an incubation task is sufficient for breaking the frame constructed by misleading information by achieving a decay. Secondly, both of the hypotheses emphasize the importance of reaching an impasse. Actually, an impasse is a critical topic in studies of insight problems, with many defixation studies conducted with consideration of an impasse. An impasse is a mental state that individuals reach when they cannot make any further progress in their problem solving process (Ohlsson, 1992). An impasse can be not only a feeling reported by the individual (e.g., Segal, 2004), but can also be observed in various ways, such as through behavior (e.g., Ohlsson, 1992), protocol (e.g., Fleck and Weisberg, 2004) and eye movement (e.g., Tseng et al., 2014). An impasse is considered to be vital, and it is described as one of the fundamental stages in an insight sequence for solving insight problems (Ohlsson, 2011). Insight is thought to be a consequence of an impasse from the perspective of productive thinking in Gestalt psychology (Haavold and Sriraman, 2022). Further, being fixated is argued to be a cognitive state that is prior to an impasse (Beeftink et al., 2008). In the investigation of an effective defixation approach, given that reaching an impasse is not an essential condition for solving insight problems (Fleck and Weisberg, 2004; Tseng et al., 2014) and a longer impasse might produce more fixation (Lu et al., 2017), studies were conducted to examine the defixation effect of reducing impasses. For instance, instructing individuals to switch task before reaching an impasse is found to contribute to enhancing solution rates (Lu et al., 2017). Further, Beeftink et al. (2008) revealed that individuals who switched tasks at their own discretion solved more problems. It was reported that those switching before reaching an impasse solved more problems than those instructed to switch after reaching an impasse. However, reducing impasses does not necessarily ensure higher solution rates than, for instance, sequentially engaging in tasks (Beeftink et al., 2008). Importantly, reaching the status of an impasse is also crucial in defixation, since it is considered to be a factor which triggers a new search (Seifert et al., 1995; Segal, 2004; Moss et al., 2011). Moreover, it relates to a failure experience which encourages individuals to reflect (Fleck and Weisberg, 2004). Reflection, which is a well-studied topic in research of education, is not only shown to be effective in defixation (e.g., Neroni and Crilly, 2021), but also significantly related to creative thinking (Akpur, 2020), and a higher level of reflection involves double-loop learning (Greenwood, 1998), which is a transformative learning that involves the modification of habituated action (Argyris, 1994). Therefore, studies also examined the defixation effect of providing intervention with consideration of the point at which an impasse is reached. For instance, a study on the timing of implementing defixation interventions revealed that providing incidental hints aimed at enhancing representational change (i.e., a form of cognitive restructuring) was most effective in improving solution rates when offered at the point of an impasse (Moss et al., 2011). Further, studies were also conducted to examine the effectiveness of encouraging individuals to reach the status of an impasse to trigger cognitive dissonance that prompts reflection, such as the investigation of a failure experience (Neroni and Crilly, 2021), physical interaction (Vallée-Tourangeau et al., 2011) and blunder solution (Sheridan and Reingold, 2013) in eliminating fixation induced by misleading information. To overcome fixation induced by problem information-related memory, Kiyokawa and Nagayama (2007) confirmed that inserting a reflection session about failure experience by asking participants to write down the failed solutions that were attempted while solving insight problems effectively increased the solution rates.

In the meanwhile, defixating by restructuring is not limited to incubation. There is more supportive evidence showing the effectiveness of restructuring in defixation. Based on the theory proposed by Kaplan and Simon (1990), representational change, which is a restructuring of problem representation, is shown to be an effective defixation approach for solving the classical insight problem, the matchstick problem (Knoblich et al., 1999). Specifically, the decomposition of the chunks that are developed from patterning familiar items or events, and the relaxation of constraints, which is defined as the prior knowledge not adaptable to solving the given problem, are proposed as two processes for achieving representational change. In studies that replicated this experiment, this proposal was confirmed by eye movement data (Knoblich et al., 2001; Tseng et al., 2014). In addition, according to results which revealed that providing hints for averting attention to a key area, which was the area involved in fixation and needed to be restructured to achieve successful problem solving, enhanced solution rates. Averting attention away from the fixated area was argued to be another critical process for overcoming fixation (Tseng et al., 2014). Similar to the intervention of averting attention to defixate, though chunk decomposition and constraint relaxation are specified as an individual's response to repeated failures during trial-and-error in problem solving (Knoblich et al., 1999, 2001), studies were also conducted to examine whether these processes could be promoted. For instance, similar to what has been examined in the study of overcoming fixation induced by misleading information, Weller et al. (2011) presented the matchstick problem in a three-dimensional format which an individual could physically manipulate. As it found that the solution rates of individuals who had an interactive experience were significantly higher than of the group with the problem presented on a piece of paper, the physical interaction was reported to be effective in facilitating chunk decomposition by providing the opportunity to perceive the elements of a given problem in a different way, and to enhance constraint relaxation by new representations that were constructed by the action of manipulation. In addition, according to the discussion about eliminating the fixation induced by misleading information, feedback received from the interaction with the environment could also be seen as a potential trigger for enhancing these two cognitive processes. Further, McCaffrey (2012) developed the generic-parts technique by integrating the enhancement of personal interpretation to chunk decomposition to increase the solution rate for insight problems. Patrick and Ahmed (2014) confirmed that representational change could be enhanced by training that consisted of three stages: being provided information about fixation, practicing with support, and practicing without support.

Various approaches have been developed for relieving fixation induced in closed-ended problems. Considering the source of fixation, there are approaches effective for overcoming fixation by the same mechanism regardless of its source, such as approaches which encourage individuals to reflect. Critically, the present review also indicates that the mechanism of a specific effective defixation approach varies according to the source of fixation. For instance, incubation is found to be effective for diminishing fixation induced by misleading information through the decay of the influence of information that misleads problem solving. However, as the influence of fixation cannot decay when it is induced by problem information-related memory, which involves the activation of long-term memory, this approach is reported to relax such fixation by enhancing the restructuring of the frame that is constructed by failed attempts. As a correct solution is not contained within the frame constructed by previously failed solutions, the enhancement of a search beyond the existing frame is essential for successful defixation. Specifically, interventions contribute to restructuring in a direct approach to prompt a beyond-frame search, and intervention which allows the influence of misleading information to decay and individuals to reflect is considered to be an approach which offers an opportunity to trigger the enhancement of a beyond-frame search.

4.2. Fixation in open-ended problems

4.2.1. Mechanism of fixation induced by misleading information in open-ended problems

The first empirical study that confirmed fixation induced by misleading information in open-ended problems was conducted by Jansson and Smith (1991). In their experiment asking participants to solve design problems with the presentation of example solutions, it was found that participants copied features, even including flawed ones, from the examples provided, and such copying impeded creativity. This finding was also reported in other domains, such as creative idea generation (Smith et al., 1993).

Subsequent to the study conducted by Jansson and Smith (1991), further investigations were conducted into how designers were fixated by a given example were conducted, and theoretical frameworks were proposed to explain this phenomenon. For instance, in a meta-analytic review by Sio et al. (2015), attention allocation was identified as the mechanism of fixation induction. Specifically, it suggested that examples direct designers' attention to specific domains, thereby narrowing the range of their search in problem space. Concurrently, Viswanathan et al. (2014) offered two possible explanations for the mechanism of such fixation. The first, grounded in the network models of memory, claimed that once an initial concept is activated by a given example, related concepts become more likely to be retrieved unconsciously. The second explanation considered the speciality of the domain of design and proposed that the adverse effects of examples might arise from the strategies that designers employ, as they often generate ideas based on their first concept or familiar examples.

Alongside these theoretical discussions, empirical investigations have also been conducted to elucidate the mechanism. For instance, by considering that designers often rely on existing design solutions, Perttula and Liikkanen (2006) performed an experimental study that challenged the notion that design fixation is due to subconscious conformity to given examples. Instead, they introduced the concept of the sampling probability effect as an alternative explanation for such fixation. This effect suggests that certain solutions are easier to access cognitively, and exposure to these solutions can preoccupy the solution space, thereby reducing the diversity of ideas generated.

Additionally, Agogué et al. (2014) proposed that the way of using spontaneously activated knowledge may induce fixation in design problems. Further, the notion of sunk cost has been widely discussed as another explanatory theory (e.g., Viswanathan et al., 2014; Sio et al., 2015; Hu et al., 2020). Moreover, theoretical modeling of design fixation has been established by Nguyen and Zeng (2017), contributing to a rich body of literature on fixation induced by misleading information in open-ended problems. However, existing studies have either offered theoretical discussion without empirical data or limited their discussions to specific domains, such as design, where misleading information is predominantly presented as example solutions. Importantly, the problem type was usually not taken into account in these discussions. As different types of problems involve different cognitive processes (Schraw et al., 1995), rather than simply applying the knowledge from the previous studies which only involved closed-ended problems or did not consider the problem type, it is legitimate to suggest that it is necessary to examine how fixation is induced by misleading information in open-ended problems based on empirical data that reveals the cognitive process.

4.2.2. Mechanism of fixation induced by problem information-related memory in open-ended problems

Besides examining the influence from example solutions, studies on design fixation also indicated that fixation was not only induced by given examples but could also be induced by internal elements, such as designers' experience (e.g., Crilly, 2015). The phenomenon of being fixated by experience or prior knowledge in solving open-ended problems was reported across different domains. For instance, in the domain of design, a study reported that both novices and experts generated ideas within similar categories in solving design problems (Bonnardel and Marmèche, 2004). Further, in general idea generation, studies revealed that individuals were bounded by their prior knowledge of creatures on earth in generating imaginative ideas of extraterrestrials (Ward, 1994). To clarify the mechanism of such a restraining effect of prior knowledge, Ward et al. (2002) conducted a study to investigate how the generation of new ideas was impeded by prior knowledge by asking participants to list items from different categories, such as animals and fruits. According to the results, firstly, the fixation induced by prior knowledge was confirmed by showing that the ideas generated by the majority of participants were based on specific category knowledge. Further, rather than other measures, such as typicality, familiarity, frequency of occurrence or rating of ideas, it was identified that the retrievability or coming-to-mindedness, which was the measure of how readily an item would be activated when a problem was presented, was the main predictor of how likely an item would be adopted in idea generation in an imaginative task. This is not only consistent with what is proposed in the path-of-least-resistance model (Ward, 1994), which assumes that the items retrieved from basic level exemplars are used as the base for generating novel ideas, but also similar to what is claimed by Wiley (1998), who suggested that the generation of prior knowledge-bound ideas was not a subjective choice in solving closed-ended problems. However, as there is no certain answer for open-ended problems. It is still a mystery why individuals kept generating ideas in such a way even when they were told to be creative. Though Ward et al. (2002) proposed several explanations, such as inappropriate monitoring, as there was no data collected for examining the process of creative idea generation, further studies are necessary.

4.2.3. Defixation approach for fixation induced by misleading information in open-ended problems

The same as studies involving closed-ended problems, the effect of explicit instructions not to copy flawed features of an example was examined in Jansson and Smith's (1991) study. Participants kept copying unwanted features even when they were told not to. Similarly, in studies examining the effect of warning participants about the problematic features, again instruction was ineffective regardless of whether the warnings were (Viswanathan and Linsey, 2013a,b) or were not (Viswanathan et al., 2014) accompanied by an explanation of why these features were negative. However, in a replication of the experiment conducted by Jansson and Smith (1991), results indicated that instruction did relax the fixation (Chrysikou and Weisberg, 2005). Chrysikou and Weisberg (2005) explained that these contradictory results for the same defixation approach might due to a difference in experimental conditions, since the earlier study was conducted in a group and the replicated study was conducted individually. With consideration of the source of fixation, another possible explanation for this result might be the participants, since the individuals engaged in the study which reported that instruction contributed to defixation were psychology students, while the participants in the study which found instruction was ineffective were either senior engineering students, professional design engineers, or freshmen on an engineering course. In other words, the participants' knowledge-base relating to the given problem was different. Similar to the fixation investigated in Wiley's (1998) experiment, though misleading information was provided, the source that induced fixation was domain knowledge, since the task was designed to be biased by domain knowledge. In solving design problems, an example design solution provided for students majoring in design-related courses might activate prior knowledge of design. Based on previous discussion, it might be considered that instruction is sufficient to prompt an individual to conduct a search beyond the frame constructed by example, whereas it is insufficient to enhance the search beyond the frame constructed by example and prior knowledge. A study which showed that presenting an example that involved domain knowledge of mechanical engineering only fixated individuals who were majoring in the related domain of solving mechanical engineering design problems (Purcell and Gero, 1996) provides a supporting evidence to indicate the necessity of considering the source of fixation in overcoming its negative effect. Consequently, further study might be necessary to validate the effectiveness of such instruction on overcoming fixation induced by misleading information in solving open-ended problems with consideration of the source of fixation.

However, as Agogué et al. (2014) suggested that the direct use of spontaneously activated knowledge can induce fixation in idea generation, mentioning examples in warning instructions may paradoxically act as a trigger that activates related knowledge, thereby offering individuals the opportunity to utilize this activated knowledge directly. To address this complexity, rather than merely warning individuals to avoid using examples, Ezzat et al. (2020) investigated the impact of instructional approaches that considered the manner in which examples were presented. Specifically, they reported that warning instructions mentioning examples at a higher level of abstraction not only mitigated fixation, but also enhanced the originality of the generated ideas. Such instructions are considered to serve dual functions: as warnings for avoidance and as tools for abstraction. Actually, numerous studies had been conducted to examine the effect of how examples are presented on mitigating the fixation induced by misleading information in open-ended problems.

Along with the experiment conducted by Jansson and Smith (1991), the majority of studies on design fixation focused on the influence of example. As design is usually thought to be based on the adaptation of previous products (Eckert et al., 2005), practically example is an unavoidable issue in generating design solutions. Therefore, how to present examples in a way that would induce less fixation is a predominant topic in the study of design fixation. Importantly, producing less fixation is usually described as successful defixation in studies of design fixation (e.g., Cardoso and Badke-Schaub, 2009a). In this sense, it is legitimate to consider that examining the approach to decreasing fixation induced by provided example solutions contributes to the development of a defixation approach for design fixation. Accordingly, though information from research on the effect of example is summarized in the category of Fixation in Table 3, examinations of how to present examples in a less fixated way are discussed in the present review through representative studies of the approach to relaxing fixation induced by misleading information by modifying the source of fixation. Moreover, it should also be noted that the discussion in this section only focuses on the influence of example in terms of defixation rather than obtaining a comprehensive review of example effect.

As most previous studies adopted examples presented in line drawings (e.g., Jansson and Smith, 1991; Chrysikou and Weisberg, 2005; Viswanathan and Linsey, 2013a,b), studies attempted to adjust the amount of information that the example delivered to defixate, such as presenting examples in photos, computer-aided designs (CAD) or sketches, and predicted that the degree of fixation would depend on the richness of the information that examples conveyed. Though results rejected this prediction by showing that there was no significant difference found in fixation by presenting examples with different amounts of information (Cardoso and Badke-Schaub, 2011; Atilola and Linsey, 2015), examples presented in CAD and photos enhanced the quality of solutions generated by demonstrating working principles more clearly (Atilola and Linsey, 2015), and photos and line drawing examples improved the manufacturability (Cardoso and Badke-Schaub, 2011). To explain the ineffectiveness for defixation in these studies, in terms of analogical reasoning, as a possible reason, it was proposed that the distance between source (i.e., the example) and target (i.e., the generated solution) was too close (Cardoso and Badke-Schaub, 2011). Therefore, the defixation effect of distant examples was examined. For instance, compared with human-engineered examples, presenting biological examples, which were superficially dissimilar to the target, significantly improved the novelty and variety of design solutions (Wilson et al., 2010). As the product of a design solution is usually presented in a visual form, pictorial examples could be considered to be close sources, and textual examples as distant sources in terms of modality. In the light of this notion, study confirmed the effect of presenting examples written in words in defixation by reporting that textual examples reduced fixation by reducing the accessibility of the source and providing information in a more abstract way that allowed more personal interpretation compared with pictorial examples (Cardoso and Badke-Schaub, 2009a). However, in the replication of the study conducted by Cardoso and Badke-Schaub (2009a), a contradictory result was reported, revealing that there was no difference in the level of the fixation induced by examples presented in pictures and text (Cardoso and Badke-Schaub, 2009b). To clarify the defixation effect of presenting textual examples, studies utilized well-structured techniques developed on the basis of written information. For instance, Atilola et al. (2016) demonstrated that presenting examples in a function tree (Figure 2), which is an approach that conveys textual information about design solutions without specifying particular features, successfully mitigated fixation. This was evidenced by a decrease in the number of copied features from examples, while the quantity of ideas generated remained constant. Moreover, this approach also enhanced the quality of the ideas generated. These findings align with a study which showed that instructions to avoid using examples were effective and originality was enhanced when examples were mentioned at a more abstract level. Notably, Ezzat et al. (2020) suggested that the abstraction of examples forced participants to extend their search beyond the fixation frame, thereby mitigating fixation. This is consistent with Agogué et al. (2014), who confirmed the efficacy of expansive examples (examples which were identified to widen the range of the search in solving specific design problems) in the mitigation of fixation and the enhancement of idea originality. As such, an approach which can prompt a beyond-frame search is shown to be beneficial for defixating and enhancing other aspects which are expected in a solution, such as originality. However, Atilola et al. (2016) also reported that the defixation effect and the enhancement of other aspects dissipated when a sketch of an example was added, and this was not as effective in enhancing novelty and variety compared with sketch examples alone (Atilola et al., 2016). Given these considerations, presenting examples in a function tree can be understood as an abstraction technique that facilitates beyond-frame searching. Moreover, when sketches displaying specific features accompany such textual examples, the ineffectiveness of providing examples in a function tree and sketch in defixation could be considered to be a result of the integration of the narrowing effect brought about by visual examples and the expanding effect brought about by textual examples in the search range. This integrated effect was not sufficient in enhancing a beyond-frame search. However, as the results indicated that novelty and variety were not affected, the enhancement in beyond-frame searches seems not to be related to the improvement in these two aspects. This result is similar to studies which revealed that adjusting the richness of the information that examples conveyed enhanced either the quality or the manufacturability of generated ideas even though it did not defixate (Cardoso and Badke-Schaub, 2011; Atilola and Linsey, 2015). In terms of search range, even though beyond-frame searches could not be prompted as it was shown that there was no defixation effect, there might be an enhancement within the frame that was constructed by example and this enhancement in within-frame searches also might

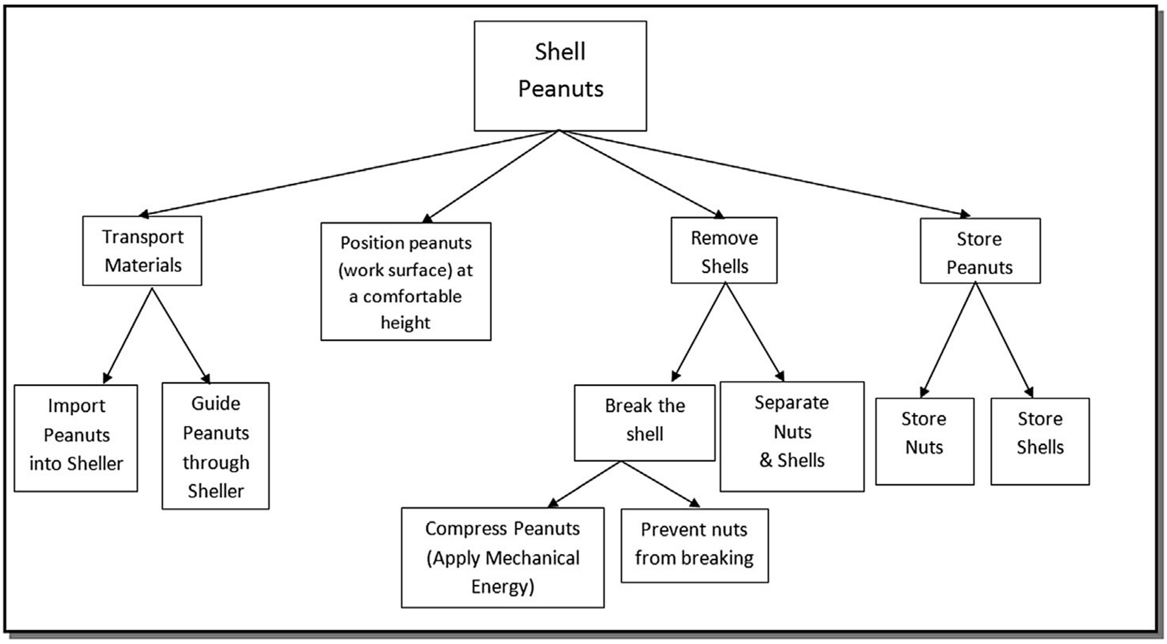

FIGURE 2
Example of design solution of peanut sheller presented in function tree. Reprinted from Design Studies, 42, Atilola, O., Tomko, M., & Linsey, J. S., The effects of representation on idea generation and design fixation: A study comparing sketches and function trees, p. 122, Copyright (2016), with permission from Elsevier.

bring about an advancement, such as improving the idea quality and manufacturability. Accordingly, though beyond-frame searches might eliminate fixation as well as bringing advancement in other aspects, the advancement in other aspects might not only depend on the enhancement in beyond-frame searches, but also be related to the enhancement in within-frame searches. Therefore, the ineffectiveness in improving novelty and variety of presenting examples in a function tree might be due to its insufficiency in enhancing within-frame searches.

Based on this discussion, defixation and advancement in other aspects seem not to share exactly the same mechanism. However, studies do not always take this into account. For instance, one study showed that presenting partial photo examples reduced fixation compared with full photos. The part presented was selected to contain rich information. Rather than the richness of the example, partial information affected the way of information processing and then broke the path of least resistance. This was proposed as the mechanism in providing incomplete information in defixation (Cheng et al., 2014). However, this result is arguable since the effectiveness of incomplete examples for defixation was indicated by showing an improvement in originality rather than measuring how fixation was influenced. In other words, such measurement was not able to distinguish whether this increase in originality was due to a search beyond or within the frame constructed by the given information. In traditional discussion of fixation, fixation is usually considered to be an inhibitory factor in problem solving. Therefore, successful defixation is commonly treated as an enhancement in problem solving performance. Specifically, in solving problems with specific answers (i.e., closed-ended problems), as relaxation of fixation leads individuals to successfully solve the problem, it is rational to claim that measuring the solution rates is sufficient to reflect how fixation is influenced by the intervention. Nevertheless, results of studies involving open-ended problems indicated that such a relationship might not always be true (e.g., Cardoso and Badke-Schaub, 2011; Tsenn et al., 2014; Atilola and Linsey, 2015; Moreno et al., 2016). Importantly, the solution to an open-ended problem is not limited to a specific answer, and the expected solution to an open-ended problem varies according to the aim of the particular study. This means that successful defixation might not necessarily direct an individual to generate an expected solution. Therefore, neither claiming the effect of defixation by measuring items related to aspects which are expected in a solution, such as variety, novelty, or originality without considering items related to fixation (e.g., Wilson et al., 2010; Cheng et al., 2014; Smith et al., 2017), nor by only measuring fixation without a discussion of expected aspects to show further effects (e.g., Viswanathan et al., 2014) is sufficient. Instead, the inclusion of measurements of both fixation and advancement in items that are expected in specific studies, such as creativity related items, is essential for examining the effects of a defixation approach.

Besides modifying the source of fixation (i.e., the example), other approaches are also examined, such as incubation. Specifically, in a study which investigated the effect of a two-day incubation, results revealed that incubation did contribute to overcoming the influence of an example solution by showing a decrease in the number of features copied from the example and an increase in variety of ideas generated on the second day. However, based on results which reported that participants still repeated many ideas from the first day after the incubation, it claimed that neither the forgetting hypothesis nor the set-breaking hypothesis, which suggests that the incubation period provides a chance to depart from initial ideas, could explain these results (Tsenn et al., 2014). Considering the source of fixation, an example solution was misleading information provided by an experimenter. The decay in the influence of the information given could occur during the two-day break, and this decay allowed a search

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beyond the frame constructed by the trigger example given, as the study reported a decrease in features copied and an increase in variety. Meanwhile, the ideas generated on the first day might also have involved problem information-related memory, such as prior knowledge related to the given problem. Therefore, the decay effect of incubation might not be applicable in decreasing repetition of the first-day ideas. Further, in a study which failed to show the incubation effect in diminishing the fixation induced by a given example, an inappropriate incubation task and the presentation of examples during the incubation period were proposed as an explanation (Cardoso and Badke-Schaub, 2009b). This is consistent with a study which suggested the forgetting theory, showing that incubation was ineffective when problems kept being presented during incubation (Kohn and Smith, 2009). In a more general setting, Kohn and Smith (2011) confirmed the incubation effect by revealing that the categories and number of ideas generated were enhanced after taking a break, and the forgetting hypothesis was proposed as the mechanism of the incubation effect in overcoming fixation induced by ideas of others. Nevertheless, as fixation was not measured in this study, it is difficult to identify whether an increase in categories and numbers of ideas was due to a search that broke the frame constructed by others' ideas or a search that was expanded within this frame.

Similar to that examined in studies involving closed-ended problems, the effect of providing feedback is also examined in open-ended problems. As the answer in open-ended problems is uncertain, instead of providing information as feedback to explicitly show whether the attempted solution is correct or wrong, offering extra information by externalizing the generated ideas through building and testing physical models was examined for defixation (Viswanathan et al., 2014). Results confirmed that instant feedback that was received from the process of building and testing successfully inhibited the negative effect of examples by helping individuals to realize the flawed features of a given solution. Unfortunately, it is still unknown whether building physical models contributes to other aspects, such as creativity, as there was no extra measurement. Specifically, though providing feedback was effective in defixation by helping individuals to reflect and then to realize the fixated concept in solving closed-ended problems (Neroni and Crilly, 2021), as there is no certain answer for open-ended problems, realization of fixation does not necessarily lead an individual to break the frame constructed by fixated concepts, a further step, such as the construction of a new perspective, is essential (Okada and Ishibashi, 2017; Wang et al., 2022). Therefore, further studies including both a discussion of fixation and other aspects that are related to the aim of study are necessary.

4.2.4. Defixation approach for fixation induced by problem information-related memory in open-ended problems

As the majority of the studies of design fixation focused on example (i.e., the fixation induced by misleading information), few studies investigated how to overcome fixation induced by problem information-related memory. Among these studies, Moreno et al. (2016) utilized service design problems, which is design that does not involve any physical commodity, to examine the effects of two defixation techniques developed on the basis of analogy. The results indicated that the WordTree, which is a technique involving representational change and expansion of search space, reduced fixation and increased the novelty of ideas generated. In contrast, SCAMPER, which is a technique that instructs individuals to Substitute, Combine, Adapt, Modify, Put to other uses, Eliminate and Reverse to direct an analogical search, showed the highest level of novelty even though there was no effect on defixation. Based on previous discussion on the search range, the defixation and improvement in novelty achieved by WordTree could be considered to be a result of the enhancement of beyond-frame searches, as this technique commits to prompting representational change. In contrast, as SCAMPER allows the repetition of procedures of the search followed by instruction, the fixation was considered to be strengthened in these repetitions. In terms of search range, though SCAMPER was also suggested to involve the expansion of search, this technique might be sufficient to expand the search within a certain frame rather than the search beyond the frame.

In a more general setting, similar to the mechanism of effective defixation shown in these techniques, restructuring is also indicated to be a mechanism of incubation effect in overcoming the fixation induced by problem information-related memory in open-ended problems. Specifically, based on results which revealed that switching task was only effective in enhancing the novelty of generating the idea from a flexible category rather than a stable category, it clarified that incubation was effective by restructuring rather than decaying (Smith et al., 2017). Although it was not reported how fixation was influenced in this study, in a study which verified the timing of switching task, this mechanism was confirmed by showing the same results with the measurement of fixation. Specifically, results indicated that switching tasks before reaching an impasse was found to contribute not only to reducing fixation, but also to enhancing flexibility and novelty of the ideas generated (Lu et al., 2017). Further, in a study which revealed that the later the participants switched to a main task-related incubation task at their own discretion, the better they performed in creativity tasks. Opportunistic assimilation theory, which suggests a restructuring of existing attempts by encountering new information with the emphasis on the status of reaching an impasse, was proposed as the mechanism of the incubation effect (Madjar et al., 2019). According to the discussion of impasses in closed-ended problems, it is suggested to examine the defixation effect of encouraging individuals to reach an impasse, since an impasse relates to critical cognitive processes related to defixation, such as reflection. However, this is especially difficult in solving open-ended problems. Though an impasse is usually used as an indicator of the status of being fixated in solving closed-ended problems, as it is measurable, it might not be reported or even observed in solving open-ended problems. Specifically, because there is no certain answer in open-ended problems, instead of failing to solve the problem and feeling stuck because of not being able to find the correct answer, an open-ended problem may still be solved by submitting an answer with poor performance, such as a solution with low creativity. In the light of this notion, a study which allowed individuals to externalize ideas to reflect and realize fixation by testing ideas which copied flawed features of an example solution (Viswanathan et al., 2014) is an instance of overcoming the fixation induced by misleading information by prompting the status of an impasse. For the relaxation of the fixation induced by problem information-related memory, creating an environment that is designed to force individuals to reach an impasse by inhibiting the accessibility to the source of fixation is effective in defixating and increasing creativity in drawing, which is a kind of open-ended problem solving (Wang et al., 2022). In this study, for example, participants were required to color a given picture while wearing red-tinted sunglasses. The red sunglasses functioned as a filter, impeding participants' visual perception and consequently inhibiting their ability to access prior knowledge of color when attempting to color the given picture. In such an environment, the study found that participants began to engage in reflection on color, leading to a decrease in the retrieval of prior knowledge of color. Further, when an instruction on the concept of fixation along with a reflective session was provided after the coloring task, defixation was achieved through critical reflection, and a subsequent enhancement in drawing creativity was observed.

Actually, reflection is claimed to be an approach that expert designers usually take to overcome fixation (Crilly, 2015). Though fixation is a universal phenomenon that challenges everyone, including experts (e.g., Bonnardel and Marmèche, 2004), studies also revealed that experts behaved differently from novices. For instance, in a study involving chess problems, though both expert and novice players were reported to be constrained by fixation induced by misleading information, experts could gradually disengage their attention from the solution which fixated them (Sheridan and Reingold, 2013). In solving open-ended problems, for instance, Bonnardel and Marmèche (2004) investigated the influence of expertise level on the effect of examples in design problem-solving. Specifically, they found that though both novices and experts were constrained by problem information, when examples were presented, experts demonstrated not only greater sensitivity to these examples but also engaged in beyond-frame searches, irrespective of whether the examples belonged to the same conceptual domain as the target or not. In the light of this notion, studies attempted to apply approaches that are used by experts to novices for defixation. For instance, interaction is proposed as an effective approach by experts. Though study showed that individuals are fixated by ideas generated by others in general idea generation during brainstorming (Kohn and Smith, 2011), rather than simply acquiring ideas from others, Okada and Ishibashi (2017) examined the effect of an in-depth interaction with the external world, which is an approach taken by artists in their conceptualization of artwork (Takagi et al., 2013), on mitigating the constraint of realism, which is the fixation induced by problem information-related memory in novices' drawing. Specifically, it confirmed that defixation and enhancement in creativity could be achieved either by prolonged appreciation or imitation of artwork in an unfamiliar style rather than artwork in styles already familiar to the participants. In terms of the search range, artwork in unfamiliar styles provided art novices with an opportunity to expand their range of search beyond the frame constructed by their prior knowledge in drawing. In support of this perspective, Okada and Ishibashi (2017) also identified achievement in representational change (i.e., beyond-frame search), as the mechanism underlying this defixation effect. Further, considering the status of impasse, similar to creating an environment that inhibits the accessibility of prior knowledge (Wang et al., 2022), interacting with artworks of an unfamiliar style, which is a style that is difficult to match to stored knowledge, could also be viewed as a way of directing individuals to reach an impasse to trigger cognitive dissonance for reflection. However, the intervention provided in these studies is more likely to be described as offering an opportunity to encounter or perceive the external world. None of them involved a reciprocal interaction as there was no feedback. Therefore, further studies on interaction with a focus on active feedback might contribute to developing an effective defixation approach to overcoming fixation induced by problem information-related memory.

Defixation in open-ended problems involves multiple aspects. Similar to what has been discussed in the section on closed-ended problems, the enhancement of a search beyond the frame constructed either by misleading information or problem information-related memory is essential for an effective defixation approach. Specifically, defixation can be achieved not only by approaches which are designed to directly expand the search range, but also by approaches which aim to develop triggers for expanding the search range. When the frame is constructed from misleading information, approaches which allow the influence of the information given to decay, encourage individuals to reflect, and directly contribute to expanding the search range, are shown to be effective. Approaches that prompt reflection and enhance the expansion of the search range, are also effective in enhancing a search beyond the frame constructed by problem information-related memory. However, as there is no certain answer to open-ended problems, more issues are considered. In closed-ended problem solving, defixation leads to an improvement in solution rates, which is the expected result. Similarly, when successful elimination of fixation in open-ended problems is accompanied by an improvement in aspects that are expected in the solution of the problems in different studies, such as creativity, the enhancement of a beyond-frame search is sufficient to achieve effective defixation. However, defixation and advancement in other aspects do not share exactly the same mechanism. Successful defixation (i.e., enhancement of beyond-frame searches) does not necessarily cause an improvement in other aspects. In other words, defixation cannot guarantee the production of expected solutions. Even though no beyond-frame search is enhanced, an advancement in other aspects could still be achieved as long as there is an expansion within the existing frame. This conclusion is supported by a study conducted by Boudier et al. (2023), which suggested that experts in the evaluation of design ideas either contribute to the development of a design solution within the frame constructed by the initial idea, or to the engagement in defixation by initiating alternative solutions beyond the existing frame. Accordingly, to ensure the effectiveness of the defixation approach to open-ended problems, an examination of the influence on both fixation and the measures that are related to the aim of the specific study is necessary to identify whether there is an enhancement in beyond-frame searches or within-frame searches.

5. Discussion

With the intention of contributing to the development of an effective defixation approach for enhancing creativity, we have reviewed empirical studies examining how fixation is induced and how fixation is eliminated on the basis of the axis of the source of fixation and problem type.

The review indicates that the mechanism of fixation induction is influenced by the source of fixation, and the way of overcoming fixation varies according to both the source of fixation and the problem type (Figure 1). Specifically, in the process of solving problems, when misleading information is given, such as newly learned solutions and cues which impede problem solving performance, fixation is induced by the interaction of the memory related to misleading information, the perception and the attention to information that is related to activated memory of misleading information. In contrast, when there is no misleading information, fixation might still be induced by long-term memory which is activated by information about the problem due to its retrievability and recency. To overcome fixation induced in the process of problem solving, the key is to enhance a search which can break the frame constructed either by misleading information or problem information-related memory. Specifically, when fixation is induced by misleading information, approaches which allow the influence of misleading information to decay, encourage individuals to reflect, or directly contribute to expanding the search range are effective in enhancing beyond-frame searches. When fixation is induced by problem information-related memory, approaches prompting reflection and expansion of search range are effective. However, in contrast to closed-ended problem solving, in solving open-ended problems, successful defixation does not necessarily lead to an improvement in aspects that are expected in solutions in certain studies, such as creativity, and an improvement in other aspects can still be achieved by the enhancement of the search within the existing frame. Therefore, examining how fixation as well as how the expected aspects are influenced is essential for developing an effective defixation approach for open-ended problem.

This proposal is especially critical for fostering creativity. Firstly, defixation is shown to be effective in increasing the solution rates of solving closed-ended problems. When a closed-ended problem involves creativity, such as the RAT problem, it is reasonable to claim that enhancing a beyond-frame search, which is sufficient for defixation, is viable for prompting creativity. In contrast, though a beyond-frame search is effective in overcoming fixation in solving open-ended problems, defixation does not necessarily achieve an advancement in creativity, and creativity might still be enhanced if there is an enhancement in within-frame searches. Accordingly, instead of claiming the effect on creativity by showing the elimination of fixation, clarifying the effects on both of fixation and creativity is necessary for ensuring the effectiveness of defixation approach in prompting creativity in solving open-ended problem.

To develop an effective approach to overcoming fixation, besides the future research suggested in previous discussions, some more issues should be considered due to the limitations of the present review.

Firstly, as shown in Table 1, most studies focused on closed-ended problems and fixation induced by misleading information in open-ended problems. However, dealing with fixation induced by problem information-related memory in open-ended problems is a critical issue in education. Specifically, though knowledge acquired in previous educational practice is the foundation for learning new knowledge, it might also be a fixation that restrains performance in solving problems which require an atypical perspective (Chesney et al., 2013). Therefore, how to effectively utilize the prior knowledge, which is memory activated by information about a problem, without the fixation effect is an important issue in education. Further, this becomes particularly crucial for cultivating individuals who are capable of dealing with unpredictable problems with ambiguous answers in a changing future. Accordingly, it is suggested that more studies should be conducted on internally induced fixation in open-ended problems.

Further, though the present review has examined studies involving fixation induced by misleading information and problem information-related memory, there is fixation involving both of these two sources. For instance, in a study conducted by Viswanathan and Linsey (2013a,b), the influence of the timing of using different materials to test ideas was examined, and it was reported that whether or not the type and use of materials influenced the level of fixation. This study has often been cited as research which revealed the mechanism of fixation induction as a sunk-cost effect. However, considering the source of fixation, the fixation investigated in this study involves both of the two sources: knowledge of different materials, which might be considered to be misleading information that was provided by the experimenter, and memory activated by problem information. Further, the mixed source of fixation is also mentioned in this review (e.g., Tsenn et al., 2014). As the effect of defixation is influenced by the source of fixation, studies on mixed sources of fixation are indispensable for developing an effective approach for defixation.

Moreover, personal difference is another well-studied factor that is found not only to influence the effect of the defixation approach but also affect the level of fixation. For instance, an individual's visuospatial skills significantly affect the effectiveness of defixating by physical interaction in solutions (Vallée-Tourangeau et al., 2011). Further, an individual's preference for complexity and symmetry predict the ability to overcome fixation (Kharkhurin and Yagolkovskiy, 2019), while preference for cognitive simplicity and structure predict the level of fixation (Schultz and Searleman, 1998). To develop an effective approach to defixation, a discussion of personal factors which influence the level of fixation and the effectiveness of defixation might be helpful.

Finally, a study which reported that individuals were fixated by the ideas of others during brainstorming (Kohn and Smith, 2011) has been discussed in the present review. However, another study also revealed that working in pairs contributed to overcoming fixation (Okada and Simon, 1997). The reason for these contradictory results is that the discussion about the influence of the ideas of others was conducted at a level that considered individuals, rather than pairs, as the cognitive system. In terms of defixation, experts proposed interaction as an effective approach (Crilly, 2015). However, the studies on interaction that have been discussed in the present review are more likely to be considered to provide opportunities for individuals to encounter new information (e.g., Vallée-Tourangeau et al., 2011; Okada and Ishibashi, 2017). To obtain an understanding of the effect of reciprocal interaction in defixation, further discussion which takes pairs or groups as the cognitive system is necessary.

Although further discussions should be conducted to obtain a more comprehensive view, the present review offers a systematic understanding of empirical studies of fixation and defixation by establishing the axis of fixation source and problem type. Particularly, in terms of overcoming fixation to enhance creativity, the present review not only indicates the significance of the two axes, but also reveals critical issues that should be considered in developing an effective defixation approach.

Author contributions

SW and TO contributed to the conception of the study. SW conducted the review and wrote the first draft of the manuscript. TO and KT provided suggestions for the modification of the draft. All the authors contributed to manuscript revision, and read and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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