Trial and Error Mindset of R&D Personnel and its Relationship to Organizational Creative Climate

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Abstract:

This paper aims to reveal the mindset of corporate R&D personnel's behavior when they break through a difficult problem. In addition, we examine the relationship between that mindset and the organizational creative climate. We defined trial and error behavior as the process of continuous knowledge creation and acquisition until success is achieved, and constructed a model. We distributed a questionnaire survey on invention and discovery activities to 706 corporate R&D personnel who had received awards from leading Japanese science academies. The results of qualitative data analysis revealed six mindsets and approaches: (i) Elimination approach, (ii) Idea exploration-oriented mindset, (iii) Cause exploration-oriented mindset, (iv) Repetitive approach, (v) Passion for trial and error, and (vi) Experience-oriented mindset. In addition, the results showed that the creative climate did not have a significant impact on the exploration-oriented trial and error mindsets of R&D personnel, such as with (ii) and (iii). Technology-oriented firms cannot develop innovative achievements if they are not willing to encourage risk taking. Our findings indicate that managers should try to understand their employees' trial and error mindsets and create an effective organizational climate that goes beyond an organizational creative climate.

Keywords: R&D management, trial and error behavior, organizational creative climate

1. Introduction

Innovative achievements such as inventions and discoveries of new things by R&D personnel are very important for corporate growth. To encourage and forecast these achievements, it is necessary to understand the activities of R&D personnel [1-2]. Two analytical perspectives are dominant in academic research in terms of understanding the activities of R&D personnel; one is concerned with individual behavioral mechanisms [3], and the other with the organizational environment that affects individual behavior and the absorptive capability of knowledge [4]. In the process of invention and discovery, R&D personnel often face difficult problems that they need to overcome. Regarding individual behavioral mechanisms, studies have been conducted on R&D personnel's personal inspirations [5], intrinsic motivation [6-7], cognitive types [8], and serendipity [9] as factors contributing to the ability to discover important things by accident. However, few studies have been done that focus on the detailed activities of R&D personnel, including their everyday trials at work, regardless of the importance of understanding individual behavioral mechanisms.

R&D management studies have recently emphasized the importance of managing R&D personnel's trial and error activities [9-11], which consist of detailed tasks of R&D personnel. In Webster's dictionary, trial and error is "a finding out of the best way to reach a desired result or a correct solution by trying out one or more ways or means and by noting and eliminating errors or causes of failure and also means the trying of one thing or another until something succeeds." The concept of trial and error includes the process of knowledge creation to find the key knowledge that can lead to a breakthrough. This indicates that the concept of trial and error is a kind of knowledge creation that includes repetitive actions carried out to reach a breakthrough. This paper focuses on the concept of trial and error and defines it as a continuous knowledge creation and acquisition process until something succeeds.

Many aspects of the organizational environment have been studied to determine the important catalysts that influence R&D personnel's behavior. These aspects include leadership [12-14], circumstances that influence R&D personnel, such as the organizational climate affecting the behavior of personnel [15-21], having a team leader [22], and corporate systems implemented to improve R&D personnel creativity [23]. In addition, the importance of team communication [24-26] and closeness of partners [27] is also widely acknowledged in research on factors leading to breakthroughs. These studies are valuable for analyzing the relationship between organizational factors and R&D personnel output. However, there is a need to further analyze organizational factors and detailed trial and error activities of R&D personnel in order to forecast an effective people management strategy in R&D settings.

Based on this background, we set two research questions to promote R&D management research focusing on generating innovative achievements. The first question was intended to determine what kind of mindset highly successful R&D personnel had when carrying out trial and error activities. The second one was intended to determine to what extent organizational factors including the organizational climate and the corporate system affected R&D personnel's trial and error behavior. The purpose here is to answer these questions. We set two research perspectives: trial and error behavior and the organizational creative climate. This paper first proposes a model of trial and error behavior based on knowledge creation behavior. Next, we analyze a questionnaire survey we distributed based on the model to find the reality of the trial and error mindset of accomplished corporate researchers who had made valuable inventions and discoveries. Then we analyze the relationship between R&D personnel's mindsets and organizational creative climate using structural equation modeling analysis.

2. Research perspectives

2.1 Trial and error behavior

Although trial and error behavior is relevant to the concept of knowledge creation, the relevant study focusing on corporate R&D personnel is in an early phase of academic research [9]. In general, researchers have expert knowledge and experience, and this includes tacit knowledge to "connect" their knowledge and experience. In problematic situations that the researchers have already dealt with, they often try to solve the problems using their existing experience and knowledge [28-30]. However, if researchers face a problematic situation that they have never experienced before, they need to carry out trial and error activities outside their realm of experience and knowledge.

Gourlay [31] addressed the concept of knowledge creation by organizing knowledge types using previous studies about knowledge concepts. He categorized knowledge by 'knowledge-what' as decontextualized knowledge and 'knowledge-how' as processual knowledge. In R&D settings, trial and error regarding knowledge-what corresponds to cause investigation. This means that researchers seek to generalize decontextualized knowledge by investigating the bottleneck of the problematic situation from various perspectives. In contrast, knowledge-how corresponds to exploring research methods or approaches. This means that researchers seek process-oriented knowledge [32] by searching for ways and strategies to improve the problematic situation. The quality of both types of knowledge depends on the definition of problematic situations. Learning has dealt with incremental improvements to adapt to an environment in technology management studies [33-36]. Argyris and Schon indicated the importance of problem definition using the term double-loop learning [37] when adapting to or creating an environment. As we already defined, trial and error is a process of continuous knowledge creation in which it is necessary to sophisticate a kind of "space" of thoughts consisting of knowledge and experience that a person already has. These studies about knowledge creation were the basis for three behavioral points we set that illustrate how to cross the knowledge space that someone already has: cause investigation, method and approach exploration, and problem definition.

Researchers generally aspire to achieve a goal using their own experiential knowledge and new knowledge gained through trial and error under the proper balance of three behavioral patterns [28]. This consists of four basic behaviors: implementing an idea with no specific strategies, exploring new approaches and implementing them, exploring new causes and trying to overcome hurdles, and exploring new causes and new approaches and implementing them. Researchers conduct these basic behaviors again and again, thereby creating knowledge. These strategies to traverse one's own known space lead to several potential types of trial and error. For example, one researcher may aspire to achieve a goal using their own experiential knowledge and new knowledge acquired through the trial and error of cause investigation and problem definition. Another researcher may aspire to achieve a goal by using their own experiential knowledge and new knowledge gained from the trial and error of method exploration and cause investigation under the same problem. The important points of trial and error behavior are related to retaining or changing existing ideas and exploring approaches for problem solutions or the cause of the problem. Thus, the ways of trial and error will differ depending on how the set of trial and error strategies was determined.

2.2 Organizational creative climate

The belief that a positive organizational climate is an important factor of success in R&D companies is widely accepted (e.g.[15]). Organizational climate is defined as an attribute of the organization—a conglomerate of attitudes, feelings, and behaviors that characterize life in the organization [16-17]. The concept of organizational climate refers to behavioral patterns that emerge on a daily basis in the organizational environment. Individuals in the organization experience, understand, and interpret these patterns [20,38]. Therefore, individuals can be affected by the climate and can change their motivation and behavior.

It is generally important for a company to form a positive organizational climate in which employees work together and strive to achieve a common organizational goal, such as to outperform the competition [39]. In industry, many companies have introduced “work team” and “quality control” activities to promote a collaborative mindset among their employees [40] and have worked to create a positive organizational climate. However, more importantly, there is a need to create an organizational climate that stimulates individuals’ intrinsic motivation, which refers to doing something because it is inherently interesting and enjoyable [41]. This factor relevant to human emotion is thought to affect individual creative behaviors that will lead to innovative performance [42-44]. One study on organizational climate discussed the concept of the creative climate that has an organizational influence on human creativity [45] and innovativeness [46]. The impacts of a creative climate on workload have been reported to be both positive and negative [45]. However, especially in R&D settings, creativity is an important resource and therefore, the relative organizational climate assumed to be deliberately created [20]. The majority of studies on organizational creative climate in the workplace have focused on the relationship between leadership and climate creation [47-48]. Although there are several important factors that influence employees’ behavior and behavioral changes, there are few insights into what effects the climate has on R&D personnel’s trial and error behavior. This paper analyzes the effect of organizational creative climate on R&D personnel’s trial and error behavior.

3. Methodology

3.1 Sample and data collection procedures

The targets of our investigation were corporate R&D personnel who had received awards from 15 Japanese science academic societies in fields including physics, hardware building, chemistry, software, medicine, electronics, and automotive hardware. We asked our targets about the process they used to achieve their award-winning outputs, a few examples of which are the development of an aluminum-magnesium alloy, new insights on the dependence of threshold voltage on back-gate voltage, and the use of a superconducting detector array for terahertz imaging applications. We selected 706 targets starting in 2008 and going back as much as three years earlier. Our questionnaire was an anonymous mail-in survey and was administered from July 11, 2008 to August 1, 2008. We circulated 706 copies and received a total of 442 answers (return rate: 63%). We had 26 invalid responses that had blanks in trial and error related questions.

The respondents we obtained data from comprised 55 hardware-oriented basic research (13.2%), 211 hardware-oriented applied research (50.7%), 25 software-oriented basic research (6.0%), 88 software-oriented applied research (21.2%), 3 service-oriented basic research (0.7%), and 24 service-oriented applied research (5.8%). The remaining 10 respondents (2.4%) did not respond to the question about research type.

3.2 Questionnaire items

3.2.1 Trial and error behavior

We designed the questionnaire items as listed in Table 1; they consisted of questions concerning trial and error, the creative climate of the workplace, the workplace environment focusing on the corporate system, management clarity, and details about their personal characteristics based on Fowler [49]. We measured the R&D personnel's trial and error behavior from two perspectives; one was general trial and error, and the other was breakthrough behavior just before achieving an invention or discovery. This is because in R&D activities, some trial and error activities are routine [50-51], and we assumed that there might be other patterns that were different from the routine trial and error behavior. We created questionnaire items based on the trial and error behavior model. A Likert type four-point scale was used for the answers.

We attempted to gain an understanding of general trial and error behavior by estimating the ordinary R&D personnel's “newness-oriented mindset.” We did this by asking them questions about what new things they did to improve frequently occurring problem situations from the two perspectives of cause investigation and method exploration (e.g. "We would like to ask you questions about your attitudes when you face some problems and difficulties in the process of R&D. Please choose the most suitable answer for each of the following items..."). We listed items about “everyday newness-oriented mindset (GTE 9 and 10)” and set several hypothetical constraints on each question such as having a tight time restriction (GTE 1 and 7), already experiencing a lot of failures (GTE 2 and 8), facing issues they had no experience with (GTE 3 and 6), and having interest or motivation (GTE 4 and 5).

To understand their breakthrough behavior just before achieving an invention or discovery, we estimated the R&D personnel's newness-oriented mindset when they achieved discoveries and inventions. We asked them questions about what they did just before their achievements from the cause investigation and method exploration perspectives. The questions include following form that "We would like to ask you questions about what kinds of behavior you exhibited when solving the most difficult problems in the process of generating the output that led to your academic award. Please choose the most suitable answer for each of the following items..." We listed items about newness-oriented actions for breakthroughs (BTE 9, and 10) and set hypothetical responses on each question such as reconsideration of what they had already tried (BTE 4 and 5), repetition and confirmation of trial results (BTE 1 and 2), avoidance of previous trials and errors (BTE 3 and 6), and avoidance of exploring new causes and methods (BTE 7 and 8).

3.2.2 Organizational creative climate

Our first step in investigating the organizational creative climate was to translate the questions from Sundgren et al.'s [20] study into Japanese. The questions, listed in Table 1, are based on a clear constructive concept and are recognized as factors leading to innovation; therefore, we determined that it was possible to conduct a detailed analysis using the results from the questions (e.g. "We would like to ask you questions about your organizational climate. Please choose the most suitable answer for each of the following items...").

In addition, we also set relevant questions about the workplace environment and management clarity using questions from a work motivation survey by the Japan Information Technology Services Industry Association (e.g. "We would like to ask you questions about your organizational system. Please choose the most suitable answer for each of the following items..."). The questionnaire items on organizational factors including creative climate are also listed in Table 1.

3.2.3 Performance level

We set a question about performance level as one of the face sheet items. Because we searched for targets based on information about award winners in academic societies, it was necessary to know what impact the output had on the company's growth. We partly employed a study that included new product performance and market entry as performance measures [52] to reflect the dimensions of performance. In addition, we used the categories of “efficiency” and “effectiveness” that have been widely used [53]. Efficiency includes cost reduction and productivity improvement, while effectiveness includes the capability to acquire new technologies. Thus, we added the following question and answer: When you achieved your research output, what effect did it have on your company? (Product and service sales improvement / Organizational transformation / Improvement of QCT and productivity / New business creation / Did not have any effect / Other).

3.3 Data analysis

To analyze the data effectively, we eliminated questionnaire items that had no response data. This resulted in 416 usable samples. First, we conducted an explorative factor analysis (Principal factor method, Promax rotation) to determine the mindset of R&D personnel in their trial and error behavior. Then we focused on R&D personnel in small R&D groups. In this paper, we refer to a previous study on small R&D team management [9], and we define a small R&D group as a group that has from two to five people. This is because O’Connor and McDermott [54] indicated that successful R&D teams were often composed of a rather small (5-6) group of members through their longitudinal investigation of radical innovation cases. In addition, they found there are a number of organizational factors that leverage the human side of making radical innovations happen. Therefore, we assumed organizational factors closely affect R&D personnel’s trial and error behaviors. We carried out a structural equation modeling analysis and analyzed the relationship between the trial and error mindset of R&D personnel and the organizational factors of their workplace.

4. Results

4.1 Researchers’ mindsets for trial and error

Table 2 lists the results of the explorative factor analysis of corporate R&D personnel. We obtained six factors. These factors include both mindsets and approaches for continuous knowledge creation.

- Factor 1: Elimination approach

  This factor includes eliminative statements for R&D activities such as "did not try to search" and "did not try to think"; therefore, we defined it as an "Elimination approach" toward problem solution.

- Factor 2: Idea exploration-oriented mindset

  This factor includes the contents of a new idea generation mindset for achieving breakthroughs (e.g., I value new ideas to improve problems more than established methods); therefore, we defined it as "Idea exploration-oriented mindset" for R&D activities.

- Factor 3: Cause exploration-oriented mindset

  This factor includes the mindset of cause exploration for breakthroughs (e.g., I searched for the causes that needed to be reviewed from the causes that I had already considered); therefore, we defined it as "Cause exploration-oriented mindset" for R&D activities.

- Factor 4: Repetitive approach

  This factor includes the statements of repetitive action for improving problematic situations (e.g., I repeated implementing a plan that I had practiced); therefore, we defined it as the "Repetitive approach" toward problem solving.

- Factor 5: Passion for trial and error

  This factor refers to R&D personnel's strong motivation for achieving breakthroughs (e.g., Even if I have experienced failures, I often continue to analyze the cause that I am focusing on with no hesitation); therefore, we defined this as "Passion for trial and error."

- Factor 6: Experience-oriented mindset

  This factor refers to the mindset of applying experience to solve a problem (e.g., When I face a problem for the first time, I consider a strategy to solve it using my own experience and knowledge); therefore, we defined this as an "Experience-oriented mindset" for R&D activities.

In summary, we extracted six factors from the survey results obtained from high-achieving R&D personnel: the Elimination approach (F1), Idea exploration-oriented mindset (F2), Cause exploration-oriented mindset (F3), Repetitive approach (F4), Passion for trial and error (F5), and

Experience-oriented mindset (F6). The correlation between factors indicated that "F1 and F4" have a relatively weak correlation (r=0.38). Because both F1 and F4 concern an approach to research, the weak correlation is considered to be valid. Similarly, "F2 and F5" and "F3 and F5," which concern the researchers' mindsets, also reveal a weak correlation ($r_{2,5}$=0.30, $r_{3,5}$=0.24). The inverse correlations between "F1 and F2" ($r_{1,2}$=-0.27) and "F1 and F3" ($r_{1,3}$=-0.26) indicate the difference between decreasing options (elimination) and increasing options (exploration). Of the others, we found that each factor was nearly independent.

We output factor scores based on the factor analysis and then conducted an analysis of variance (ANOVA) between factor scores and research types, as indicated in Table 3. There were six R&D categories: hardware-oriented basic R&D, hardware-oriented applied R&D, software-oriented basic R&D, software-oriented applied R&D, service-oriented basic R&D, and service-oriented applied R&D. The results of the ANOVA revealed that all p-values were over 0.05. For example, the ANOVA result for F1 revealed a p-value of 0.22. All p-values over 0.05 means there were no statistically significant differences in any of the six categories. This means that the mind and action of trial and error did not depend on the R&D category.

Table 4 lists the results of the ANOVA between factor scores and output levels. Some differences between output levels were found for F1, F2, and F4 (F1: 3.403 ($p<0.01$), F2: 4.809 ($p<0.001$), F4: 3.640 ($p<0.01$)). The results of Tukey's honestly significant difference (HSD) test show that there was a statistically significant difference between Improvement of QCT / productivity and New business creation. In general, new business creation requires innovative ideas and concepts as well as the thinking that generates them. Compared to the output level, an improvement in QCT / productivity requires more incremental thinking such that people try continuously to achieve small breakthroughs using conventional methods. The results of Table 4 seem to correspond to the types of output level. Those who contribute to QCT / productivity improvement are more motivated to use the Elimination approach (mean difference = 0.470). Similarly, they are more motivated to take the Repetitive approach than those who contribute to New business creation through their R&D output (mean difference = 0.398). On the contrary, the R&D personnel contributing to New business creation have more Idea exploration-oriented mindsets than those dealing with Incremental improvement (mean difference = -0.550).

4.2 Relationship between trial and error mindsets and organizational creative climate

We focused on R&D personnel belonging to small R&D groups and obtained 212 samples for analysis. This is because we considered that R&D personnel in small-sized groups might be more directly affected by the organizational climate than those in large groups.

We conducted a structural equation modeling analysis in order to analyze the effects of organizational factors on the trial and error mindset of R&D personnel and their R&D approach. We set the model shown in the upper left side of Fig. 1 as the basic model. Due to the complexity of the model, we analyzed the relationship between trial and error behavior and the organizational creative climate and other organizational factors by changing the content of "Trial and error mindset of R&D personnel." The factors of "Trial and error mindset of R&D personnel" correspond to the factors of the three mindsets found through explorative factor analysis: Idea exploration-oriented mindset (F2), Cause exploration-oriented mindset (F3), and Experience-oriented mindset (F6). We analyzed the three cases according to the contents of "Trial and error mindset of R&D personnel."

We found that based on the results of GFI, AGFI, and RMSEA as shown in Fig. 1, model 1 (GFI= 0.894, AGFI= 0.861, RMSEA=0.051), model 2 (GFI= 0.879, AGFI= 0.842, RMSEA=0.059), and 3 (GFI= 0.889, AGFI= 0.854, RMSEA=0.052) are considered to be relatively well-fitted. In Fig. 1, the bold, double, and solid lines indicate statistical significance at the $p<0.001$, $p<0.01$, and $p<0.05$ level, whereas the dotted line means there was no statistical significance.

The basic model is based on the hypothesis that the creative climate of the workplace will affect the R&D personnel's trial and error mindset and their R&D efforts and motivation. In addition, we speculate that the creative climate will be affected by a workplace environment that allows R&D personnel to sufficiently exercise their potential and by the degree of management clarity based on everyday management. This environmental factor will also affect the attitudes of R&D personnel when carrying out their trial and error activities. Furthermore, we assume that the trial and error mindset of R&D personnel will affect their R&D approach and that their passion for R&D will also have an impact on their R&D approach.

As shown in Fig. 1, the creative climate is affected by workplace environment factors such as an enriched support system for career development, a reward system based on an employee's experience and continued service, and guarantees given to employees enabling them to work in R&D for many years.

However, the last factor does not seem to have a significant impact on R&D personnel's trial and error mindset. In addition, the management clarity factor does not seem to have a significant impact on either R&D personnel's trial and error mindset or on the creative climate of the workplace.

There were two significant findings regarding the impact of the organizational creative climate of the R&D organization. First, in terms of the trial and error mindset of R&D personnel, the creative climate was found to have only a significantly negative impact on the Experience-oriented mindset (path coefficient: -0.59). This means that the creative climate will affect the R&D personnel's thinking that they avoid depending on their existing experience as much as possible, whereas the creative climate does not seem to encourage R&D personnel attitudes of idea generation or cause exploration mindsets. Second, the creative climate had a relatively small impact on R&D personnel's passion for trial and error. However, the climate does not seem to have a direct influence on a worker's R&D approach. The creative climate will indirectly affect R&D personnel's R&D approach by increasing their passion for trial and error.

In terms of the trial and error mindset of R&D personnel, the "Experience-oriented mind" was found to have a significantly positive impact on both the Elimination approach (path coefficient: 0.24) and the Repetitive approach (path coefficient: 0.46). When people use the elimination approach, they need some options to practice elimination. Regarding the relationship between the experience-oriented mindset and the elimination approach, R&D personnel who have a highly experience-oriented mindset will reflect on their R&D activities to recall similar problems and collect cases that include successes and failures, thereby advancing their research. Therefore, it seems that the experience-oriented mindset has a significantly positive impact on the elimination approach. It also has a significantly large positive impact on the repetitive approach. R&D personnel often carry out the same specific tasks again and again in their trial and error activities. Therefore, it seems to be natural that those who have an experience-oriented mindset tend to apply a repetitive approach in their R&D.

As shown in Model 2 of Fig. 1, the "Idea exploration-oriented mindset" has a significantly negative impact on both the Elimination approach (path coefficient: - 0.49) and the Repetitive approach (path coefficient: - 0.54). Because the factor "Idea exploration-oriented mindset" consists of newness-oriented items that we assumed, it seems to be natural that a higher value for this mindset will lead to a decreased implementation of both the elimination and repetitive approaches. In addition, model 3 in Fig. 1 indicates that the Cause exploration-oriented mindset has no significant impact on either the Elimination approach or the Repetitive approach.

5. Implication of trial and error research

5.1 Theoretical implication

This paper investigated the mindsets of trial and error behavior that are indispensable for technological inventions and discoveries. We set two research questions to explore in this study. The first is, "What is the trial and error mindset of high-achieving R&D personnel?" and the second is "To what extent do organizational factors, including the organizational climate and the corporate system, affect the trial and error behavior of R&D personnel?"

The most important contributions to answer question 1 come from understanding the variety of trial and error mindsets of successful R&D personnel. We found in our investigation that high-achieving corporate researchers have three mindsets of trial and error behavior: an Idea exploration-oriented mindset (F2), Cause exploration-oriented mindset (F3), and Experience-oriented mindset (F6). In addition, we also found that they had strategies to achieve breakthroughs: the Elimination approach (F1) and the Repetitive approach (F4). We initially assumed that there were both new and past-oriented trial and error mindsets that consisted of defining or redefining a problem, investigating a cause, and exploring a method in the hypothetic model and assumed that there were potential types of R&D personnel based on the balance of trial and error behavior. As a result, because highly effective R&D personnel usually seem to conduct every kind of trial and error behavior regardless of the type of research they are involved in, we had difficulty clearly identifying the potential types.

Regarding the second research question, the results of structural equation analysis revealed that the creative climate and other organizational factors did not have a significant impact on R&D personnel's exploration-oriented mindset. Members of small groups are more directly affected by the organizational climate compared with other group sizes [54]. Previously, the creative climate has been considered to be a factor that encourages R&D personnel's innovative behavior (eg. [17,20,45]). However, our results revealed that the creative climate functions as a catalyst to help R&D personnel refrain from doing things that they have already done rather than cultivating the mindset to explore new things. We need a new perspective on the organizational climate that is effective for achieving technological inventions and discoveries. The results in this paper also showed the limitations of the organizational creative climate on affecting trial and error behavior. However, we found that the creative climate positively affects R&D personnel's motivation and passion for trial and error. This result corresponds to studies on the nature of the organizational climate [16-17,20]. In addition, the ANOVA and structural equation modeling analysis results indicate that trial and error attitudes varied depending not on research type but on output levels. For example, because a creative climate will decreasingly affect a member's Experience-oriented mindset, which seems to require the generation of outstanding QCT and productivity improvement outputs, managers and team leaders who study QCT and productivity improvement should promote experienced-based learning [55] and foster an effective organizational climate that helps R&D personnel reconsider the things they have already done.

This study broadened the areas of human behavioral studies in R&D management. Previously, R&D management studies focusing on individuals have been conducted on personal inspirations [5], intrinsic motivation [6-7], cognitive types [8], and serendipity [9]. Few studies have been done on R&D personnel's detailed knowledge creation activities including their everyday trials at work. Previous studies on the subject of knowledge management in R&D management have mainly focused on sharing expertise knowledge and organizational knowledge creation. Our study is focused on individual knowledge creation and its dynamic process. This will be a fresh perspective in R&D management.

5.2 Managerial implications

Our findings provide three practical perspectives for R&D management.

The first relates to the strategy for successful trial and error. Managers play a significant role in organizational climate creation, and therefore, it is necessary to think about promotion strategies for success-oriented creative trial and error in an organization. The results reported in this paper suggest that the creative climate that many researchers have focused on is limited in its ability to change R&D personnel's trial and error mindset. Therefore, managers should pay more attention to cultivating a newness-oriented trial and error mindset in their subordinates. One cue mentioned by Farson and Keyes [56] is that managers should manage innovation processes with less evaluation and more interpretation. We can employ this attitude in managing trial and error behavior. That is, managers should provide opportunities to interpret research findings to subordinates who are conducting trial and error activities. In fact, Table 5 presents the relationship between the source of the direct cues they received and the contents of cues that led to breakthroughs. There were three types of cue contents, and they occurred at the same rate. In terms of source of cue, data-related cues were the most common (Total 233: Observation data (145), Observed facts without evidential data (64), Literature (24)). This result is relevant to previous study about information seeking [57]. People inside the company were the second most common source of cues (Total 117: told by colleagues and junior researchers (49), told by boss (68)). The other group was people outside the company (47). These results are relevant to previous studies indicating that innovation performance in product and process can be explained using non-R&D activities including marketing [54, 58-59] and consumers' perception [60]. There are many varieties of sources; therefore, managers and leaders need to create opportunities for R&D personnel to reflect on data and provide support to researchers in communicating with different people in order to promote successful trial and error activities.

While successful trial and error exists, some trial and error has a strong relationship with failure (in other words, "give up"). Most R&D personnel usually had some confidence and felt positive thoughts towards their trial and error behavior. Table 6 summarizes our questionnaire data about R&D personnel's thoughts occurring up to the point where they generate outstanding output and the thoughts occurring when they obtain cues to create outstanding output. The table indicates that most R&D personnel had positive thoughts about their research (315 / 409), whereas a smaller number of people felt anxiety about their research (94 / 409). R&D personnel tend to conduct R&D with willpower and rigid confidence to achieve success. These data reveal the difficulties in getting subordinates to quit their trial and error behavior. Ghoshal and Bruch [61] pointed out the problem in which human willpower sometimes blinds people and hampers disengagement and suggested the stopping rule based on clear criteria as a managerial solution. There is a need to set effective criteria. However, what is more important is an explanation, that is, helping R&D personnel understand why the stopping criteria are necessary. Amabile et al. [62] indicated that creativity can be supported under specific restrictions (eg. time-pressure conditions) if people can understand the reason for restrictions. Therefore, if managers set a stopping rule, they should set it based on the R&D personnel’s mindsets of trial and error (e.g., the period of exploration activities) and explain stopping criteria effectively.

The third perspective relates to the potential target of trial and error. In the trend toward a service economy, the R&D theme will shift from a product focus to a service focus and will include an emphasis on potential customer satisfaction. Therefore, R&D personnel need to consider not only the functional value of products but also the value-in-use [63] of products. Managers and leaders should not only manage research-oriented trial and error but pay attention to establishing connections with customers and people outside the company as part of a business-oriented trial and error strategy in the future.

6. Conclusion

This paper focused on the research-oriented trial and error behaviors of high-achieving R&D personnel. We defined trial and error behavior as the process of continuous knowledge creation and acquisition until something succeeds. We created a behavioral model based on this definition and conducted a questionnaire survey to identify the mindsets behind trial and error behavior. We also analyzed the relationship between this behavior with the organizational creative climate. The results of the questionnaire survey revealed six mindsets and approaches and a unique relationship to organizational factors.

A technology-oriented firm cannot develop innovative achievements if it is not willing to encourage risk-taking. Managers should try to understand their subordinates' trial and error mindsets and create an effective organizational climate. They should also create opportunities to reflect on data and provide support to researchers in communicating with different people to promote successful trial and error activities.

One limitation of this study is that we investigated only R&D personnel who had succeeded in their inventions or discoveries and did not compare it with failure cases. Therefore, we cannot describe how different the trial and error mindsets of successful R&D personnel are from unsuccessful ones. In addition, we mainly focused on small R&D teams and analyzed the relationship between trial and error mindsets and the organizational creative climate. Therefore, our results may well accurately reflect the small group environment, as researchers in such an environment may have substantial autonomy. However, we need to expand the investigation to consider the results for large R&D teams.

The journey to understand R&D personnel behaviors leading to innovative output is long. Our model of trial and error mainly focused on scientific based R&D activities. Corporate R&D personnel need to have a scientific base and also to take part in human-oriented trial and error. Therefore, in the future we need to consider human-oriented trial and error behavior such as the behavior used in bargaining and making presentations in addition to scientific trial and error.

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Fig. 1 Result of structural equation modeling analysis

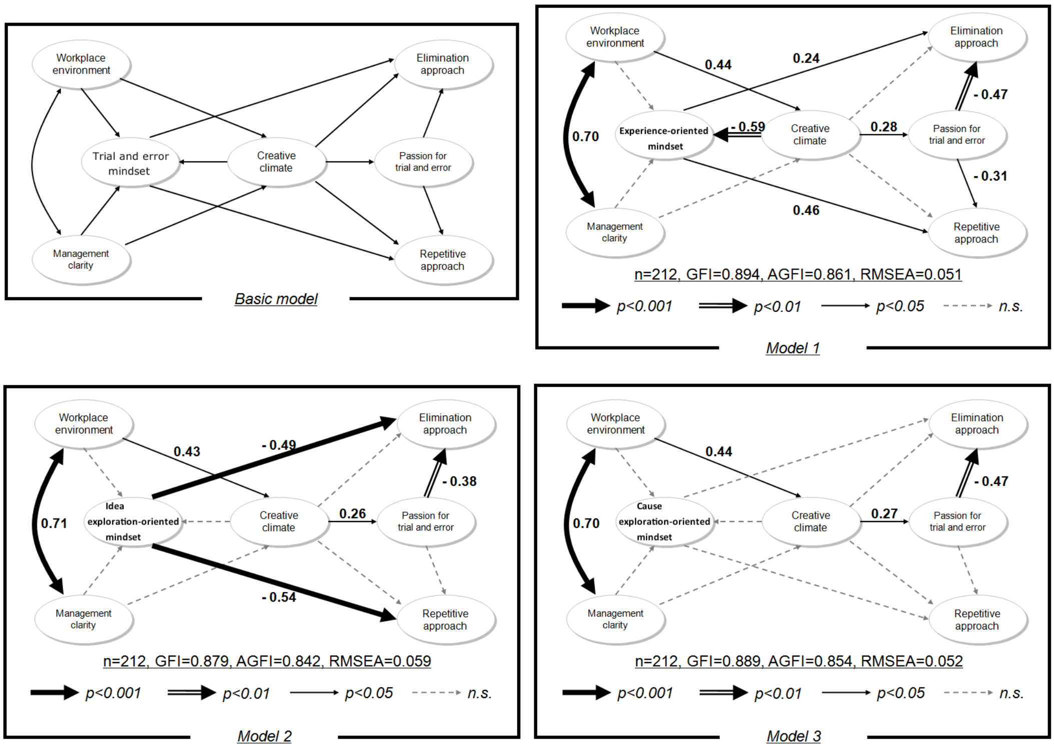

Table 1 Questionnaire items

Items	Contents
GTE1	Even if it takes a lot of time to search for a new cause that I have not yet analyzed, I will do it.
GTE2	Even if I have experienced failures, I often continue to analyze the cause that I am focusing on with no hesitation. (-)
GTE3	I consider the causes of problems without using my own experience and knowledge when I encounter problems that I have never faced.
GTE4	I search for new or different causes when I am devoted to research.
GTE5	I understand causes broadly rather than analyze a specific cause deeply. (-)
GTE6	When I face a problem for the first time, I think about a strategy to solve it using my own experience and knowledge. (-)
GTE7	I often consider an idea deeply that I have tried to apply even if it is getting close to a deadline. (-)
GTE8	I often try to practice an idea to solve a problem if I cannot get the ideal data.
GTE9	I use established methods to solve problems. (-)
GTE10	I value new ideas to solve problems more than established methods.
BTE1	I searched for the causes that needed to be reviewed from the causes that I had already considered. (-)
BTE2	I implemented a plan that I had already tried. (-)
BTE3	I did not positively explore the causes that I was analyzing.
BTE4	I repeated implementing a plan that I had tried before. (-)
BTE5	I did not try to think about the causes that I had analyzed before.
BTE6	I did not implement a plan that I had failed to achieve a breakthrough with.
BTE7	I did not try to search for causes that I had never analyzed. (-)
BTE8	I eliminated the ideas that I had never tried as targets of consideration. (-)
BTE9	I reconsidered whether there were any causes that had not been considered.
BTE10	I came up with a new idea for a breakthrough and implemented it.
CC1	I feel that the climate in the company is basically positive and encourages new ideas.
CC2	I feel that people in the company can bring up new ideas and opinions without quickly being criticized.
CC3	I feel that the company allows me to solve problems and take actions that I think are most suitable in a given situation.
CC4	I feel that there is a free atmosphere in the organization, where the seriousness of the task can be mixed with unusual ideas and humor.
CC5	I have experienced situations in which different opinions, ideas, experience, and knowledge could be discussed in projects.
CC6	I feel that the organization has a dynamic atmosphere.
WE1	I think that my company has enriched the support system for career development.
WE2	I think that my company rewards employees for their experience and continued service.
WE3	I think that my company guarantees an environment to work as R&D personnel for many years.
MC1	I clearly understand my role and objectives in my job.
MC2	I think that the company clearly sets standards to evaluate employee performance.
MC3	I think that the company communicates well with R&D personnel about their management policy.

(-) Reverse item in terms of the degree of newness

Table 2 Result of the explorative factor analysis

Items	Factor					
	I	II	III	IV	V	VI
I did not try to search for causes that I had never analyzed. [BTE7]	0.75					
I did not try to think about causes that I had analyzed before. [BTE5]	0.58					
I eliminated the ideas that I had never tried as targets for consideration. [BTE8]	0.48					
I did not accept to implement the plan that I have failed to breakthrough. [BTE6]	0.36					
I value new ideas to solve problems more than established methods. [GTE10]		0.69				
I often try to practice the just idea to solve problems if I cannot get ideal data. [GTE8]		0.49				
I came up with a new idea for a breakthrough and implemented it. [BTE10]		0.40				
I use established methods to solve problems. [GTE9]		-0.40				
I reconsidered whether there were any causes that had not been considered. [BTE9]			0.84			
I searched for causes that needed to be reviewed from the causes that I had already considered. [BTE1]			0.51			
I understand causes broadly rather than analyze a specific cause deeply. [GTE5]						
I repeated implementing a plan that I had tried before. [BTE4]				0.64		
I implemented a plan that I had already tried. [BTE2]				0.49		
I did not positively explore the causes that I was analyzing [BTE3]				0.42		
Even if I have experienced failures, I often continue to analyze the cause that I am focusing on with no hesitation. [GTE2]					0.54	
Even if it takes a lot of time to search for a new cause that I have not yet analyzed, I will do it. [GTE1]					0.36	
I search for new or different causes when I am devoted to research. [GTE4]					0.31	
I often consider an idea deeply that I have tried to apply even if it is getting close to a deadline. [GTE7]					0.30	
When I face a problem for the first time, I think about a strategy to solve it using my own experience and knowledge. [GTE6]						0.66
I consider the causes of a problems without using my own experience and knowledge when I encounter problems that I have never faced. [GTE3]						-0.49
Correlation between factors I		-0.27	-0.26	0.38	-0.21	0.02
II			0.29	-0.28	0.30	-0.11
III				-0.06	0.24	0.05
IV					-0.12	0.17
V						-0.11
Variance (%)	13.9	6.5	5.5	3.9	3.4	2.4

Table 3 ANOVA between trial and error related factor scores and research types

Factors	*df*	Sum of square	Mean square	*F-value*	*p-value*
Elimination approach (F1)	5	5.202	1.040	1.402	0.222
Idea exploration-oriented mindset (F2)	5	2.813	0.563	0.770	0.571
Cause exploration-oriented mindset (F3)	5	4.887	0.997	1.290	0.267
Repetitive approach (F4)	5	2.395	0.476	0.722	0.607
Passion for trial and error (F5)	5	2.085	0.417	0.752	0.585
Experience-oriented mindset (F6)	5	3.416	0.683	1.128	0.345

Table 4 Results of ANOVA between trial and error related factor scores and output levels (including HSD method by Tukey)

Factors	*df*	Sum of squares	Mean square	*F-value*	*p-value*
Elimination approach (F1)	5	12.163	2.433	3.403	.005
Idea exploration-oriented mindset (F2)	5	16.873	3.375	4.809	.000
Cause exploration-oriented mindset (F3)	5	7.902	1.580	2.106	.064
Repetitive approach (F4)	5	11.930	2.386	3.640	.003
Passion for trial and error (F5)	5	4.325	.865	1.575	.166
Experience-oriented mindset (F6)	5	5.440	1.088	1.804	.111

HSD method by Tukey

Factors	Group 1	Group 2	Mean difference between 1 &2 (1-2)	*p-value*
Elimination approach (F1)	Improvement of QCT / productivity	New business creation	0.470	0.004
Idea exploration-oriented mindset (F2)	Improvement of QCT / productivity	New business creation	-0.550	0.000
Repetitive approach (F4)	Improvement of QCT / productivity	New business creation	0.398	0.016

Table 5 Details of cues to breakthrough

		Source of cues						
		Told by colleagues and junior fellows	Told by boss	Told by someone outside the company	Observa-tion data	Observed facts without evidential data	Literature	Total
Contents of cues	About the cause that the R&D personnel has analyzed	12	17	9	58	26	3	125
	About the breakthrough idea that the R&D personnel had	24	30	27	58	19	13	171
	About the R&D procedures	13	21	11	29	19	8	101
	Total	49	68	47	145	64	24	397

Table 6 R&D personnel's thoughts

		Thoughts they had when they obtained cues to create outstanding output		
		I thought that my R&D activities were on target	I thought that my R&D activities were wrong	Total
Thought until outstanding output generation	If I keep on researching, I will surely achieve success	299	16	315
	If I keep on researching, I do not know whether I will achieve success	71	23	94
	Total	370	39	409