Analysis of the Cognitive Processes Underlying Discussions in Complex Problem Solving

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Abstract. The efficiency of solving complex problems in groups determines the productivity of a society. Existing guidelines for these collaborations are action-focused, and the few cognitive-oriented ones require time and training to be executed accurately. This research aims to propose intuitive and light-weighted recommendations for Complex-Problem-Solving (CPS) collaborations. The underlying cognitive process in CPS discussion was explored, especially the explicit knowledge used. It was found that episodic memory functions better at expanding the conversation scope, while semantic memory appeared to be a more straightforward foundation to initiate new ideas. Since the episodic memory serves as an outstanding primer in the conversation, the results could imply that the better episodic memory is communicated, the more fluence the discussion could be.

Keywords: Cognitive process · Episodic memory · Semantic memory · Problem complexity

1 Introduction

A complex problem is a problem that has no clear definition, nor a clearly defined goal. The means of moving towards the diffusely described goal state are also unclear. Many social challenges can be seen as complex problems: choosing a career, finding a life-partner, climate change, population growth, etc. [1]. A meeting has been identified as a means of Complex-Problem-Solving (CPS) in collaboration, however, also a source that leads to losses in productivity [2]. In Japan, the enterprises spend 67000 h on non-productive meetings every year [3]. A survey from Harvard Business Review shows that 129 out of 182 senior managers in a range of industries said meetings are unproductive and inefficient [4].

The difficulty of holding a productive problem-solving meeting brought an increased attention to the Design Thinking (DT) Workshop, a methodology for creative problem-solving. The operations employed by DT originate from the cognitive process that designers engaged in solving complex problems [5]. Given that knowledge and

E. Markopoulos et al. (Eds.): AHFE 2020, AISC 1218, pp. 52–59, 2020.
https://doi.org/10.1007/978-3-030-51626-0_6

experience have been regarded as critical components of thinking processes aimed at the creation of the new [6, 7], DT helps the non-designers to leverage their knowledge and experience in generating novel ideas. Although the DT workshops are now widely employed in real-world problem-solving, they still cannot replace meetings. This is because these workshops (1) require significant execution time, usually 1 to 4 days, to fit the entire analytic and iterative design process; (2) need experienced facilitators to lead the thinking process. Since the issue is only partially solved, an intuitive and light-weighted collaborative problem-solving method is still needed.

Nevertheless, not all meetings are ineffective. It is curious that some people are capable of generating more quality solutions than others, given the same environmental settings.

This research aims at proposing recommendations for CPS discussion. In order to do so, the underlying cognitive process in CPS discussion needs to be explored, especially the knowledge and memories used. This objective can be divided into two parts - (i) To understand the ability of problem-solving regarding the complexity; (ii) To identify the pattern of memory and knowledge used in a discussion.

This paper covers the results of the current work in progress: for objective (i), the methodology of problem complexity evaluation has been developed. For objective (ii), one preliminary discussion was conducted to test the experimental formats and data analysis techniques.

2 Literature Review

2.1 To Understand the Ability of Problem-Solving Regarding the Complexity

In early works, the ability to solve complex problems is typically measured via dynamic systems that contain several interrelated variables that participants need to alter. Researchers used simulation scenarios with different degrees of fidelities to measure the ability to solve complex problems of individuals [1, 8, 9]. However, there were difficulties in transferring the research results into real-world scenarios for the researches were using simulated scenarios and toy questions.

In this research, instead of using variables set by researchers, the complexity was identified by individuals and measured using the score of conflicts among the set of solution strategies.

2.2 To Identify the Pattern of Memory and Knowledge Used in a Discussion

There were many researches for hosting productive meetings from behavior science perspectives [10, 11]—many of them concerning the ‘actions’ (for example, sending the agenda beforehand) rather than the cognitive process in solving complex problems.

CPS requires creative combinations of knowledge and a broad set of strategies [1]. Recently, the use of explicit memory, especially episodic memory, has been actively studied in problem-solving creativeness.

Episodic Specificity Induction (ESI) has been shown to selectively enhance performance on divergent thinking tasks by boosting the fluency and flexibility of ideas [12]. It could be assumed that the more effective the participants communicate episodic memories (personal-related information), the more effective the discussion could be.

On the other hand, semantic memory (universe-related information) is thought to support creative thinking by presenting a knowledge base of facts that can be coupled to solve creative problems and generate novel ideas [13].

3 Methodology

3.1 Experimental Preparation

An intuitive base topic was chosen for the experiment: 'improve presentation skills.' The topic was selected because it is a typical scene for the potential participants. The complexity was controlled by adding various constraints to the base topic. Shown in Table 1, five topics were created with 5 different constraints. The OR constraints extends the problem space, while AND constraints limit the problem space.

Table 1. Decomposition of topics' structure after adding constrains

Topics	Constrains
To help improving one's presentation skills in a foreign language	~OR improve one's foreign language
To help improving one's presentation skills for those with poor memory	~OR improve one's memory
To help improving one's presentation skills using online tools	~AND using online tools
To help improving one's presentation skills during the commute	~AND using commuting time
To help improving one's presentation skills in 4 weeks	~AND using 4 weeks

There were three steps in the experiment: two questionnaires and one experimental discussion. The objectives, data to-be-collected, and sample size of each step are listed in Table 2. The detailed of each step are explained in Sect. 3.2, 3.3 and 3.4 correspondingly.

Table 2. Experimental process

Steps	Questionnaire 1: personal relevancy	Questionnaire 2: problem complexity	Experimental discussion: problem solving process
Objectives	Select participant with relevant experience and motivation	Evaluate the subjective problem complexity	Identify the memories used in the solution
Data to-be-collected	Rating of: Personal interest Personal involvement	Solutions to a topic Rating of: - Difficulty of each solution - Conflict among the solutions	30-min-discussion of 2-person group: - Audio data - Video data - Writings during the discussion
Sample size	22–55 people	22–55 people	4–5 two-person groups

3.2 Questionnaire of Personal Relevancy

In this research, personal relevancy to a problem was measured from two perspectives: interest and involvement in problem-solving. 'Interest' indicates the participant's motivation of solution creation. 'Involvement' shows the relative level of episodic memory one possesses.

The participants were asked to provide ratings using a five-point scale, to four relevancy factors regarding their interests and involvement in a set of topics in Table 1: R_1 = I am interested in this topic; R_2 = I am interested in creating solutions for this topic; R_3 = I am/was involved in this topic; R_4 = I am/was involved in creating solutions for this topic. The personal relevancy will be calculated as the average value of the captioned factors.

3.3 Questionnaire of Problem Complexity

In the questionnaire of problem complexity, participants were asked to create two to five solutions to the selected topics based on the results in Questionnaire of Personal Relevancy. After that, the participants were asked to evaluate the necessity and difficulty of executing each solution, moreover, the potential conflicts among the created solutions.

The problem complexity is calculated using the mathematical definition that follows the structure of COSYSMO parametric estimator shown in Eq. 1 [14]. It contains additive factors when the variable has local effects; multiplicative factors when the effect is global; and exponential factors when the variable has global and emergent effects depending on the size of the variable [14].

$$\text{Complexity} = \left(\sum\nolimits_{i=1}^{n} \text{sol.difficulty}_{\text{i}} \cdot \text{sol.necessity}_{\text{i}}\right) \cdot \prod\nolimits_{j=1}^{m} \text{H}_{\text{j}} \quad (1)$$

where:
n = number of essential solutions in a solution-set
m = number of applicable types of conflict within the solution set
H = number of solutions having conflict type j.

There are four types of conflicts, which are based on heuristics to identify conflicting components in a solution: phases of matter, resource, laws of physics, and logic [14]. The complexity is defined by the unavoidable conflicts within the solution set, if a participant believes there is no conflict, the problem is not complex to this participant.

3.4 Experimental Discussion: Problem-Solving Process

The participants were asked to conduct two discussions in a two-person group, using their native language. The participants with similar relevancy and problem complexity ratings were arranged into the same group. This is to ensure the balance of knowledge contribution in their discussion. Discussions were held on separate days to minimize the carried-over solutions from one topic to another. Participants could use a white-board to assist their discussion. The fundamental data to be analyzed is the transcript of the conversation. The writings on the whiteboard, together with the video recording, serve as references.

The discussion was coded into episodic memories, which related to participant's experiences; semantic memories, which related to the knowledge participants learnt through text; initial idea, a new concept of the solution; developed idea, a concept with more details added into the initial idea; finally, interpreter, the change of representation of the problem. The coding scheme will be adjusted on an evolving base.

4 Results

4.1 Participant's Information

At the current stage, 51 responses for Questionnaire of Personal Relevancy were collected. The participants aged from 24 to 33, with a majority of Chinese and Japanese native speakers (Chinese Mandarin: 26, Japanese: 16, English: 3, Others: 6). There were 12 responses obtained for problem complexity (tentatively). One preliminary experiment of problem-solving process was conducted by two Japanese-speaking participants.

Relevancy is calculated as the mean of the scores of the four sub-questions (interest, interest in solving, involve, involve in solving). Topic 1 has the highest relevancy (3.84 out of 5), followed by topic 5 with relevancy 3.10. Therefore, only topic 1 and 5 can be considered as relevant to the participants.

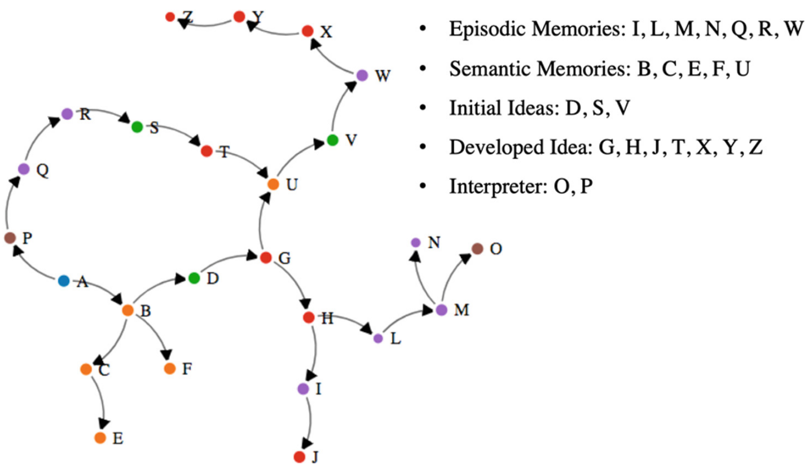

Fig. 1. The two participants conducted a discussion about Topic 1. The cognitive process of discussion coded based on 25 identified utterances. During this discussion, the two participants used more episodic memory (7 out of 25) compared to semantic ones (5 out of 25) to develop their solution. They produced twice as many developed ideas (7 out of 25) from the ones initially proposed (3 out of 25). There was one successful problem reinterpretation, which generated one initial and one developed idea.

4.2 To Identify the Pattern of Memory and Knowledge Used in a Discussion

The two participants suffered from impasses of resolving the conflicts after they kept brainstorming for 15 min. Figure 1 was plotted based on the discussion of the 15 min productive discussion. The nodes represent the coded utterances in the discussion. The letters indicate the sequence of these utterances in the discussion.

4.3 To Understand the Ability of Problem-Solving Regarding the Complexity

After comparing the solutions of topic 1 and 5, a negative correlation between the complexity difference and sematic similarity of the solution was found. Semantic similarity is obtained by comparing the solution descriptions. From the 12 responses, there was a moderately negative correlation (−0.362) between problem complexity difference and semantic solution novelty.

5 Discussion

Participants tend to generate ideas based on their semantic memory rather than episodic ones. One of the possible explanations is generating ideas by communicating, and analyzing episodic memory requires more working memory. However, since the episodic memory serves as an outstanding primer in the conversation, the better they are communicated, the more productive the discussion could be.

Developing an existing idea appears to be easier than generating a new idea in this discussion. However, since this process only recorded the cognitive process before the impasse happened, it is unclear whether this trend is a temporary or general nature in longer discussions.

In the analysis of the results of the discussion, fragility of the data processing method was found. The cognitive process analysis relies heavily on verbal analysis. Due to the difficulty of utterance extraction and data cleaning, the amount of information preserved, and finally analyzed is hard to be evaluated, which makes it difficult to replicate the experiment.

More data is needed to validate the observation in Sect. 4. If the negative correlation could still be observed, it could be suggested the solution to one problem could be used as semantic priming to another. Whereas the two problems shall share the same general settings, and possesses similar complexities.

6 Conclusion

This research aims at proposing recommendations for CPS discussion. The underlying cognitive process in CPS discussion was explored, especially the knowledge and memories used. This objective was divided into two parts - (i) To understand the ability of problem-solving regarding the complexity; (ii) To identify the pattern of memory and knowledge used in a discussion.

To achieve objective (i), methods for evaluating personal relevancy and perspective toward problem complexity was developed. The participants are found to be sensitive toward the specific scenarios, which created a spectrum of complexity and relevancy for questions under the same general background.

To achieve objective (ii), this research also implicated a preliminary analysis of the cognitive process of problem-solving discussion. It was found that the episodic memory functions better at expanding the conversation scope, while semantic memory appeared to be a more straightforward foundation to initiate new ideas.

As a next step, a more robust analysis method needs to be developed to capture the information in the discussion. Besides, more conversation factors needed to be incorporated in order to analyze the collaborative effects.

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