Research article
UDC 159.955.4
https://doi.org/10.21702/rpj.2025.3.3

Impact of Initial Task Conditions on Reflexive Loop Formation in Network Thinking

Denis F. Dautov[1*], Yulia A. Tushnova[1], Evgeny A. Pronenko[2]

[1]Don State Technical University, Rostov-on-Don, Russian Federation

[2]Southern Federal University, Rostov-on-Don, Russian Federation

[*]Corresponding author: dautov-80@ mail. ru

Abstract

Introduction. The accelerating proliferation of network technologies into all spheres of human life is driving the adoption of principles from network structures to inform new approaches across many domains of individual and, particularly, collaborative activity. This is especially important for mental processes, which are forced to adapt to new emerging conditions. To study the phenomenon of networks in relation to collaborative thinking, a study was conducted to examine reflective feedback loops in networked thinking. **Methods.** Semantic content analysis was used as a data collection. Mathematical processing of the results was performed using multivariate analysis of variance. **Results.** The study identified the most significant initial conditions that influence the formation of reflective loops in network thinking. The decisive role of purposefulness of thinking in the implementation of reflective loops was noted. The effect of positive and negative feedback loops in the process of solving problems with different initial conditions was discovered. Based on the results of the study, conclusions were drawn about the ability of initial conditions to have a significant impact on reflective loops in network thinking, jointly and separately from each other. It was established that the presence of a known solution reduces the number of questions, while the absence of such a solution leads to a stable predominance of questions over answers at all stages. **Discussion.** The data obtained allowed us to form an idea of the significance of reflective loops for network thinking processes, showing their role in achieving a dynamic equilibrium of the thinking system through the interaction of positive and negative feedback. This makes it possible to use the results in network learning to activate students' thinking activity by controlling the initial conditions of tasks.

Keywords

network, network thinking, reflective cycles, positive and negative feedback

For citation

Dautov, D. F., Tushnova, Yu. A. & Pronenko, E. A. (2025). Impact of initial task conditions on reflexive loop formation in network thinking. *Russian Psychological Journal, 22*(3), 43–56. https://doi.org/10.21702/rpj.2025.3.3

Introduction

The concept of a *network* is often metaphorical in nature, allowing it to encompass a very wide range of phenomena (Donald, 2012). In general terms, the concept of a network is explored in the works of Gao, Barzel & Barabási (2016), Castells (2011), and Latour (2007).

In psychology and pedagogy, a network is typically understood as a form of human interaction, primarily using digital tools (Ioannou, Brown, & Artino, 2015; Pavlova et al., 2019). At the same time, considerable attention is paid to such network phenomena as network communication and network thinking (Ermakov, & Belousova, 2021; Sutcliffe, Binder & Dunbar, 2018).

Several researchers believe that network activity can influence the behavior of its participants regardless of their individual goals (Donald, 2012; Pishchik et al., 2019). In other words, the network as an independent phenomenon can direct the activities of its components.

Among the theories that examine network structures, we can highlight A.-L. Barabási's network theory and M. Castells' concept of network society, W. Varela and F. Maturana's autopoiesis theory, and E. Morin's complex thinking theory (Gao, Barzel & Barabási, 2016; Castells, 2013; Maturana & Varela, 2012; Morin, 2014).

According to a number of leading experts in network theory, network structures have complementary characteristics in relation to self-organization (Castells, 2013; Lynn, Holmes & Palmer, 2024). A.-L. Barabási, together with other researchers, was able to establish that in network structures, regardless of their specific purpose, the characteristics of an individual network node can be unique, not repeating themselves throughout the entire network (Gao, Barzel & Barabási, 2016). As M. Castells notes, the processes occurring in a network are similar to natural selection in biological environments, where the participants in such selection, adapting to the environment, ultimately shape that environment themselves (Castells, 2020). By demonstrating its adaptive capabilities, the network shows its ability to actively adapt to changing conditions (Treur, 2020; Mukeriia, Treur & Hendrikse, 2024; Zinchenko et al, 2020). It not only adapts to various unpredictable conditions, but also shapes the environment through its inherent internal processes. It can be said that the network is an environment for itself.

The creators of the theory of autopoiesis, W. Maturana and F. Varela, believed that such a complex adaptive structure as a network structure simultaneously strives for independence from the external environment and forms numerous connections with it (Maturana & Varela, 2012). N. Luhmann agreed with this, believing that complex self-organizing systems build complex relationships between their structure and the external environment, constantly checking themselves and the environment for compatibility with each other (Luhmann, Baecker & Gilgen, 2013).

In this sense, the self-organization of network thinking is expressed in the spontaneous formation of a certain form of interaction between the nodes of the network, inherent in it under the existing conditions (Haken, 2012). In his actor-network theory, B. Latour particularly notes that not only people, but also various information objects, can act as such nodes (Latour, 2007; Schwarz et al., 2024).

The presence of unstable forms of interaction inherent in network thinking due to the specific conditions of the digital environment may, in fact, be its notable advantage over traditional forms of thinking. Despite the significant negative factors accompanying online interaction, especially for young people, the advantages are also significant (Davydova, Suroedova, Grishina, 2023). In studies devoted to various forms of interaction, a special place is occupied by the so-called 'weak ties' discovered by M. Granovetter. Weak ties, realized, for example, in social networks, facilitate the rapid exchange of information with minimal resource costs, facilitating the establishment of new connections between network nodes, thereby ensuring a diversity of opinions, ways of thinking, and forms of interaction (Granovetter, 2018). However, at the same time, weak ties and the specific nature of the implementation of network thinking self-organization processes as a whole make it unstable and less sustainable compared to traditional thinking (Brennecke, Ertug & Elfring, 2024; Wiener, 2019; Sundararajan, 2020).

Therefore, processes that ensure a certain level of stability are particularly important for network thinking, while at the same time preventing it from entering a state of stagnation that hinders self-organization and has a destructive effect on such structures.

One such process, recognized as the most important for the existence of a network, is the generation of feedback loops that ensure self-regulation and self-control in complex self-organizing systems (Luhmann, Baecker & Gilgen, 2013).

In general terms, feedback loops are a cyclical process of cause-and-effect relationships in which each element influences the next until the last element affected begins to influence the first element in the chain (Wiener, 2019). An important feature of feedback is its ability to amplify or suppress emerging trends in the system. Positive feedback supports and amplifies changes that have occurred in the system, contributing to its development, while negative feedback suppresses them, thereby returning the system to a stable state (Krancher, Luther & Jost, 2018; Skene, 2024).

In his study of self-reinforcing deviations from a cybernetic perspective, M. Magoroh established the importance of positive feedback between elements within a complex system for its development (Magoroh, 2017).

Subsequently, researchers have established that self-organization in a system is only possible if positive feedback prevails over negative feedback. Otherwise, negative feedback quickly stabilizes the system, preventing any possible changes (Haken, 2012; Wiener, 2019). However, the obvious predominance of positive feedback in the system quickly destabilizes it, destroying the boundary between the internal and external environments (Latour, 2007). Therefore, network structures need an alternation of positive and negative loops for their existence (Zhang & Wang, 2024).

Feedback loops in network thinking are implemented through the processes of self-reference described by N. Luhmann using the example of interaction between people (Luhmann, Baecker, & Gilgen, 2013). Such loops are based on the reflection of thinking, when people, communicating with each other, evaluate the incoming information, ask questions to clarify their understanding, and build mental operations (Korbak, 2023).

Thus, the reflective loop manifests itself in the form of positive feedback for network thinking, causing targeted changes in thinking under the influence of this activity itself (Roedema et al., 2022).

In the process of interaction, participants in network thinking are able to build chains of unique conclusions based on questions and answers, closing the information received in reflective loops necessary to clarify the incoming information (Zienkowski, 2017). The main function of reflective loops from the point of view of self-organization is to strengthen feedback in understanding of synergistic and cybernetic theory (Haken, 2012; Wiener, 2019). Reflective loops, through the manifestation of positive feedback in mental activity, cause changes in thought processes by strengthening the selection of incoming information, which, through the implementation of recursion, leads to the subsequent strengthening of the selection of similar information (Jeon, 2022). In the course of cognitive activity, thinking itself influences its implementation through recursive reasoning initiated by reflective cycles (Igamberdiev, 2017).

Thus, the study of reflective loops can advance our understanding of the internal mechanisms of network thinking. At the same time, the psychological aspect of this area has hardly been studied. The manifestations of reflective loops in network thinking are unexplored, and the factors that influence the ratio of positive and negative feedback loops implemented in the process of network thinking have not been considered. To provide a preliminary description of the issues raised, a study was conducted to analyze the influence of initial conditions on reflective loops implemented in network thinking.

Methods

Websites dedicated to solving intellectual problems were used as data sources. Preference was given to those that contained a large number of diverse tasks, which expanded the range of choices, allowing tasks to be selected according to the study design. In addition, preference was given to those web sources that displayed not only the conditions of the task itself but also comments on their solution. As a result, two sites were selected as such sources: Smekalka (http://www.smekalka.pp.ru) and Braingames (https://www.braingames.ru). An important feature of the research websites is the opposite approach to describing tasks. The first website does not typically present the solution itself directly in the descriptions of the conditions or comments of the participants. Messages with the correct solution are deleted by the moderator. Completed tasks must be sent for verification on an individual basis. Thus, to solve a problem, it is necessary, first of all, to use direct reasoning, moving from beginning to end in the thought process. The second site, in contrast, publishes the solution to the problem immediately after describing its conditions. Thanks to this approach, participants should not so much offer their solution, as to recreate the chain of reasoning, moving in reverse order from the end to the beginning.

Tasks for further analysis were selected based on two parameters. The first parameter was the number of ways to solve the task, its variability. Based on this parameter, the tasks on the websites were divided into two groups: those with several possible solutions and those with one acceptable option. This division of tasks made it possible to assess the influence of constraints on the characteristics of collaborative thinking, which, according to the autopoietic approach, as a complex self-organizing system is capable of forming parameters of order depending on the degree of such limiting conditions (Maturana & Varela, 2012). The second parameter is the presence of a ready-made solution to the task, known to the participants in the discussion. As in the first case, the tasks were divided into two groups:

- Tasks with a known solution, which makes network thinking more spontaneous, since participants cannot join forces to achieve a goal that is clear to everyone, namely finding a solution;
- Tasks with an unknown solution, which set the traditional direction for collaborative thinking. Due to this, the parameter contributes to or hinders the spontaneity of network thinking to a greater or lesser extent.

The two parameters of the tasks presented determine, as initial conditions, the degree of limitation and spontaneity of network thinking, which are important for self-organization processes (Haken, 2012).

Based on these parameters, four types of tasks were identified:

- Tasks that have one correct solution, initially unknown to the participants in the discussion;
- Tasks with one correct solution that is known in advance;
- Tasks with several possible solutions, none of which are known in advance;
- Tasks with several possible solutions, where at least one of them is known in advance.

Thus, two main parameters, the limited nature and spontaneity of network thinking, can be considered as initial conditions that influence self-organization processes.

A total of 16 tasks were identified in accordance with the parameters presented. Thus, four tasks corresponding to each combination of parameters were found. Because of the equal number of tasks for each type of task, it was possible to obtain observations for the sample as a whole, which made it possible to avoid the difficulties that arise when calculating heterogeneous complexes.

Semantic content analysis based on expert comments evaluations aimed at solving the tasks listed on the websites was used as the main method to analyze the statements of participants in solving intellectual tasks. This type of content analysis was chosen because of its ability to identify the content component of selected text components.

The content analysis was carried out in four stages.

The first stage involved coding related to signs of reflective loops in network thinking. In this case, sequences of statements in which participants asked questions about the conditions of the task and received responses from other participants in the discussion were selected as units of analysis to identify reflective loops, thereby supporting a specific topic in network thinking and demonstrating positive feedback. The more questions the discussion participants asked, the more intense the discussion of the task conditions became, the more questions were asked, which in turn led to a change in the direction of network thinking and, as a result, a new series of questions. Coding was carried out using latent coding, which allowed for the analysis of implicit meanings based on a specific context.

The second stage was devoted to assessing the reliability of the coding. For this purpose, two pairs of independent-working evaluators were selected, whose task was to analyze the data obtained. The results obtained by these evaluators were then compared to verify the consistency of the data. As a result of such comparisons, the level of inconsistency was estimated at 16% of the analyzed cases, which indicates a high degree of reliability of the analyzed information (Cohen's kappa 0.83).

The third stage involved conducting a frequency analysis, which was carried out in accordance with the characteristics of reflective loops described previously.

In the fourth stage, the quantitative data obtained as a result of the analysis were entered into a table for statistical analysis.

Data analysis

Statistical analysis was performed using SPSS Statistics for Windows (17.0; IBM Corp.). To analyze the data obtained through content analysis, multivariate analysis of variance was used after testing the assumptions of normality and homoscedasticity. The statistical analysis method was used to assess the impact of task parameters on changes in the number of questions and answers during the problem solving process. Dependent variables were the number of questions and answers at the initial, intermediate, and final stages of task discussion. The independent variables remained unchanged: the familiarity and variability of task solutions. The critical level of significance was established at $\alpha = 0.05$.

Results

After the data necessary for further research were obtained by content analysis, it was converted into conditional indicators. This was done by dividing one indicator by another. In this way, the problem of the unequal number of questions and answers characteristic of different tasks was solved. Using this procedure, three conditional indicators of reflective loops were obtained.

The indicators 'Question on solving the task' (QST) and 'Answer to question' (AQ) were obtained by dividing the questions and answers by the total number of relevant comments on this task. The Question-to-Answer (QAR) indicator was obtained by dividing the Question-on-Task Solution indicators by the 'Answer to question' indicators.

The 'Question on solving the task' indicator allows us to assess which part of the total number of comments relates to those that initiate reflective loops. The 'Answer to Question' indicator allows us to determine the degree of representation of reflective loops in network thinking. As for the 'Ratio of questions to answers' indicator, it demonstrates the predominance of positive or negative feedback loops in network thinking. If the number of questions exceeds the number of answers, this may indicate a predominance of positive feedback in reflective loops, as each question stimulates new answers, which in turn raise even more questions, thereby reinforcing reflective tendencies in network thinking. If the number of answers prevails over the questions, this may indicate a predominance of negative feedback in reflective loops, where the answers suppressed new questions, thereby reducing the reflection of network thinking as a whole.

To study the influence of task parameters on changes in reflective loop indicators in the initial, middle, and final stages of network thinking, multivariate analysis of variance (MANOVA) was used. The final results are presented in Table 1, Table 2, and Table 3.

Table 1

Results of MANOVA analysis to assess the influence of task parameters on the 'Question on solving the task' indicator as a component of reflective loops of network thinking at the initial, middle and final stages

Task parameters Task	Test Statistic	Value	F	Hypothesis df	Error df	Sig.(p)	Partial η 2
Question on solving the task							
Fame	Wilks'λ	0.107	27.781	3.000	10.000	<0.001	.893

Task parameters Task	Test Statistic	Value	F	Hypothesis df	Error df	Sig.(p)	Partial η 2
Variability	Wilks'λ	0.863	0.530	3.000	10.000	0.672	.137
Variability and popularity	Wilks'λ	0.630	1.962	3.000	10.000	0.184	.370

The results presented in Table 1 allow us to determine the influence of such a parameter as 'Fame' on the indicator of change in the 'Question on solving the task' at different stages of network thinking (Wilks'λ = 0.107, $F (3.10) = 27.781$, $p < 0.000$, $\eta = 0.893$). A univariate analysis made it possible to clarify specific changes in indicators at the beginning, middle and end of the network thinking process. The 'Fame' parameter had an impact on the indicator change in the 'Question on solving the task' in the initial ($F (3.10) = 76.438$, $p < 0.001$, $\eta = 0.864$), middle ($F (3.10) = 69.522$, $p < 0.001$, $\eta = 0.853$) and final ($F (3.10) = 96.026$, $p < 0.001$, $\eta = 0.889$) stages of network thinking aimed at problem solving. Marginal means indicate an increase in the number of questions in the case of an unknown solution in the initial (M = 0.301), middle (M = 0.284) and final (M = 0.310) stages, compared to tasks with a known solution (M = 0.037) (M = 0.031) and (M = 0.024), respectively.

Table 2

Results of MANOVA analysis to assess the influence of task parameters on the 'Answer to question' indicator as a component of reflective loops of network thinking at the initial, middle, and final stages

Task parameters Task	Test Statistic	Value	F	Hypothesis df	Error df	Sig.(p)	Partial η 2
			Answer to question				
Fame	Wilks'λ	0.684	1.537	3.000	10.000	0.265	0.316

Task parameters Task	Test Statistic	Value	F	Hypothesis df	Error df	Sig.(p)	Partial η 2
Variability	Wilks'λ	0.908	0.337	3.000	10.000	0.799	0.092
Variability and familiarity	Wilks'λ	0.904	0.354	3.000	10.000	0.787	0.096

The results presented in Table 2 demonstrate that task parameters have no effect on the 'Answer to question' indicator at all stages of network thinking. A univariate analysis also revealed that the task parameters at the beginning, middle, and end of the network thinking process did not have an effect on this indicator.

Table 3

Results of the MANOVA analysis to assess the influence of task parameters on the 'Question-Answer Ratio' indicator as a component of reflective loops of network thinking at the initial, middle, and final stages

Task parameters Task	Test Statistic	Value	F	Hypothesis df	Error df	Sig.(p)	Partial η 2
		Question-Answer Ratio					
Fame	Wilks'λ	0.142	20.184	3.000	10.000	<0.001	.858
Variability	Wilks'λ	0.646	1.825	3.000	10.000	0.206	.354
Variability and popularity	Wilks'λ	0.653	1.775	3.000	10.000	0.215	.347

The results presented in Table 3 allow us to determine the influence of a parameter as 'Fame' on the indicator of change in the 'Question-Answer Ratio' (Wilks'λ = 0.142, F (3.10) = 20.184, $p < 0.000$, η = 0.858). A univariate analysis allowed for the clarification of specific changes in indicators at the beginning, middle, and end of the network thinking process. This parameter had an impact on the indicator of the 'question-to-answer ratio' at the initial stage (F (3.10) = 42.155, $p < 0.001$, η = 0.778), middle (F (3.10) = 29.923, $p < 0.001$, η = 0.714), and final (F (3,10) = 34.908, $p < 0.001$, η = 0.744). At the same time, tasks with unknown solutions increased the number of questions and answers in all stages of network thinking, compared to tasks with known solutions, which amounts to (M = 1.593), (M = 1.555) and (M = 1.321), versus (M = 0.272), (M = 0.236) and (M = 0.229).

Discussion

The aim of this study was to investigate the influence of initial conditions on solving problems on reflective loops implemented in the network thinking.

The analysis of changes in reflective loop indicators at the initial, middle, and final stages of network thinking allowed us to establish the decisive influence of the known solution to the problem on the number of questions and the ratio of questions to answers. A decrease in the number of questions relative to answers when solving intellectual problems with a known solution compared to solving problems without a known solution indicates a weakening of the self-regulation processes of network thinking. When the answer is known in advance and the discussion focuses on identifying intermediate steps, this reduces the significance of the questions. They are less useful for solving the problem. As a result, the number of answers begins to increase, suppressing the emergence of new questions, which reduces the overall intensity of network thinking.

The absence of a known answer in advance led to an increase in the number of questions and the general predominance of questions over answers in the initial, middle and final stages of network thinking (Belousova, Kozhukhar, & Pishchik, 2019; Dautov, 2021). Thus, the presence of a clear goal in solving intellectual tasks had a constant influence at each stage of network thinking (Hesse, Care, Buder, Sassenberg, & Griffin, 2015). At the same time, the number of questions in the final stage was greater than at the initial stage, and the ratio of questions to answers gradually decreased in favor of answers, while the questions remained predominant at all stages. This indicates that reflective loops gradually stabilize positive feedback by increasing the number of answers and, as a result, increasing negative feedback loops in the process of collaborative thinking.

As B. Latour's research shows, unrestrained positive loops can destroy the system (Latour, 2007). Therefore, in order to maintain its integrity, network thinking, in accordance with the principles of self-organization, generates negative feedback. As a result, as positive connections increase, reflective loops provoke the growth of negative connections, bringing the network thinking system into a state of dynamic equilibrium.

Conclusion

The results of the study demonstrated that reflective loops in network thinking are influenced by a number of initial conditions related to task parameters. These conditions have an independent influence on network thinking. The most significant influence is the presence of a goal shared by the participants, in this case expressed in the desire to solve the task. It was the participants' goal-orientedness that contributed to the initiation of reflective loops and maintained their activity throughout all stages of network thinking.

Although the number of responses depends only slightly on the task parameters, the ratio of questions to answers is an important indicator to assess the ratio of positive and negative feedback in reflective loops. This ratio in network thinking allows us to judge the intensity of reflective loops and the degree of stability of network thinking as a whole.

The study provides a more complete picture of the processes that occur in network thinking and a better understanding of its internal mechanisms that ensure self-organization processes. The data obtained can be used in collaborative network learning to initiate students' mental activity by activating reflective loops through the selection of specific initial conditions for mental activity.

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Received: November 19, 2024
Revised: March 14, 2025
Accepted: August 14, 2025

Author Contribution

Denis Fatyhovich Dautov – providing the sections "Materials and Methods," "Results," "Discussion," and "Conclusions."

Yulia Andreevna Tushnova – providing the sections "Introduction," "Data Analysis," "Conclusions" and working with scientific sources.

Evgeniy Aleksandrovich Pronenko – work with scientific sources, article text formatting.

Author Details

Denis Fatyhovich Dautov – Cand. Sci. (Psychology), Associate Professor of the Department of Psychology, Don State Technical University, Rostov-on-Don, Russia; ORCID ID: https://orcid.org/0000-0001-8147-5603; e-mail: dautov-80@mail.ru

Yulia Andreevna Tushnova – Cand. Sci. (Psychology), Associate Professor, Department of Psychology, Don State Technical University, Rostov-on-Don, Russia; ORCID ID: https://orcid.org/0000-0001-8579-2630; e-mail: trubulya@yandex.ru

Evgeny Aleksandrovich Pronenko – Cand.Sci (Psychology), Associate Professor of the Department of General and Educational Psychology, Southern Federal University, Rostov-on-Don, Russian Federation; Scopus Author ID: 57351954200, SPIN-code RSCI: 9896-5451, ORCID ID: https://orcid.org/0000-0002-6032-6059; e-mail: pronenko@sfedu.ru

Conflict of Interest Information

The authors have no conflict of interest to declare.